CK-12 FlexBook

7th Grade Science Student Edition

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Introduction to Matter

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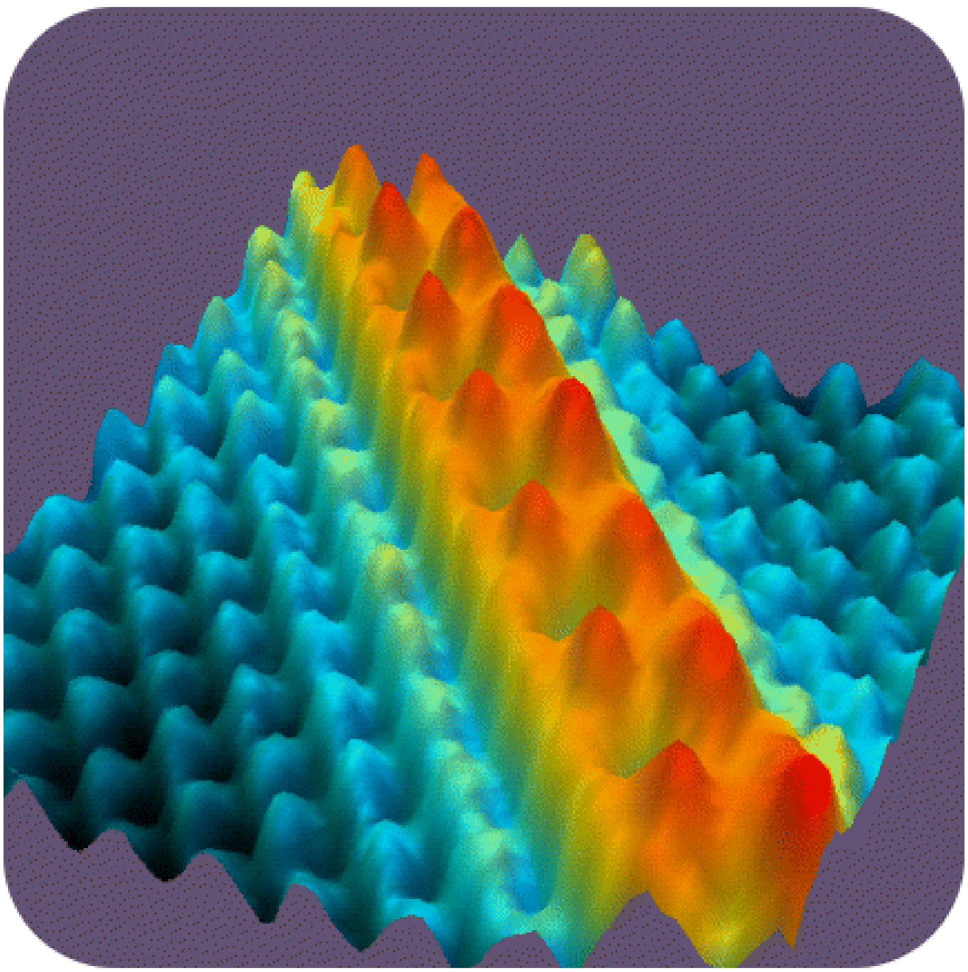

The reddish-orange peaks in this picture are individual atoms of cesium on a background of gallium arsenide (GaAs). This amazing image was made by a scanning tunneling microscope. It's the only kind of microscope that can make images of things as small of atoms. The invention of the scanning tunneling microscope was so significant that its inventors got a Nobel prize for it. Why is being able to see atoms so important? Atoms are the basic building blocks of all the matter in the universe. You will learn more about atoms and matter when you read this chapter.

Courtesy of National Institute of Standards and Technology. www.nist.gov/pml/general/stm/index.cfm. Public Domain.

1.1 Properties of Matter

Lesson Objectives

- Define matter, mass, and volume.
- Identify physical properties of matter.
- List examples of chemical properties of matter.

Vocabulary

- chemical property
- density
- flammability
- mass
- matter
- physical property
- reactivity
- volume
- weight

Introduction

Here's a riddle for you to ponder: What do you and a tiny speck of dust in outer space have in common? Think you know the answer? Read on to find out.

What is Matter?

Both you and the speck of dust consist of atoms of matter. So does the ground beneath your feet. In fact, everything you can see and touch is made of matter. The only things that aren't matter are forms of energy, such as light and sound. Although forms of energy are not matter, the air and other substances they travel through are. So what is matter? **Matter** is defined as anything that has mass and volume.

Mass

Mass is the amount of matter in a substance or object. Mass is commonly measured with a balance. A simple mechanical balance is shown in **Figure** 1.1. It allows an object to be matched with other objects of known mass. SI units for mass are the kilogram, but for smaller masses grams are often used instead.

FIGURE 1.1
This balance shows one way of measuring mass. When both sides of the balance are at the same level, it means that objects in the two pans have the same mass.

Mass versus Weight

The more matter an object contains, generally the more it weighs. However, weight is not the same thing as mass. **Weight** is a measure of the force of gravity pulling on an object. It is measured with a scale, like the kitchen- scale in **Figure** 1.2. The scale detects how forcefully objects in the pan are being pulled downward by the force of gravity. The SI unit for weight is the newton (N). The common English unit is the pound (lb). With Earth's gravity, a mass of 1 kg has a weight of 9.8 N (2.2 lb).

FIGURE 1.2
This kitchen scale measures weight. How does weight differ from mass?

Problem Solving

Problem: At Earth's gravity, what is the weight in newtons of an object with a mass of 10 kg?

Solution: At Earth's gravity, 1 kg has a weight of 9.8 N. Therefore, 10 kg has a weight of $(10 \times 9.8 \text{ N}) = 98 \text{ N}$.

You Try It!

Problem: If you have a mass of 50 kg on Earth, what is your weight in newtons?

An object with more mass is pulled by gravity with greater force, so mass and weight are closely related. However, the weight of an object can change if the force of gravity changes, even while the mass of the object remains constant. Look at the photo of astronaut Edwin E. Aldrin Jr taken by fellow astronaut Neil Armstrong, the first human to walk on the moon, in **Figure** 1.3. An astronaut weighed less on the moon than he did on Earth because the moon's gravity is weaker than Earth's. The astronaut's mass, on the other hand, did not change. He still contained the same amount of matter on the moon as he did on Earth.

The amount of space matter takes up is its **volume**. How the volume of matter is measured depends on its state.

- The volume of liquids is measured with measuring containers. In the kitchen, liquid volume is usually

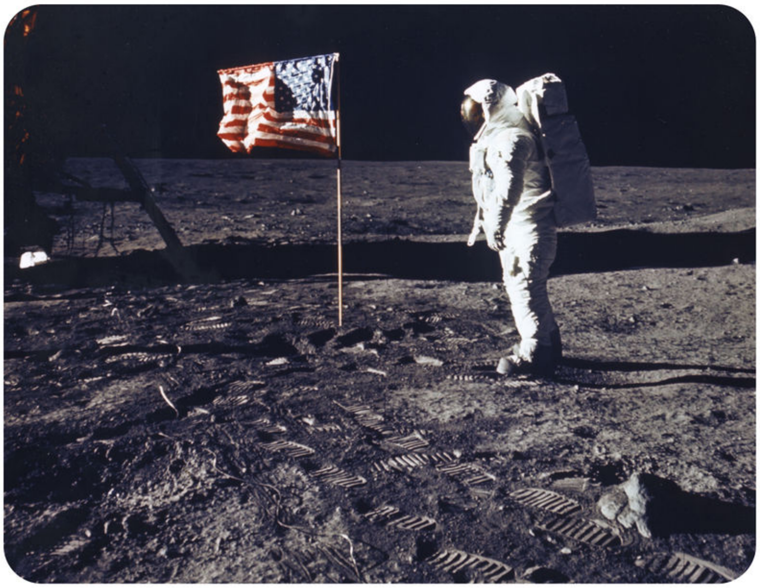

FIGURE 1.3
If the astronaut weighed 175 pounds on Earth, he would have weighed only 29 pounds on the moon. If his mass on Earth was 80 kg, what would his mass have been on the moon?

measured with measuring cups or spoons. In the lab, liquid volume is measured with containers such as graduated cylinders. Units in the metric system for liquid volume include liters (L) and milliliters (mL).

- The volume of gases depends on the volume of their container. That's because gases expand to fill whatever space is available to them. For example, as you drink water from a bottle, air rushes in to take the place of the water. An "empty" liter bottle actually holds a liter of air. How could you find the volume of air in an "empty" room?
- The volume of regularly shaped solids can be calculated from their dimensions. For example, the volume of a rectangular solid is the product of its length, width, and height (l × w × h). For solids that have irregular shapes, the displacement method is used to measure volume. You can see how it works in **Figure** 1.4 and in the video below. The SI unit for solid volumes is cubic meters (m^3). However, cubic centimeters (cm^3) are often used for smaller volume measurements.

http://www.youtube.com/watch?v=q9L52maq_vA

Physical Properties of Matter

Matter has many properties. Some are physical properties. **Physical properties** of matter are properties that can be measured or observed without matter changing to a different substance. For example, whether a given substance normally exists as a solid, liquid, or gas is a physical property. Consider water. It is a liquid at room temperature, but if it freezes and changes to ice, it is still water. Generally, physical properties are things you can see, hear, smell, or feel with your senses.

Examples of Physical Properties

Physical properties include the state of matter and its color and odor. For example, oxygen is a colorless, odorless gas. Chlorine is a greenish gas with a strong, sharp odor. Other physical properties include hardness, freezing and boiling points, the ability to dissolve in other substances, and the ability to conduct heat or electricity. These properties are demonstrated in **Figure** 1.5. Can you think of other physical properties?

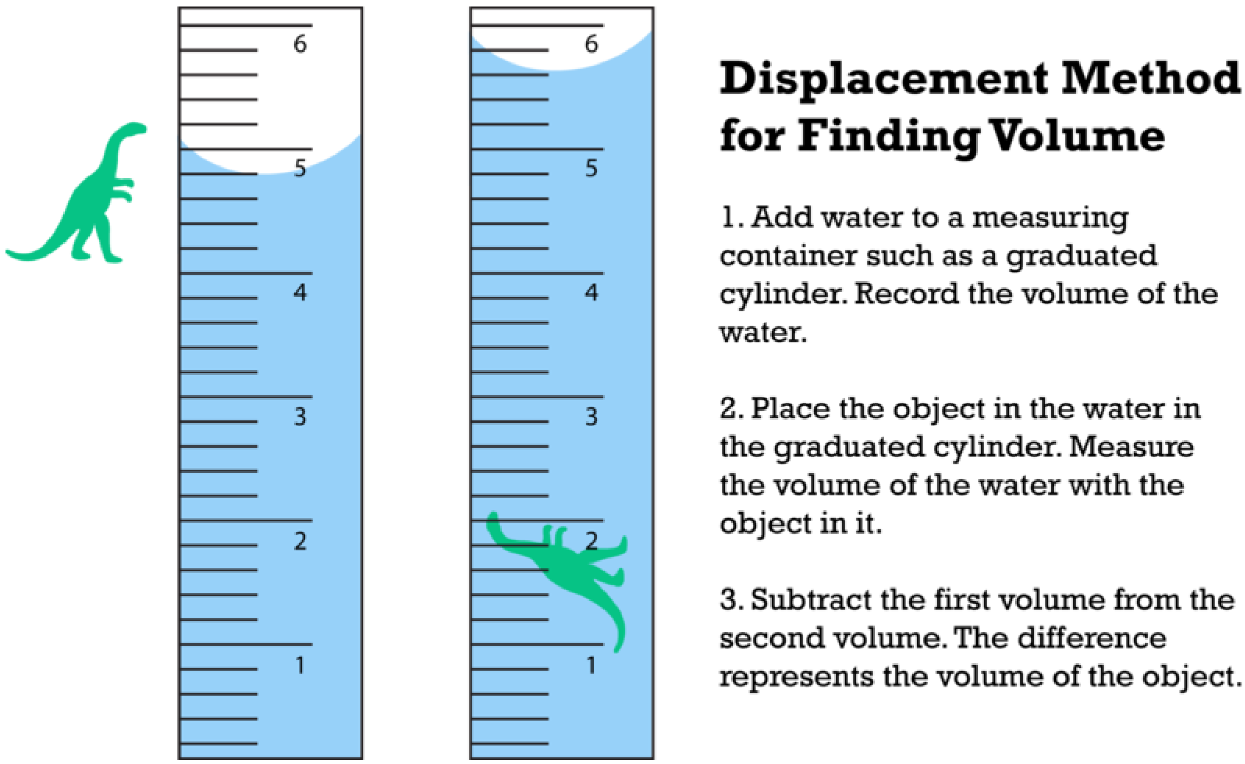

FIGURE 1.4
The displacement method is used to find the volume of an irregularly shaped solid object. It measures the amount of water that the object displaces, or moves out of the way. What is the volume of the toy dinosaur in mL?

Density

Density is an important physical property of matter. It reflects how closely packed the particles of matter are. Density is calculated from the amount of mass in a given volume of matter, using the formula:

$$\text{Density } (D) = \frac{\text{Mass } (M)}{\text{Volume } (V)}$$

Problem Solving

Problem: What is the density of a substance that has a mass of 20 g and a volume of 10 mL?

Solution: $D = 20 \text{ g}/10 \text{ mL} = 2.0 \text{ g/mL}$

You Try It!

Problem: An object has a mass of 180 kg and a volume of 90 m^3. What is its density?

To better understand density, think about a bowling ball and a volleyball. The bowling ball feels heavy. It is solid all the way through. It contains a lot of tightly packed particles of matter. In contrast, the volleyball feels light. It is full of air. It contains fewer, more widely spaced particles of matter. Both balls have about the same volume, but the bowling ball has a much greater mass. Its matter is denser.

FIGURE 1.5
These are just a few of the physical properties of matter.

KQED: Aerogel

It looks like frozen smoke, and it's the lightest solid material on the planet. Aerogel insulates space suits, makes tennis rackets stronger and could be used one day to clean up oil spills. Lawrence Livermore National Laboratory scientist Alex Gash shows us some remarkable properties of this truly unique substance. For more information on aerogel, see http://science.kqed.org/quest/video/quest-lab-aerogel/ .

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Chemical Properties of Matter

Some properties of matter can be measured or observed only when matter undergoes a change to become an entirely different substance. These properties are called **chemical properties**. They include flammability and reactivity.

Flammability

Flammability is the ability of matter to burn. Wood is flammable; iron is not. When wood burns, it changes to ashes, carbon dioxide, water vapor, and other gases. After burning, it is no longer wood.

Reactivity

Reactivity is the ability of matter to combine chemically with other substances. For example, iron is highly reactive with oxygen. When it combines with oxygen, it forms the reddish powder called rust (see **Figure** 1.6). Rust is not iron but an entirely different substance that consists of both iron and oxygen.

FIGURE 1.6
The iron in these steel chains has started to rust.

Lesson Summary

- Matter is anything that has mass and volume. Mass is the amount of matter in a substance. Volume is the amount of space matter takes up.
- Matter has both physical and chemical properties. Physical properties can be measured or observed without matter changing to a different substance.
- Chemical properties of matter can be measured or observed only when matter undergoes a change to become an entirely different substance.

Lesson Review Questions

Recall

1. Define matter.
2. How does mass differ from weight?
3. Describe the displacement method for measuring the volume of an object.
4. Identify two physical properties and two chemical properties of matter.

Apply Concepts

5. Create a table comparing and contrasting physical properties of tap water and table salt.
6. Apply the concept of density to explain why oil floats on water.

Think Critically

7. Some kinds of matter are attracted to a magnet. Is this a physical or chemical property of matter? How do you know?

Points to Consider

The physical and chemical properties of substances can be used to identify them. That's because different kinds of matter have different properties.

- What property could you use to tell the difference between iron and aluminum?
- How could you tell whether a liquid is honey or vinegar?

1.2 Types of Matter

Lesson Objectives

- Describe elements and atoms.
- Describe compounds, molecules, and crystals.
- Define mixture, and identify types of mixtures.

Vocabulary

- atom
- colloid
- compound
- crystal
- element
- mixture
- molecule
- solution
- suspension

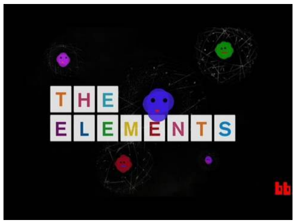
Introduction

The properties of matter, both physical and chemical, depend on the substances that matter is made of. Matter can exist either as a pure substance or as a combination of different substances.

Elements

An **element** is a pure substance. It cannot be separated into any other substances. There are more than 90 different elements that occur in nature. Some are much more common than others. Hydrogen is the most common element in the universe. Oxygen is the most common element in Earth's crust. **Figure** 1.7 shows other examples of elements. Still others are described in the video below.

http://www.youtube.com/watch?v=d0zION8xjbM (3:47)



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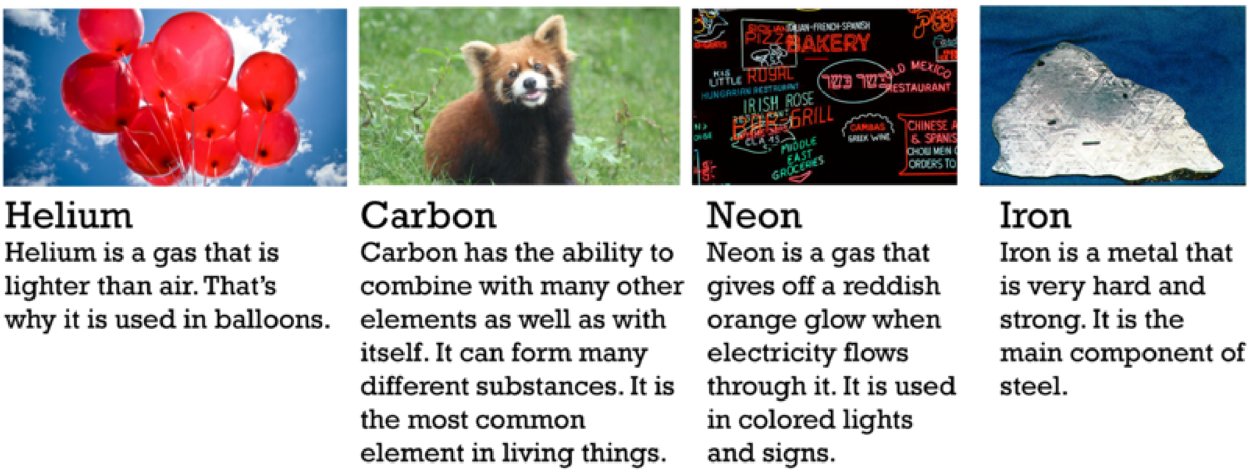

FIGURE 1.7

Each of the elements described here has different uses because of its properties.

Properties of Elements

Each element has a unique set of properties that make it different from all other elements. As a result, elements can be identified by their properties. For example, the elements iron and nickel are both metals that are good conductors of heat and electricity. However, iron is attracted by a magnet, whereas nickel is not. How could you use this property to separate iron objects from nickel objects?

History of Elements

The idea of elements is not new. It dates back about 2500 years to ancient Greece. The ancient Greek philosopher Aristotle thought that all matter consists of just four elements. He identified the elements as earth, air, water, and fire. He thought that different kinds of matter contain only these four elements but in different combinations.

Aristotle's ideas about elements were accepted for the next 2000 years. Then, scientists started discovering the many unique substances we call elements today. You can read when and how each of the elements was discovered at the link below. Scientists soon realized that there are far more than just four elements. Eventually, they discovered a total of 92 naturally occurring elements. http://www.nndc.bnl.gov/content/origindc.pdf

Elements and Atoms

The smallest particle of an element that still has the element's properties is an **atom**. All the atoms of an element are alike, and they are different from the atoms of all other elements. For example, atoms of gold are the same whether they are found in a gold nugget or a gold ring (see **Figure** 1.8). All gold atoms have the same structure and properties.

FIGURE 1.8
Gold is gold no matter where it is found because all gold atoms are alike.

Compounds

There are millions of different substances in the world. That's because elements can combine in many different ways to form new substances. In fact, most elements are found in compounds. A **compound** is a unique substance that forms when two or more elements combine chemically. An example is water, which forms when hydrogen and oxygen combine chemically. A compound always has the same components in the same proportions. It also has the same composition throughout. You can learn more about compounds and how they form by watching this video: http://www.youtube.com/watch?v=-HjMoTthEZ0 (3:53).

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Properties of Compounds

A compound has different properties than the substances it contains. For example, hydrogen and oxygen are gases at room temperature. But when they combine chemically, they form liquid water. Another example is table salt, or sodium chloride. It contains sodium and chlorine. Sodium is a silvery solid that reacts explosively with water, and chlorine is a poisonous gas (see **Figure** 1.9). But together, sodium and chlorine form a harmless, unreactive compound that you can safely sprinkle on food.

FIGURE 1.9
Table salt is much different than its components. What are some of its properties?

Molecules and Crystals

The smallest particle of a compound that still has the compound's properties is a **molecule**. A molecule consists of two or more atoms that are joined together. For example, a molecule of water consists of two hydrogen atoms joined to one oxygen atom (see **Figure** 1.10). You can learn more about molecules at this link: http://www.nyhallsci.org/marvelousmolecules/marveloussub.html .

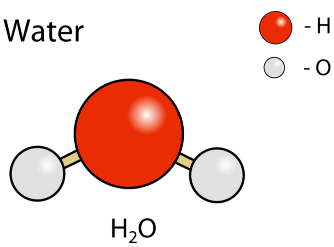

FIGURE 1.10
Water is a compound that forms molecules. Each water molecule consists of two atoms of hydrogen (white) and one atom of oxygen (red).

Some compounds form crystals instead of molecules. A **crystal** is a rigid, lattice-like framework of many atoms bonded together. Table salt is an example of a compound that forms crystals (see **Figure** 1.11). Its crystals are made up of many sodium and chloride ions. Ions are electrically charged forms of atoms. You can actually watch crystals forming in this video: http://www.youtube.com/watch?v=Jd9C40Svt5g .

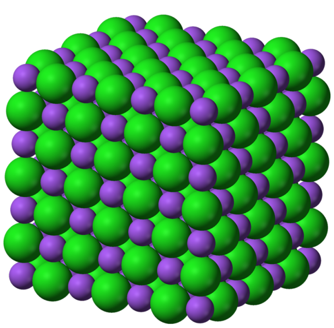

FIGURE 1.11
A crystal of table salt has a regular, repeating pattern of ions.

Mixtures

Not all combined substances are compounds. Some are mixtures. A **mixture** is a combination of two or more substances in any proportion. The substances in a mixture may be elements or compounds. The substances don't combine chemically to form a new substance, as they do in a compound. Instead, they keep their original properties and just intermix. Examples of mixtures include salt and water in the ocean and gases in the atmosphere. Other examples are pictured in **Figure** 1.12.

FIGURE 1.12
All these substances are mixtures. How do they differ from compounds?

Homogeneous and Heterogeneous Mixtures

Some mixtures are homogeneous. This means they have the same composition throughout. An example is salt water in the ocean. Ocean water everywhere is about 3.5 percent salt.

Some mixtures are heterogeneous. This means they vary in their composition. An example is trail mix. No two samples of trail mix, even from the same package, are likely to be exactly the same. One sample might have more raisins, another might have more nuts.

Particle Size in Mixtures

Mixtures have different properties depending on the size of their particles. Three types of mixtures based on particle size are described below. **Figure** 1.13 shows examples of each type. You can watch videos about the three types of mixtures at these links:

http://www.youtube.com/watch?v=q96ljVMHYLo (4:35)

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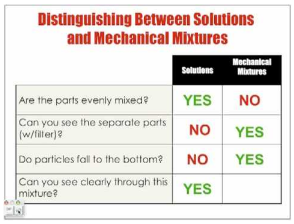
http://www.youtube.com/watch?v=96OOIL6atXs (6:13)



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- A **solution** is a homogeneous mixture with tiny particles. An example is salt water. The particles of a solution are too small to reflect light. As a result, you cannot see them. That's why salt water looks the same as pure water. The particles of solutions are also too small to settle or be filtered out of the mixture.
- A **suspension** is a heterogeneous mixture with large particles. An example is muddy water. The particles of a suspension are big enough to reflect light, so you can see them. They are also big enough to settle or be filtered out. Anything that you have to shake before using, such as salad dressing, is usually a suspension.
- A **colloid** is a homogeneous mixture with medium-sized particles. Examples include homogenized milk and gelatin. The particles of a colloid are large enough to reflect light, so you can see them. But they are too small to settle or filter out of the mixture.

FIGURE 1.13

These three mixtures differ in the size of their particles. Which mixture has the largest particles? Which has the smallest particles?

Separating Mixtures

The components of a mixture keep their own identity when they combine. Therefore, they usually can be easily separated again. Their different physical properties are used to separate them. For example, oil is less dense than water, so a mixture of oil and water can be separated by letting it stand until the oil floats to the top. Other ways of separating mixtures are shown in **Figure** 1.14 and in the videos below.

- http://www.youtube.com/watch?v=jWdu_RVy5_A (2:30)

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- http://www.youtube.com/watch?v=UsouAlL-YZU (2:41)

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FIGURE 1.14
Separating the components of a mixture depends on their physical properties. Which physical property is used in each example shown here?

Lesson Summary

- Elements are pure substances with unique properties. There are more than 100 different elements (92 of which occur naturally). The smallest particles of elements are atoms.
- Compounds are unique substances that form when two or more elements combine chemically. The smallest particles of compounds are molecules. Some compounds form crystals instead.

Lesson Review Questions

Recall

1. What is an element? Give three examples.
2. Describe compounds.
3. Identify molecules and crystals.
4. What are mixtures?

Apply Concepts

5. How could you use water and a coffee filter to separate a mixture of salt and sand?
6. Homogenized milk is a colloid. It has been treated to prevent its different components from separating when it stands. When non-homogenized milk stands, the cream rises to the top because it is less dense than the rest of the milk. Which type of mixture is non-homogenized milk? Explain your answer.

Think Critically

7. Create a table comparing and contrasting compounds and mixtures. Include an example of each.
8. How are atoms related to molecules?

Points to Consider

The properties of matter are not fixed. In fact, matter is always changing.

- What are some ways you have seen matter change?
- What do you think caused the changes?

1.3 Changes in Matter

Lesson Objectives

- Define and give examples of physical changes in matter.
- Define and give examples of chemical changes in matter.
- State the law of conservation of mass.

Vocabulary

- chemical change
- law of conservation of mass
- physical change

Introduction

You hit a baseball out of the park and head for first base. You're excited. The score is tied, and now your team has a chance of getting a winning home run. Then you hear a crash. Oh no! The baseball hit a window in a neighboring house. The glass has a big hole in it, surrounded by a web of cracks (see **Figure** 1.15). The glass has changed. It's been broken into jagged pieces. But the glass is still glass. Breaking the window is an example of a physical change in matter.

FIGURE 1.15

When glass breaks, its physical properties change. Instead of one solid sheet of glass, it now has holes and cracks.

Physical Changes in Matter

A **physical change** in matter is a change in one or more of matter's physical properties. Glass breaking is just one example of a physical change. Some other examples are shown in **Figure** 1.16 and in the video below. In each example, matter may look different after the change occurs, but it's still the same substance with the same chemical properties. For example, smaller pieces of wood have the ability to burn just as larger logs do.

FIGURE 1.16
In each of these changes, only the physical properties of matter change. The chemical properties remain the same.

http://www.youtube.com/watch?v=Cne9ncSaN5c (1:53)

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Because the type of matter remains the same with physical changes, the changes are often easy to undo. For example, braided hair can be unbraided again. Melted chocolate can be put in a fridge to re-harden. Dissolving salt in water is also a physical change. How do you think you could undo it?

Chemical Changes in Matter

Did you ever make a "volcano," like the one in **Figure** 1.17, using baking soda and vinegar? What happens when the two substances combine? They produce an eruption of foamy bubbles. This happens because of a chemical change. A **chemical change** occurs when matter changes chemically into an entirely different substance with different chemical properties. When vinegar and baking soda combine, they form carbon dioxide, a gas that causes the bubbles. It's the same gas that gives soft drinks their fizz.

Not all chemical changes are as dramatic as this "volcano." Some are slower and less obvious. **Figure** 1.18 and the

FIGURE 1.17
This girl is pouring vinegar on baking soda. This causes a bubbling "volcano."

video below show other examples of chemical changes.

http://www.youtube.com/watch?v=BqeWpywDuiY (2:54)

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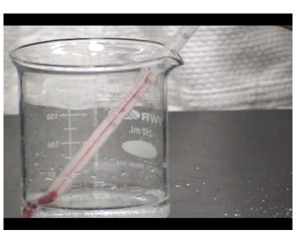
Signs of Chemical Change

How can you tell whether a chemical change has occurred? Often, there are clues. Several are demonstrated in **Figures** 1.17 and 1.18 and in the video below.

http://www.youtube.com/watch?v=gs0j1EZJ1Uc (9:57)



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To decide whether a chemical change has occurred, look for these signs:

- Gas bubbles are released. (Example: Baking soda and vinegar mix and produce bubbles.)
- Something changes color. (Example: Leaves turn from green to other colors.)
- An odor is produced. (Example: Logs burn and smell smoky.)
- A solid comes out of a solution. (Example: Eggs cook and a white solid comes out of the clear liquid part of the egg.)

FIGURE 1.18

These chemical changes all result in the formation of new substances with different chemical properties. Do you think any of these changes could be undone?

Reversing Chemical Changes

Because chemical changes produce new substances, they often cannot be undone. For example, you can't change a fried egg back to a raw egg. Some chemical changes can be reversed, but only by other chemical changes. For example, to undo the tarnish on copper pennies, you can place them in vinegar. The acid in the vinegar reacts with the tarnish. This is a chemical change that makes the pennies bright and shiny again. You can try this yourself at home to see how well it works.

Conservation of Mass

If you build a campfire, like the one in **Figure** 1.19, you start with a large stack of sticks and logs. As the fire burns, the stack slowly shrinks. By the end of the evening, all that's left is a small pile of ashes. What happened to the matter that you started with? Was it destroyed by the flames? It may seem that way, but in fact, the same amount of matter still exists. The wood changed not only to ashes but also to carbon dioxide, water vapor, and other gases. The gases floated off into the air, leaving behind just the ashes.

Assume you had measured the mass of the wood before you burned it. Assume you had also trapped the gases released by the burning wood and measured their mass and the mass of the ashes. What would you find? The ashes and gases combined have the same mass as the wood you started with.

This example illustrates the **law of conservation of mass**. The law states that matter cannot be created or destroyed. Even when matter goes through physical or chemical changes, the total mass of matter always remains the same. (In

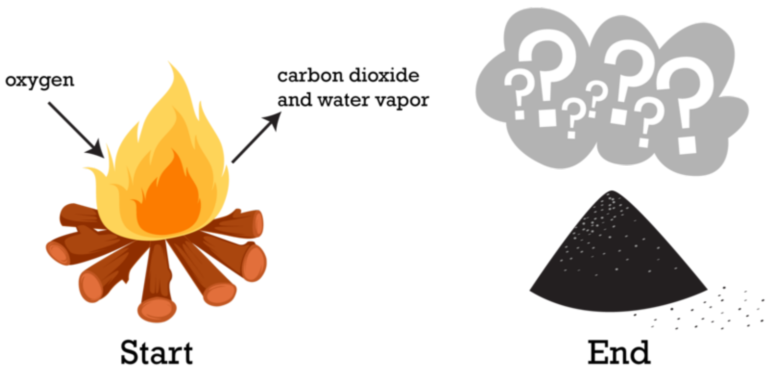

FIGURE 1.19
Burning is a chemical process. Is mass destroyed when wood burns?

the chapter *Nuclear Chemistry*, you will learn about nuclear reactions, in which mass is converted into energy. But other than that, the law of conservation of mass holds.) For a fun challenge, try to apply the law of conservation of mass to a scene from a Harry Potter film at this link: http://www.youtube.com/watch?v=3TsTOnNmkf8 .

Lesson Summary

- Physical changes are changes in the physical properties of matter but not in the makeup of matter. An example of a physical change is glass breaking.
- Chemical changes are changes in the makeup and chemical properties of matter. An example of a chemical change is wood burning.
- Matter cannot be created or destroyed even when it changes. This is the law of conservation of mass.

Lesson Review Questions

Recall

1. What is a physical change in matter?
2. What happens during a chemical change in matter?
3. State the law of conservation of mass.

Apply Concepts

4. When a plant grows, its mass increases over time. Does this mean that new matter is created? Why or why not?
5. Butter melts when you heat it in a pan on the stove. Is this a chemical change or a physical change? How can you tell?

Think Critically

6. Compare and contrast physical and chemical changes in matter. Give an example of each type of change.

Points to Consider

Some physical changes in matter are changes of state.

- What are the states of matter?
- What might cause matter to change state?

1.4 References

1. Flickr:winnifredxoxo. http://www.flickr.com/photos/61056899@N06/5751301741/ . CC BY 2.0
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5. Diamond: Steve Jurvetson; Talc: Courtesy of the US Geological Survey and the Mineral Information Institute; Antifreeze: Flickr:dno1967; Water: José Manuel Suárez; Pot: Phil and Pam Gradwell (to be) (Flickr: Phil and Pam); Wire: Scott Ehardt; Sand: Jakub Michankow; Sugar: Robert Lopez and Steven Terrebonne. Diamond: http://www.flickr.com/photos/jurvetson/156830367/; Talc: http://commons.wikimedia.org/wiki/File:Talc_block.jpg; Antifreeze: http://commons.wikimedia.org/wiki/File:Antifreeze.jpg; Water: http://commons.wikimedia.org/wiki/File:Water_drop_001.jpg; Pot: http://www.flickr.com/photos/philandpam/2131629044/; Wire: http://commons.wikimedia.org/wiki/File:Stranded_lamp_wire.jpg; Sand: http://www.flickr.com/photos/glowform/5859259137; Sugar: CK-12 Foundation . Diamond: CC BY 2.0; Talc: Public Domain; Antifreeze: CC BY 2.0; Water: CC BY 2.0; Pot: CC BY 2.0; Wire: Public Domain; Sand: CC BY 2.0; Sugar: CC BY-NC 3.0
6. fujikumo. http://commons.wikimedia.org/wiki/File:Rusted_chain.jpg . CC BY 1.0
7. Balloon: LeAnn E. Crowe (Flickr:technicolor76); Red panda: Matthijs Koster; Neon signs: Dane A. Penland; Iron: Courtesy of NASA. Balloon: http://www.flickr.com/photos/86044507@N00/3705507804; Red panda: http://www.flickr.com/photos/matthijskoster/746427079/; Neon signs: http://www.flickr.com/photos/publicresourceorg/493866748/; Iron: http://commons.wikimedia.org/wiki/File:Widmanstatten_IronMet.JPG . Balloon: CC BY 2.0; Red panda: CC BY 2.0; Neon signs: CC BY 2.0; Iron: Public Domain
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12. Lemonade: Flickr:momentcaptured1; Rock: James St. John (Flickr:jsj1771); Salad dressing: Image copyright Charles Brutlag, 2013; Flower seeds: Forest Kim Starr. Lemonade: http://www.flickr.com/photos/pat_ossa/4991556821/; Rock: http://www.flickr.com/photos/jsjgeology/8475805063/; Salad dressing: http://www.shutterstock.com; Flower seeds: http://commons.wikimedia.org/wiki/File:Starr_080117-1842_Calendula_officinalis.jpg . Lemonade and Rock: CC BY 2.0; Salad dressing: Used under licenses from Shutterstock.com; Flower seeds: CC BY 3.0
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14. Lake: User:xta11/Wikimedia Commons; Coffee filter: Robert S. Donovan; Magnet: Christopher Auyeung. Lake: http://commons.wikimedia.org/wiki/File:DeadSeaIsrael3.jpg; Coffee filter: http://www.flickr.com/photos/booleansplit/7181874752/; Magnet: CK-12 Foundation . Lake: Public Domain; Coffee filter: CC BY 2.0; Magnet: CC BY-NC 3.0
15. Jef Poskanzer. http://commons.wikimedia.org/wiki/File:Broken_glass.jpg . CC BY 2.0

16. Log: Alex Murphy (Flickr: APM Alex); Braiding hair: Steven Depolo; Can: James Mackintosh Photography ; Arch: Frank Kovalchek; Candy: Image copyright Anteromite, 2013. Log: http://www.flickr.com/photos/28misguidedsouls/5128954613/; Braiding hair: http://www.flickr.com/photos/stevendepolo/4886397967/; Can: http://www.flickr.com/photos/59207552@N08/8565955392/; Arch: http://www.flickr.com/photos/72213316@N00/5242351183/; Candy: http://www.shutterstock.com . Log, Braiding hair, Can, Arch: CC BY 2.0; Candy: Used under license from Shutterstock.com
17. davidd (Flickr:puuikibeach). http://www.flickr.com/photos/puuikibeach/3446802774/ . CC BY 2.0
18. Leaves: Kenny Louie (Flickr:kennymatic); Eggs: Image copyright Fotografas Edgaras, 2013; Pennies: F Delventhal (Flickr:krossbow); Fire: Dawn Huczek. Leaves: http://www.flickr.com/photos/kwl/6282684630/; Eggs: http://www.shutterstock.com; Pennies: http://www.flickr.com/photos/krossbow/4252686414/; Fire: http://www.flickr.com/photos/31064702@N05/3810662879/ . Leaves: CC BY 2.0; Eggs: Used under licenses from Shutterstock.com; Pennies: CC BY 2.0; Fire: CC BY 2.0
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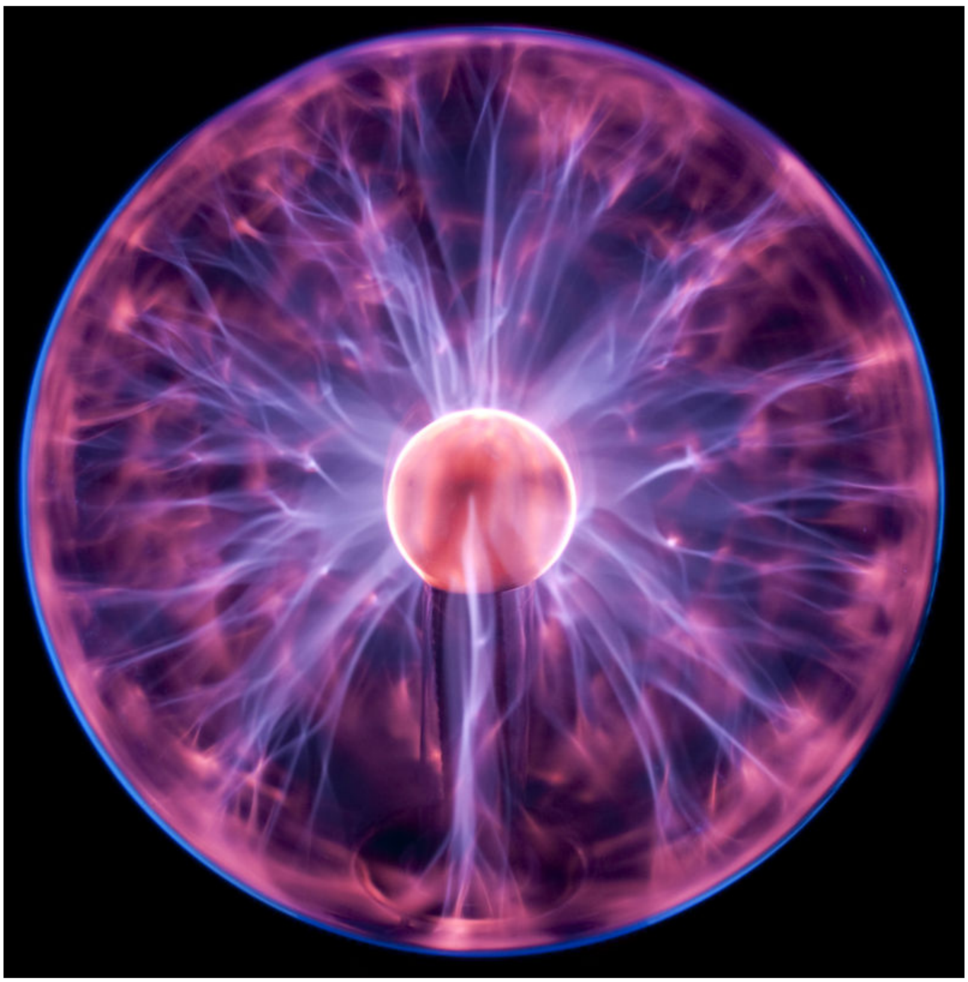
CHAPTER 2 States of Matter

Chapter Outline



Can you guess what this picture shows? The purple and blue "flames" are matter in a particular state. You're probably familiar with the states of matter most common on Earth —solids, liquids, and gases. But these "flames" are a state of matter called plasma. This plasma ball was made by humans. Plasma also occurs in nature. In fact, plasma makes up most of the matter in the universe.

What do you know about plasma? For example, do you know where it is found in nature? In this chapter, you'll find out as you read about plasma and other states of matter.

Tony Hisgett. commons.wikimedia.org/wiki/File:Plasma_ball_%283996244124%29.jpg. CC BY 2.0.

2.1 Solids, Liquids, Gases, and Plasmas

Lesson Objectives

- Describe matter in the solid state.
- State properties of liquid matter
- Identify properties of gases.
- Describe plasma.
- Explain the relationship between energy and states of matter.

Vocabulary

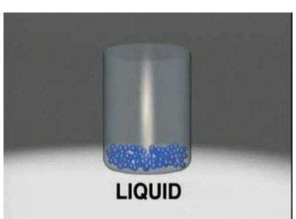
- energy
- gas
- kinetic energy
- kinetic theory of matter
- liquid
- plasma
- solid
- states of matter

Introduction

States of matter are the different forms in which matter can exist. Look at **Figure** 2.1. It represents water in three states: solid (iceberg), liquid (ocean water), and gas (water vapor in the air). In all three states, water is still water. It has the same chemical makeup and the same chemical properties. That's because the state of matter is a physical property.

How do solids, liquids, and gases differ? Their properties are compared in **Figure** 2.2 and described below. You can also watch videos about the three states at these URLs:

http://www.youtube.com/watch?v=s-KvoVzukHo (0:52)



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/641

http://www.youtube.com/watch?v=NO9OGeHgtBY (1:42)

FIGURE 2.1
This photo represents solid, liquid, and gaseous water. Where is the gaseous water in the picture?

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Click image to the left or use the URL below.
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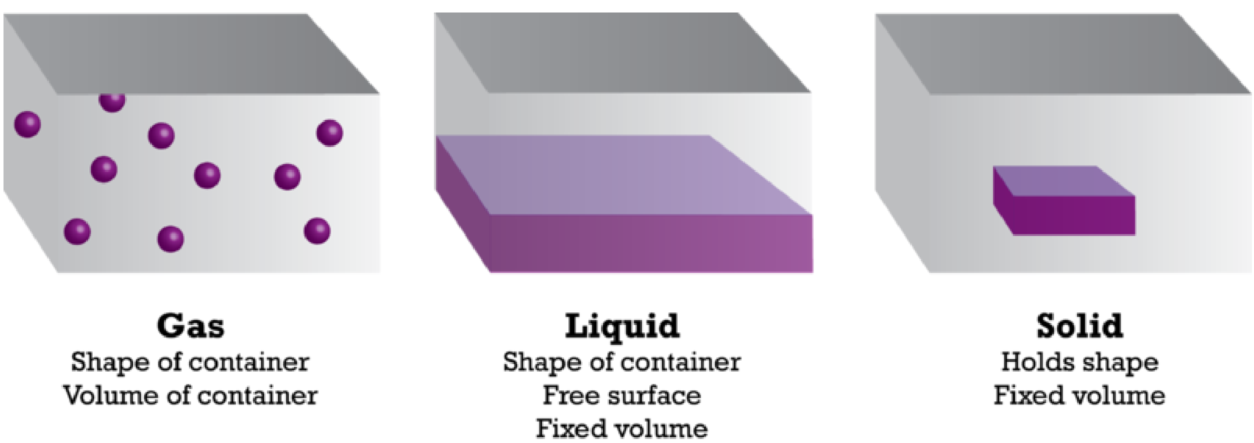

FIGURE 2.2
These three states of matter are common on Earth. What are some substances that usually exist in each of these states?

Solids

Ice is an example of solid matter. A **solid** is matter that has a fixed volume and a fixed shape. **Figure** 2.3 shows examples of matter that are usually solids under Earth conditions. In the figure, salt and cellulose are examples of crystalline solids. The particles of crystalline solids are arranged in a regular repeating pattern. The steaks and candle wax are examples of amorphous ("shapeless") solids. Their particles have no definite pattern.

FIGURE 2.3
The volume and shape of a solid can be changed, but only with outside help. How could you change the volume and shape of each of the solids in the figure without changing the solid in any other way?

Liquids

Ocean water is an example of a liquid. A **liquid** is matter that has a fixed volume but not a fixed shape. Instead, a liquid takes the shape of its container. If the volume of a liquid is less than the volume of its container, the top surface will be exposed to the air, like the oil in the bottles in **Figure** 2.4.

Two interesting properties of liquids are surface tension and viscosity.

- Surface tension is a force that pulls particles at the exposed surface of a liquid toward other liquid particles. Surface tension explains why water forms droplets, like those in **Figure** 2.5.
- Viscosity is a liquid's resistance to flowing. Thicker liquids are more viscous than thinner liquids. For example, the honey in **Figure** 2.5 is more viscous than the vinegar.

You can learn more about surface tension and viscosity at these URLs:

- http://io9.com/5668221/an-experiment-with-soap-water-pepper-and-surface-tension

FIGURE 2.4

Each bottle contains the same volume of oil. How would you describe the shape of the oil in each bottle?

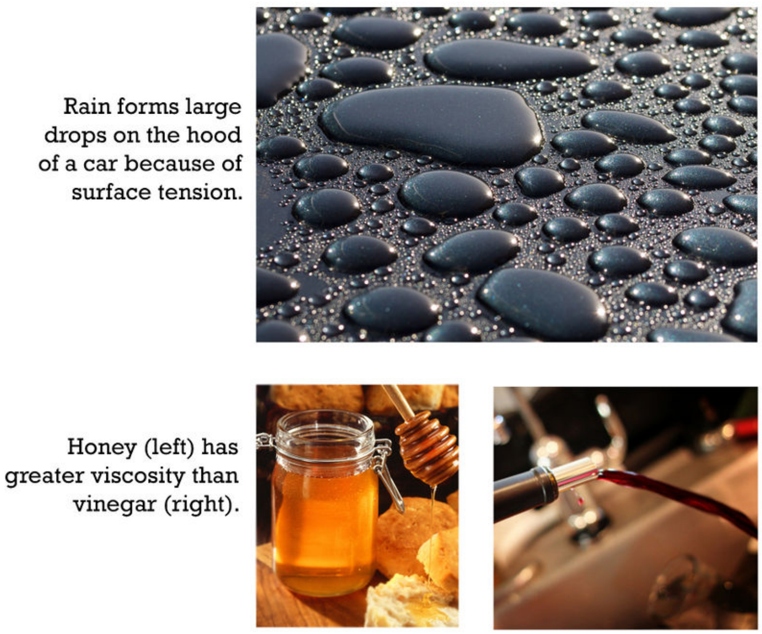

FIGURE 2.5

These images illustrate surface tension and viscosity of liquids.

- http://chemed.chem.wisc.edu/chempaths/GenChem-Textbook/Viscosity-840.html
- http://www.youtube.com/watch?v=u5AxlJSiEEs (1:40)

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URL: http://www.ck12.org/flx/render/embeddedobject/5072

Gases

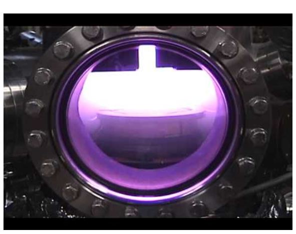
Water vapor is an example of a gas. A **gas** is matter that has neither a fixed volume nor a fixed shape. Instead, a gas takes both the volume and the shape of its container. It spreads out to take up all available space. You can see an example in **Figure** 2.6.

FIGURE 2.6
When you add air to a bicycle tire, you add it only through one tiny opening. But the air immediately spreads out to fill the whole tire.

Plasmas

You're probably less familiar with plasmas than with solids, liquids, and gases. Yet, most of the universe consists of plasma. **Plasma** is a state of matter that resembles a gas but has certain properties that a gas does not have. Like a gas, plasma lacks a fixed volume and shape. Unlike a gas, plasma can conduct electricity and respond to magnetism. That's because plasma contains charged particles called ions. This gives plasma other interesting properties. For example, it glows with light.

Where can you find plasmas? Two examples are shown in **Figure** 2.7. The sun and other stars consist of plasma. Plasmas are also found naturally in lightning and the polar auroras (northern and southern lights). Artificial plasmas are found in fluorescent lights, plasma TV screens, and plasma balls like the one that opened this chapter. You can learn more about plasmas at this URL: http://www.youtube.com/watch?v=VkeSI_B5Ljc (2:58).



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Energy and Matter

Why do different states of matter have different properties? It's because of differences in energy at the level of atoms and molecules, the tiny particles that make up matter.

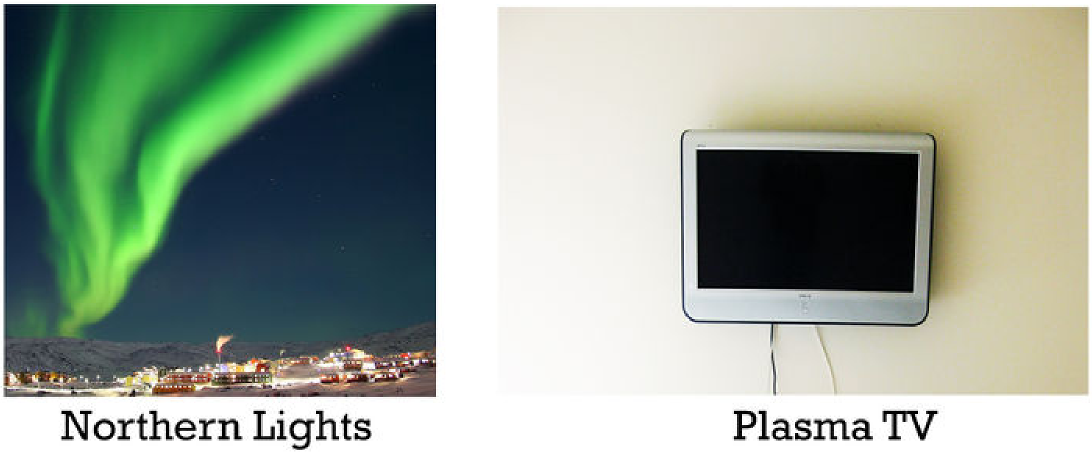

FIGURE 2.7
Both the northern lights (aurora borealis) and a plasma TV contain matter in the plasma state. What other plasmas are shown in the northern lights picture?

Energy

Energy is defined as the ability to cause changes in matter. You can change energy from one form to another when you lift your arm or take a step. In each case, energy is used to move matter — you. The energy of moving matter is called **kinetic energy**.

Kinetic Theory of Matter

The particles that make up matter are also constantly moving. They have kinetic energy. The theory that all matter consists of constantly moving particles is called the **kinetic theory of matter**. You can learn more about it at the URL below.

http://www.youtube.com/watch?v=Agk7_D4-deY (10:55)

Energy and States of Matter

Particles of matter of the same substance, such as the same element, are attracted to one another. The force of attraction tends to pull the particles closer together. The particles need a lot of kinetic energy to overcome the force of attraction and move apart. It's like a tug of war between opposing forces. The kinetic energy of individual particles is on one side, and the force of attraction between different particles is on the other side. The outcome of the "war" depends on the state of matter. This is illustrated in **Figure** 2.8 and in the animation at this URL: http://www.tutorvista.com/content/physics/physics-i/heat/kinetic-molecular-theory.php .

- In solids, particles don't have enough kinetic energy to overcome the force of attraction between them. The particles are packed closely together and cannot move around. All they can do is vibrate. This explains why solids have a fixed volume and shape.
- In liquids, particles have enough kinetic energy to partly overcome the force of attraction between them. They can slide past one another but not pull completely apart. This explains why liquids can change shape but have

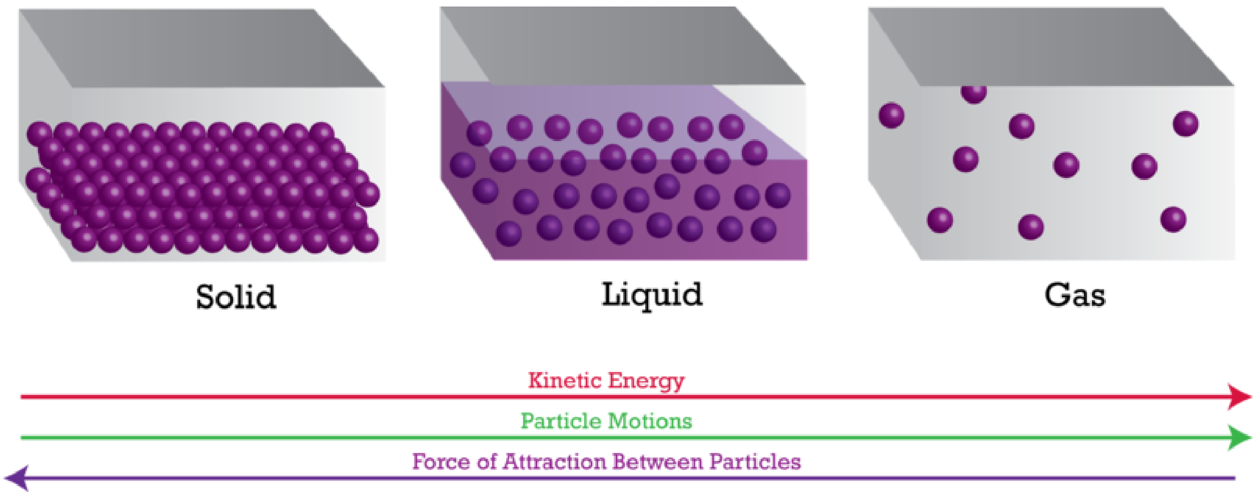

FIGURE 2.8
Kinetic energy is needed to overcome the force of attraction between particles of the same substance.

a fixed volume.

- In gases, particles have a lot of kinetic energy. They can completely overcome the force of attraction between them and move apart. This explains why gases have neither a fixed volume nor a fixed shape.

Lesson Summary

- A solid is matter that has a fixed volume and a fixed shape.
- A liquid is matter that has a fixed volume but not a fixed shape.
- A gas is matter that has neither a fixed volume nor a fixed shape.
- Like a gas, plasma lacks a fixed volume and shape. Unlike a gas, it can conduct electricity and respond to magnetism.
- The state of matter depends on the kinetic energy of the particles of matter.

Lesson Review Questions

Recall

1. What are states of matter?
2. What are the properties of solids?
3. State the properties of liquids.
4. Describe properties of gases.
5. How do plasmas compare with gases?

Apply Concepts

6. Apply the concept of surface tension to explain why the surface of water in the glass shown in the **Figure** 2.9 is curved upward. Why doesn't the water overflow the glass?

FIGURE 2.9
The surface of water in the glass is curved upward. How does surface tension explain this phenomenon?

Think Critically

7. Explain the relationship between energy and states of matter.

Points to Consider

You read in this lesson that gases expand to fill their container.

- What if gas were forced into a smaller container? Would it shrink to fit?
- What other properties of the gas might change if its particles were crowded closer together?

2.2 Behavior of Gases

Lesson Objectives

- Define pressure.
- State the gas laws.

Vocabulary

- Amonton's law
- Boyle's law
- Charles's law
- pressure

Introduction

The molecules of a gas in a closed container, such as a balloon, are not only constantly moving. They are also constantly bumping into each other and into the sides of their container. The sketch in **Figure** 2.10 shows how this happens. The force of the particles against whatever they bump into creates pressure.

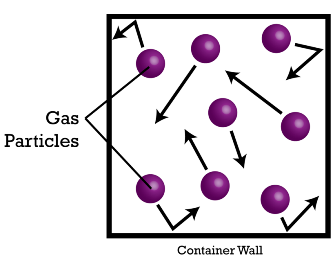

FIGURE 2.10
The particles of a gas keep bumping into the sides of its container.

What Is Pressure?

Pressure is defined as the amount of force pushing against a given area. How much pressure a gas exerts depends on the amount of gas. The more gas particles there are, the greater the pressure.

You usually cannot feel it, but air has pressure. The gases in Earth's atmosphere exert pressure against everything they contact. The atmosphere rises high above Earth's surface. It contains a huge number of individual gas particles. As a result, the pressure of the tower of air above a given spot on Earth's surface is substantial. If you were standing at sea level, the amount of force would be equal to 10.14 newtons per square centimeter (14.7 pounds per square inch). This is illustrated in **Figure** 2.11.

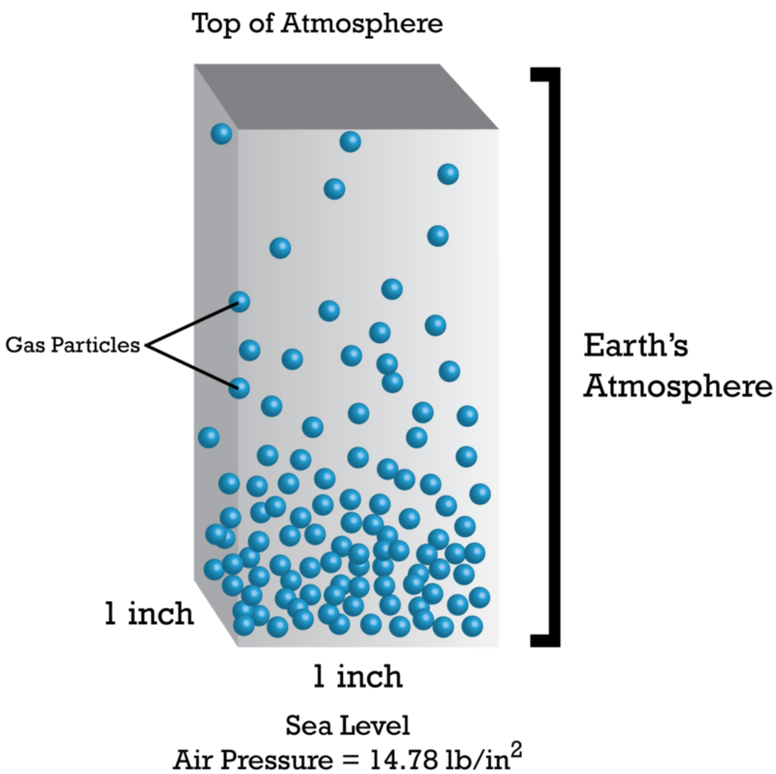

FIGURE 2.11
Earth's atmosphere exerts pressure. This pressure is greatest at sea level. Can you explain why?

The Gas Laws

For a given amount of gas, scientists have discovered that the pressure, volume, and temperature of a gas are related in certain ways. Because these relationships always hold in nature, they are called laws. The laws are named for the scientists that discovered them.

Boyle's Law

Boyle's law was discovered in the 1600s by an Irish chemist named Robert Boyle. According to **Boyle's law**, if the temperature of a gas is held constant, increasing the volume of the gas decreases its pressure. Why is this the case? As the volume of a gas increases, its particles have more room to spread out. This means that there are fewer particles bumping into any given area. This decreases the pressure of the gas. The graph in **Figure** 2.12 shows this relationship between volume and pressure. Because pressure and volume change in opposite directions, their relationship is called an inverse relationship. You can see an animation of the relationship at this URL: http://www.grc.nasa.gov/WWW/K-12/airplane/aboyle.html .

A scuba diver, like the one in **Figure** 2.13, releases air bubbles when he breathes under water. As he gets closer to the surface of the water, the air bubbles get bigger. Boyle's law explains why. The pressure of the water decreases as the diver gets closer to the surface. Because the bubbles are under less pressure, they increase in volume even though the amount of gas in the bubbles remains the same.

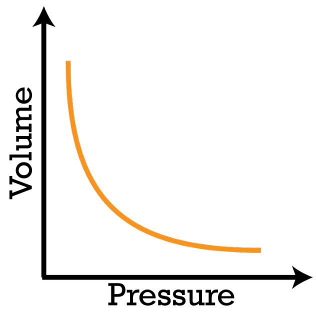

FIGURE 2.12
As the volume of a gas increases, its pressure decreases.

FIGURE 2.13
Gas bubbles get bigger when they are under less pressure.

Charles's Law

Charles's law was discovered in the 1700s by a French physicist named Jacques Charles. According to **Charles's law**, if the pressure of a gas is held constant, increasing the temperature of the gas increases its volume. What happens when a gas is heated? Its particles gain energy. With more energy, the particles have a greater speed. Therefore, they can move more and spread out farther. The volume of the gas increases as it expands and takes up more space. The graph in **Figure** 2.14 shows this relationship between the temperature and volume of a gas. You can see an animation of the relationship at this URL: http://www.grc.nasa.gov/WWW/K-12/airplane/aglussac.html .

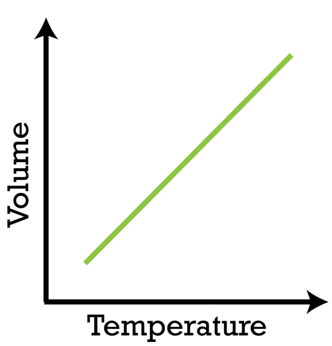

FIGURE 2.14
As the temperature of a gas increases, its volume also increases.

Roger had a latex balloon full of air inside his air-conditioned house. When he took the balloon outside in the hot sun, it got bigger and bigger until it popped. Charles's law explains why. As the gas in the balloon warmed in the sun, its volume increased. It stretched and expanded the latex of the balloon until the balloon burst.

Amonton's Law

Amonton's law was discovered in the late 1600s by a French physicist named Guillaume Amonton. According to **Amonton's law**, if the volume of a gas is held constant, increasing the temperature of the gas increases its pressure. Why is this the case? A heated gas has more energy. Its particles move more and have more collisions, so the pressure of the gas increases. The graph in **Figure** 2.15 shows this relationship.

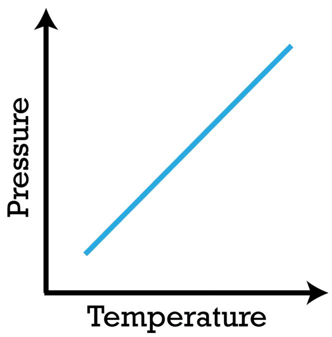

FIGURE 2.15
As the temperature of a gas increases, its pressure increases as well.

A woman checked the air pressure in her tires before driving her car on a cold day (see **Figure** 2.16). The tire pressure gauge registered 29 pounds of pressure per square inch. After driving the car several miles on the highway, the woman stopped and checked the tire pressure again. This time the gauge registered 32 pounds per square inch. Amonton's law explains what happened. As the tires rolled over the road, they got warmer. The air inside the tires also warmed. As it did, its pressure increased.

FIGURE 2.16
A tire pressure gauge measures the pressure of the air inside a car tire. Why is the pressure likely to increase as the car is driven?

Lesson Summary

- Particles of a gas are constantly moving and bumping into things. This gives gases pressure.
- The gas laws describe the relationship among pressure, volume, and temperature of a given amount of gas.

Lesson Review Questions

Recall

1. Define pressure.
2. Why do gases exert pressure?
3. What is Boyle's law?
4. State Charles's law.

Apply Concepts

5. Assume you have a closed glass container that contains only air. If you heat the air in the closed container, it will gain energy. What other property of the air will also change?
6. Draw a graph to show the relationship between the volume and pressure of a fixed amount of gas.

Think Critically

7. A weather balloon is released at Earth's surface. It rises high in the atmosphere. As the balloon rises, it expands and eventually bursts. Explain why.

Points to Consider

In this lesson, you read that heating a gas gives its particles more kinetic energy. As a result, its volume or pressure also increases. The opposite happens when a gas is cooled.

- What might happen if you cool a gas to an even lower temperature? Might it change state and become a liquid?
- Can you predict the role of energy in changes of state?

2.3 Changes of State

Lesson Objectives

- Explain the role of energy in changes of state.
- Outline the processes of freezing and melting.
- Describe vaporization and condensation.
- Define sublimation and deposition.

Vocabulary

- condensation
- deposition
- evaporation
- freezing
- melting
- sublimation
- temperature
- vaporization

Introduction

Matter is always changing state. Look at the two pictures of Mount Rushmore in **Figure** 2.17. The picture on the left was taken on a sunny summer morning. In this picture, the sky is perfectly clear. The picture on the right was taken just a few hours later. In this picture, there are clouds in the sky. The clouds consist of tiny droplets of liquid water. Where did the water come from? It was there all along in the form of invisible water vapor.

FIGURE 2.17
Both of these pictures of Mount Rushmore were taken on the same day just a few hours apart. Where did the clouds come from in the picture on the right?

Introduction to Changes of State

What causes clouds to form? And in general, how does matter change from one state to another? As you may have guessed, changes in energy are involved.

What Are Changes of State?

Changes of state are physical changes in matter. They are reversible changes that do not involve changes in matter's chemical makeup or chemical properties. Common changes of state include melting, freezing, sublimation, deposition, condensation, and vaporization. These changes are shown in **Figure** 2.18. Each is described in detail below.

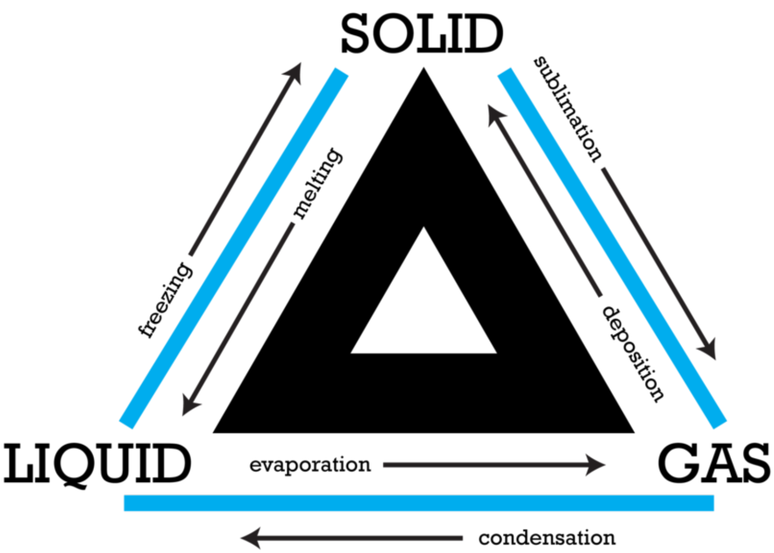

FIGURE 2.18
Which process changes a solid to a gas? Which process changes a gas to a solid?

Energy, Temperature, and Changes of State

Energy is always involved in changes of state. Matter either loses or absorbs energy when it changes from one state to another. For example, when matter changes from a liquid to a solid, it loses energy. The opposite happens when matter changes from a solid to a liquid. For a solid to change to a liquid, matter must absorb energy from its surroundings. The amount of energy in matter can be measured with a thermometer. That's because a thermometer measures temperature, and **temperature** is the average kinetic energy of the particles of matter. You can learn more about energy, temperature, and changes of state at this URL: http://hogan.chem.lsu.edu/matter/chap26/animate3/an26_035.mov .

Changes Between Liquids and Solids

Think about how you would make ice cubes in a tray. First you would fill the tray with water from a tap. Then you would place the tray in the freezer compartment of a refrigerator. The freezer is very cold. What happens next?

Freezing

The warmer water in the tray loses heat to the colder air in the freezer. The water cools until its particles no longer have enough energy to slide past each other. Instead, they remain in fixed positions, locked in place by the forces of attraction between them. The liquid water has changed to solid ice. Another example of liquid water changing to solid ice is pictured in **Figure** 2.19.

FIGURE 2.19
Water dripping from a gutter turned to ice as it fell toward the ground, forming icicles. Why did the liquid water change to a solid?

The process in which a liquid changes to a solid is called **freezing**. The temperature at which a liquid changes to a solid is its freezing point. The freezing point of water is 0°C (32°F). Other types of matter may have higher or lower freezing points. For example, the freezing point of iron is 1535°C. The freezing point of oxygen is -219°C.

Melting

If you took ice cubes out of a freezer and left them in a warm room, the ice would absorb energy from the warmer air around it. The energy would allow the particles of frozen water to overcome some of the forces of attraction holding them together. They would be able to slip out of the fixed positions they held as ice. In this way, the solid ice would turn to liquid water.

The process in which a solid changes to a liquid is called **melting**. The melting point is the temperature at which a solid changes to a liquid. For a given type of matter, the melting point is the same as the freezing point. What is the melting point of ice? What is the melting point of iron, pictured in **Figure** 2.20?

Changes Between Liquids and Gases

If you fill a pot with cool tap water and place the pot on a hot stovetop, the water heats up. Heat energy travels from the stovetop to the pot, and the water absorbs the energy from the pot. What happens to the water next?

Vaporization

If water gets hot enough, it starts to boil. Bubbles of water vapor form in boiling water. This happens as particles of liquid water gain enough energy to completely overcome the force of attraction between them and change to the

FIGURE 2.20
Molten (melted) iron is poured into a mold at a foundry. It takes extremely high temperatures to change iron from a solid to the liquid shown here. That's because iron has a very high melting point.

gaseous state. The bubbles rise through the water and escape from the pot as steam.

The process in which a liquid boils and changes to a gas is called **vaporization**. The temperature at which a liquid boils is its boiling point. The boiling point of water is 100°C (212°F). Other types of matter may have higher or lower boiling points. For example, the boiling point of table salt is 1413°C. The boiling point of nitrogen is -196°C.

Evaporation

A liquid can also change to a gas without boiling. This process is called **evaporation**. It occurs when particles at the exposed surface of a liquid absorb just enough energy to pull away from the liquid and escape into the air. This happens faster at warmer temperatures. Look at the puddle in **Figure** 2.21. It formed in a pothole during a rain shower. The puddle will eventually evaporate. It will evaporate faster if the sun comes out and heats the water than if the sky remains cloudy.

Condensation

If you take a hot shower in a closed bathroom, the mirror is likely to "fog" up. The "fog" consists of tiny droplets of water that form on the cool surface of the mirror. Why does this happen? Some of the hot water from the shower evaporates, so the air in the bathroom contains a lot of water vapor. When the water vapor contacts cooler surfaces, such as the mirror, it cools and loses energy. The cooler water particles no longer have enough energy to overcome the forces of attraction between them. They come together and form droplets of liquid water.

The process in which a gas changes to a liquid is called **condensation**. Other examples of condensation are shown in **Figure** 2.22. A gas condenses when it is cooled below its boiling point. At what temperature does water vapor condense?

FIGURE 2.21
Evaporation of water occurs even at relatively low temperatures. The water trapped in this pothole will evaporate sooner or later.

FIGURE 2.22
Water vapor condenses to form liquid water in each of the examples pictured here.

Changes Between Solids and Gases

Solids that change to gases generally first pass through the liquid state. However, sometimes solids change directly to gases and skip the liquid state. The reverse can also occur. Sometimes gases change directly to solids.

Sublimation

The process in which a solid changes directly to a gas is called **sublimation**. It occurs when the particles of a solid absorb enough energy to completely overcome the force of attraction between them. Dry ice (solid carbon dioxide, CO_2) is an example of a solid that undergoes sublimation. **Figure** 2.23 shows a chunk of dry ice changing directly to carbon dioxide gas. Sometimes snow undergoes sublimation as well. This is most likely to occur on sunny winter days when the air is very dry. What gas does snow become?

FIGURE 2.23
Solid carbon dioxide changes directly to the gaseous state.

Deposition

The opposite of sublimation is **deposition**. This is the process in which a gas changes directly to a solid without going through the liquid state. It occurs when gas particles become very cold. For example, when water vapor in the air contacts a very cold windowpane, the water vapor may change to tiny ice crystals on the glass. The ice crystals are called frost. You can see an example in **Figure** 2.24.

Lesson Summary

- Changes of state are physical changes. They occur when matter absorbs or loses energy.
- Processes in which matter changes between liquid and solid states are freezing and melting.
- Processes in which matter changes between liquid and gaseous states are vaporization, evaporation, and condensation.
- Processes in which matter changes between solid and gaseous states are sublimation and deposition.

Lesson Review Questions

Recall

1. Identify the processes involved in changes of state between liquids and solids.

FIGURE 2.24
Frost is solid water that forms when water vapor undergoes deposition.

2. Define vaporization and evaporation. State how the two processes differ.
3. What is sublimation? Give an example.
4. Define deposition. When does it occur?

Apply Concepts

5. Cliff opened the oven door to check on the cake he was baking. As hot, moist air rushed out of the oven, his eyeglasses steamed up. Explain why.

Think Critically

6. Explain the role of energy in changes of state.
7. Form a hypothesis to explain why the melting points of different solids vary.

Points to Consider

In this chapter, you read that atoms and molecules of the same kind of matter have forces of attraction between them. Atoms consist of even smaller particles. These particles are held together by certain forces as well.

- What are the particles that make up atoms?
- What forces might hold them together?

2.4 References

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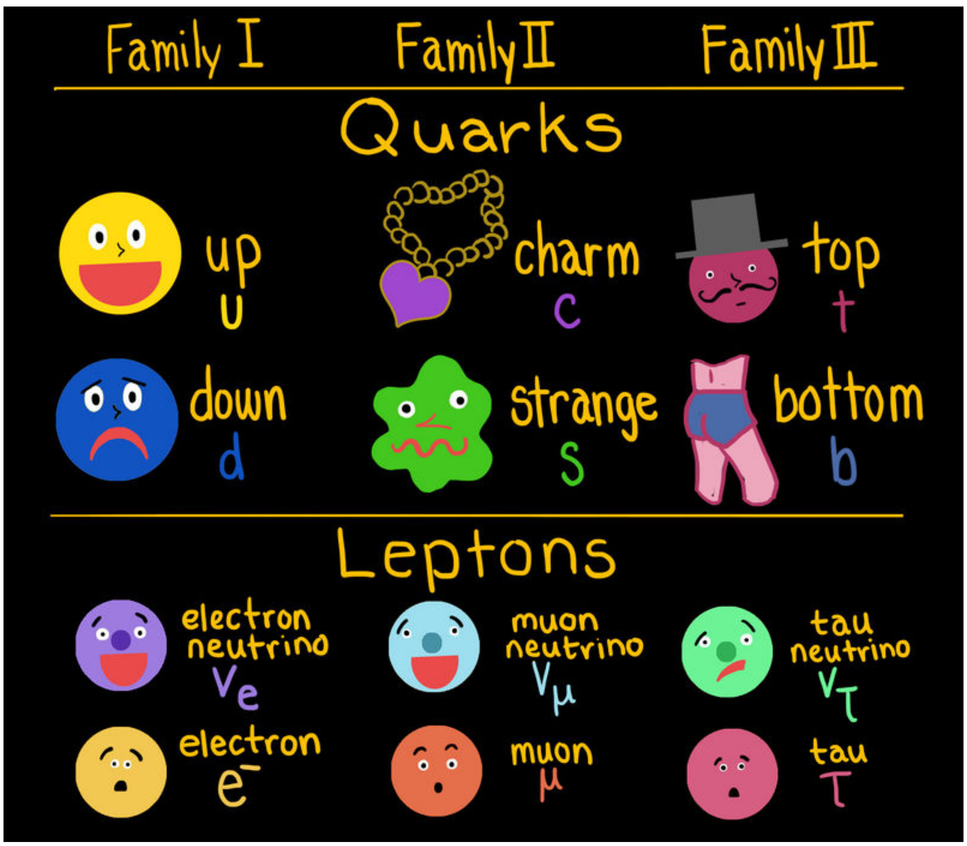
CHAPTER 3 Atoms

Chapter Outline



For many decades, scientists have known that atoms consist of electrons and other particles called protons and neutrons. Recently they found that there are even smaller particles in atoms. Scientists call these extremely tiny particles by the funny name of quarks. As you can see in this diagram, there are several different kinds of quarks, called up quarks, down quarks, top quarks, bottom quarks, charm quarks, and strange quarks. In this chapter you'll learn about these unusual particles and also other particles inside the atom.

3.1 Inside the Atom

Lesson Objectives

- Compare and contrast protons, neutrons, and electrons.
- Describe the forces that hold the particles of atoms together.
- Define atomic number and mass number.
- Describe ions and isotopes
- Identify the particles called quarks.

Vocabulary

- atomic mass unit (amu)
- atomic number
- electron
- ion
- isotope
- mass number
- neutron
- nucleus
- proton
- quark

Introduction

Atoms are the smallest particles of an element that still have the element's properties. They are the building blocks of all matter. Individual atoms are extremely small. In fact, they are so small that trillions of them would fit inside the period at the end of this sentence. Yet atoms, in turn, consist of even smaller particles.

Parts of the Atom

Figure 3.1 represents a simple model of an atom. You will learn about more complex models in later lessons, but this model is a good place to start. You can see similar, animated models of atoms at this URL: http://web.jjay.cuny.edu/~acarpi/NSC/3-atoms.htm .

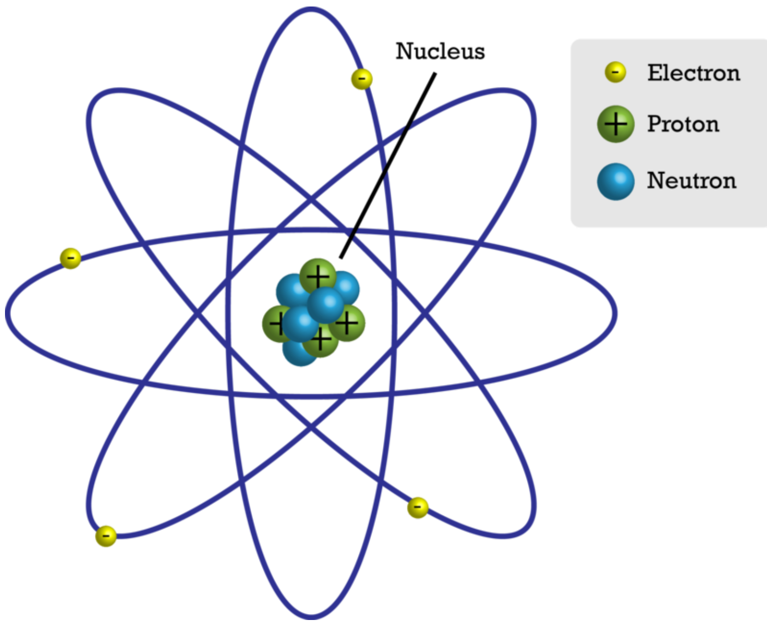


FIGURE 3.1
This simple atomic model shows the particles inside the atom.

The Nucleus

At the center of an atom is the **nucleus** (plural, nuclei). The nucleus contains most of the atom's mass. However, in size, it's just a tiny part of the atom. The model in **Figure** 3.1 is not to scale. If an atom were the size of a football stadium, the nucleus would be only about the size of a pea.

The nucleus, in turn, consists of two types of particles, called protons and neutrons. These particles are tightly packed inside the nucleus. Constantly moving about the nucleus are other particles called electrons. You can see a video about all three types of atomic particles at this URL: http://www.youtube.com/watch?v=lP57gEWcisY (1:57).

Protons

A **proton** is a particle in the nucleus of an atom that has a positive electric charge. All protons are identical. It is the number of protons that gives atoms of different elements their unique properties. Atoms of each type of element have a characteristic number of protons. For example, each atom of carbon has six protons, as you can see in **Figure** 3.2. No two elements have atoms with the same number of protons.

Neutrons

A **neutron** is a particle in the nucleus of an atom that has no electric charge. Atoms of an element often have the same number of neutrons as protons. For example, most carbon atoms have six neutrons as well as six protons. This is also shown in **Figure** 3.2.

Electrons

An **electron** is a particle outside the nucleus of an atom that has a negative electric charge. The charge of an electron is opposite but equal to the charge of a proton. Atoms have the same number of electrons as protons. As a result, the negative and positive charges "cancel out." This makes atoms electrically neutral. For example, a carbon atom has six electrons that "cancel out" its six protons.

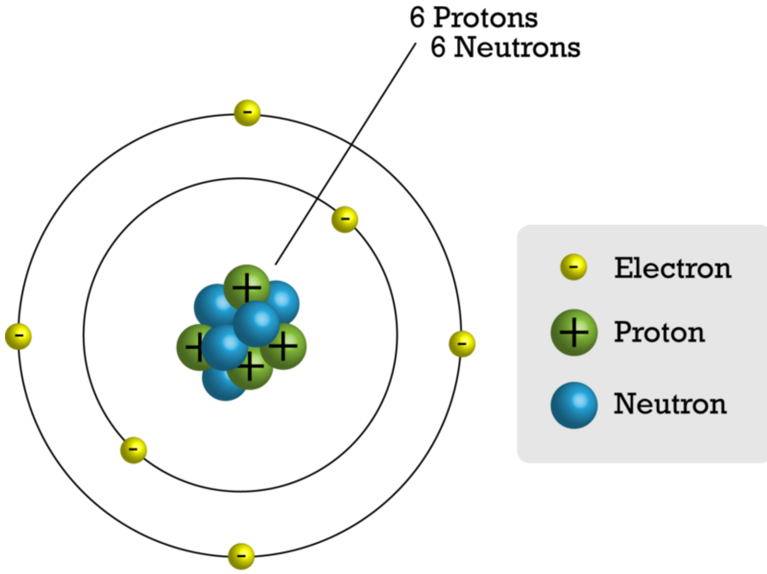


FIGURE 3.2
This model shows the particles that make up a carbon atom.

Atomic Forces

When it comes to atomic particles, opposites attract. Negative electrons are attracted to positive protons. This force of attraction keeps the electrons moving about the nucleus. An analogy is the way planets orbit the sun.

What about particles with the same charge, such as protons in the nucleus? They push apart, or repel, each other. So why doesn't the nucleus fly apart? The reason is a force of attraction between protons and neutrons called the strong force. The name of the strong force suits it. It is stronger than the electric force pushing protons apart. However, the strong force affects only nearby particles (see **Figure** 3.3). It is not effective if the nucleus gets too big. This puts an upper limit on the number of protons an atom can have and remain stable. You can learn more about atomic forces in the colorful tutorial at this URL: http://www.ric.edu/faculty/ptiskus/Atomic_Force/ .

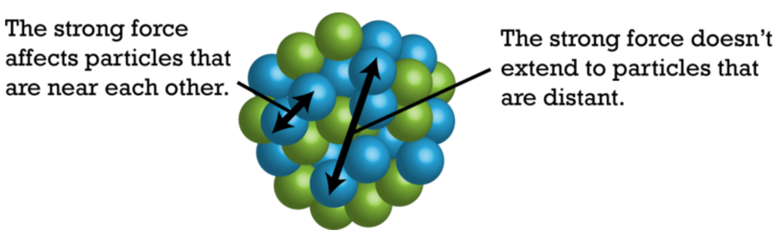


FIGURE 3.3
The strong force is effective only between particles that are very close together in the nucleus.

Atomic Number and Mass Number

Electrons have almost no mass. Instead, almost all the mass of an atom is in its protons and neutrons in the nucleus. The nucleus is very small, but it is densely packed with matter. The SI unit for the mass of an atom is the **atomic mass unit (amu)**. One atomic mass unit equals the mass of a proton, which is about 1.7×10^{-24} g. Each neutron also has a mass of 1 amu. Therefore, the sum of the protons and neutrons in an atom is about equal to the atom's total mass in atomic mass units.

Two numbers are commonly used to distinguish atoms: atomic number and mass number. **Figure** 3.4 shows how these numbers are usually written.

FIGURE 3.4
The symbol He stands for the element helium. Can you infer how many electrons a helium atom has?

- The **atomic number** is the number of protons in an atom. This number is unique for atoms of each kind of element. For example, the atomic number of all helium atoms is 2.
- The **mass number** is the number of protons plus the number of neutrons in an atom. For example, most atoms of helium have 2 neutrons, so their mass number is 2 + 2 = 4. This mass number means that an atom of helium has a mass of about 4 amu.

Problem Solving

Problem: An atom has an atomic number of 12 and a mass number of 24. How many protons and neutrons does the atom have?

Solution: The number of protons is the same as the atomic number, or 12. The number of neutrons is equal to the mass number minus the atomic number, or 24 –12 = 12.

You Try It!

Problem: An atom has an atomic number of 8 and a mass number of 16. How many neutrons does it have? What is the atom's mass in atomic mass units?

Ions and Isotopes

The number of protons per atom is always the same for a given element. However, the number of neutrons may vary, and the number of electrons can change.

Ions

Sometimes atoms lose or gain electrons. Then they become **ions**. Ions have a positive or negative charge. That's because they do not have the same number of electrons as protons. If atoms lose electrons, they become positive ions, or cations. If atoms gain electrons, they become negative ions, or anions.

Consider the example of fluorine in **Figure** 3.5. A fluorine atom has nine protons and nine electrons, so it is electrically neutral. If a fluorine atom gains an electron, it becomes a fluoride ion with a negative charge of minus one.

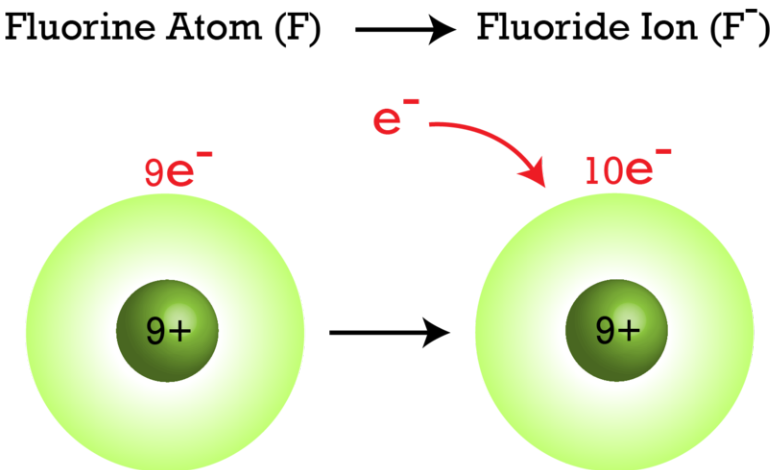
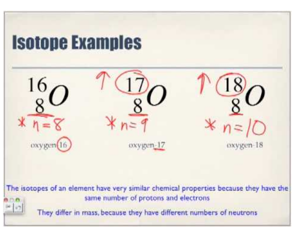


FIGURE 3.5
When a fluorine atom gains an electron, it becomes a negative fluoride ion.

Isotopes of Atoms

Some atoms of the same element may have different numbers of neutrons. For example, some carbon atoms have seven or eight neutrons instead of the usual six. Atoms of the same element that differ in number of neutrons are called **isotopes**. Many isotopes occur naturally. Usually one or two isotopes of an element are the most stable and common. Different isotopes of an element generally have the same chemical properties. That's because they have the same numbers of protons and electrons. For a video explanation of isotopes, go to this URL: http://www.youtube.com/watch?v=6w7raarHNA8 (5:23).



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An Example: Hydrogen Isotopes

Hydrogen is a good example of isotopes because it has the simplest atoms. Three isotopes of hydrogen are modeled in **Figure** 3.6. Most hydrogen atoms have just one proton and one electron and lack a neutron. They are just called hydrogen. Some hydrogen atoms have one neutron. These atoms are the isotope named deuterium. Other hydrogen atoms have two neutrons. These atoms are the isotope named tritium.

Naming Isotopes

For most other elements, isotopes are named for their mass number. For example, carbon atoms with the usual 6 neutrons have a mass number of 12 (6 protons + 6 neutrons = 12), so they are called carbon-12. Carbon atoms with 7 neutrons have an atomic mass of 13 (6 protons + 7 neutrons = 13). These atoms are the isotope called carbon-13. Some carbon atoms have 8 neutrons. What is the name of this isotope of carbon? You can learn more about this isotope at the URL below. It is used by scientists to estimate the ages of rocks and fossils.

http://www.khanacademy.org/video/carbon-14-dating-1?playlist=Chemistry

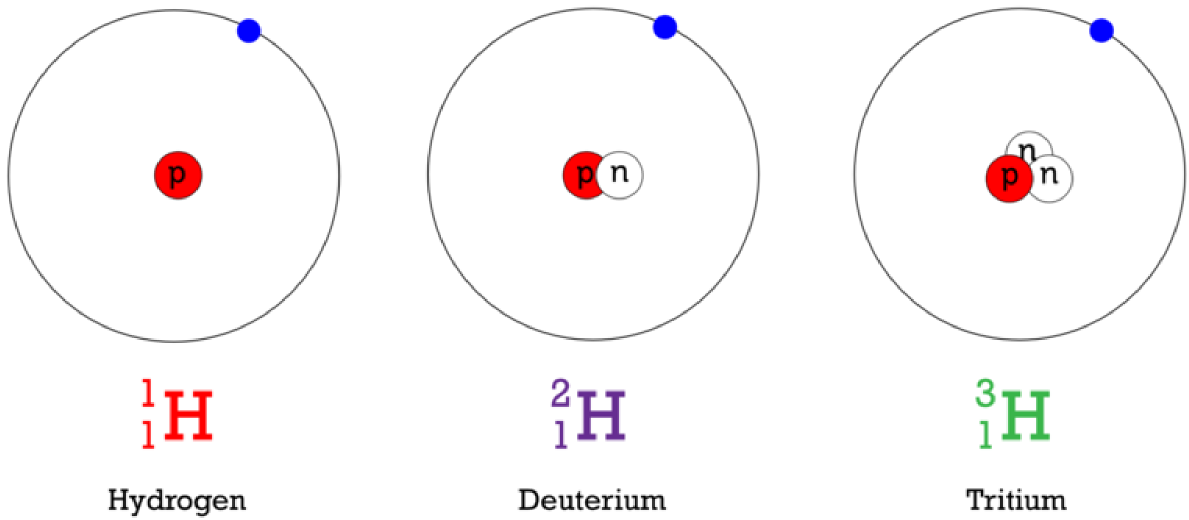

FIGURE 3.6

All isotopes of a given element have the same number of protons (P), but they differ in the number of neutrons (N). What is the mass number of each isotope shown here?

Back to Quarks

Remember the quarks from the first page of this chapter? **Quarks** are even tinier particles of matter that make up protons and neutrons. There are three quarks in each proton and three quarks in each neutron. The charges of quarks are balanced exactly right to give a positive charge to a proton and a neutral charge to a neutron. It might seem strange that quarks are never found alone but only as components of other particles. This is because the quarks are held together by very strange particles called gluons.

Gluons

Gluons make quarks attract each other more strongly the farther apart the quarks get. To understand how gluons work, imagine holding a rubber band between your fingers. If you try to move your hands apart, they will be pulled back together by the rubber band. The farther apart you move your hands, the stronger the force of the rubber band pulling your hands together. Gluons work the same way on quarks inside protons and neutrons (and other, really rare particles too).

If you were to move your hands apart with enough force, the rubber band holding them together would break. The same is true of quarks. If they are given enough energy, they pull apart with enough force to "break" the binding from the gluons. However, all the energy that is put into a particle to make this possible is then used to create a new set of quarks and gluons. And so a new proton or neutron appears.

Finding Quarks

The existence of quarks was first proposed in the 1960s. Since then, scientists have done experiments to show that quarks really do exist. In fact, they have identified six different types of quarks. However, much remains to be learned about these tiny, fundamental particles of matter. They are very difficult and expensive to study. If you want to learn more about them, including how they are studied, the URL below is a good place to start.

http://www.particleadventure.org/index.html

KQED: Homegrown Particle Accelerators

QUEST journeys back to find out how physicists on the UC Berkeley campus in the 1930s, and at the Stanford Linear Accelerator Center in the 1970s, created "atom smashers" that led to key discoveries about the tiny constituents of the atom and paved the way for the Large Hadron Collider in Switzerland. For more information on particle accelerators, see http://science.kqed.org/quest/video/homegrown-particle-accelerators/ .

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Lesson Summary

- The nucleus is at the center of the atom. It contains positive protons and neutral neutrons. Negative electrons constantly move about the nucleus.
- Atomic number is the number of protons in an atom. It is unique for the atoms of each element. Mass number is the number of protons plus neutrons in an atom. It is about equal to the mass of the atom in atomic mass units (amu).
- Negative electrons are attracted to positive protons, and this electric force keeps electrons moving about the nucleus. The force of attraction between protons and neutrons, called the strong force, holds the nucleus together.
- If atoms lose or gain electrons, they become positive or negative ions. Atoms of the same element that have different numbers of neutrons are called isotopes.
- Quarks are even tinier particles of matter that make up protons and neutrons. Scientists have identified six different types of quarks.

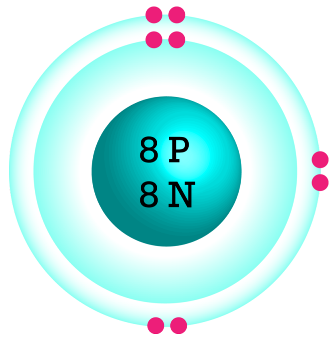
Lesson Review Questions

Recall

1. Describe the nucleus of an atom.
2. Outline the forces that hold particles together in an atom.
3. What does the atomic number of an atom represent?
4. Define isotope. Give an example.
5. What are quarks?

Apply Concepts

6. If an atom gains electrons, it becomes an ion. Is the ion positively or negatively charged? Explain your answer.
7. What is the atomic mass (in atomic mass units) of the atom represented by the model below?



Think Critically

8. Make a table comparing and contrasting protons, neutrons, and electrons. Include their location, mass, and electric charge.
9. Explain why atoms are neutral in electric charge.

Points to Consider

In this lesson, you saw several simple models of atoms. Models are useful for representing things that are very small. Scientists have used models to represent atoms for more than 200 years. In the next lesson, "History of the Atom," you'll read about some of the earlier models.

- How might scientists have modeled atoms before the particles inside atoms were discovered?
- How do you think earlier models might have differed from the models in this lesson?

3.2 History of the Atom

Lesson Objectives

- State Democritus's ideas about the atom.
- Outline Dalton's atomic theory.
- Explain how Thomson discovered electrons.
- Describe how Rutherford found the nucleus.

Introduction

Atoms are very tiny. They could not be seen before scanning tunneling microscopes were invented in 1981. However, the idea of atoms goes back to ancient Greece. That's where this brief history of the atom begins. You can watch a video about the history of the atom at this URL: http://www.youtube.com/watch?v=sxQIzPejhO8 .

Democritus Introduces the Atom

The history of the atom begins around 450 B.C. with a Greek philosopher named Democritus (see **Figure** 3.7). Democritus wondered what would happen if you cut a piece of matter, such as an apple, into smaller and smaller pieces. He thought that a point would be reached where matter could not be cut into still smaller pieces. He called these "uncuttable" pieces *atomos*. This is where the modern term atom comes from.

FIGURE 3.7
Democritus first introduced the idea of the atom almost 2500 years ago.

Democritus was an important philosopher. However, he was less influential than the Greek philosopher Aristotle, who lived about 100 years after Democritus. Aristotle rejected Democritus's idea of atoms. In fact, Aristotle thought the idea of atoms was ridiculous. Unfortunately, Aristotle's ideas were accepted for more than 2000 years. During that time, Democritus's ideas were more or less forgotten.

Dalton Brings Back the Atom

Around 1800, a British chemist named John Dalton revived Democritus's early ideas about the atom. Dalton is pictured in **Figure** 3.8. He made a living by teaching and just did research in his spare time. Nonetheless, from his research results, he developed one of the most important theories in science.

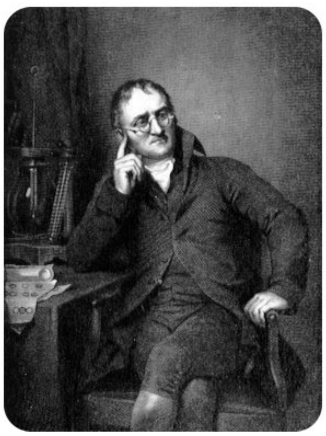


FIGURE 3.8

John Dalton used evidence from experiments to show that atoms exist.

Dalton's Research

Dalton did many experiments that provided evidence for atoms. For example, he studied the pressure of gases. He concluded that gases must consist of tiny particles in constant motion. Dalton also researched the properties of compounds. He showed that a compound always consists of the same elements in the same ratio. On the other hand, different compounds always consist of different elements or ratios. This can happen, Dalton reasoned, only if elements are made of tiny particles that can combine in an endless variety of ways. From his research, Dalton developed a theory of the atom. You can learn more about Dalton and his research by watching the video at this URL: http://www.youtube.com/watch?v=BhWgv0STLZs&feature=related (9:03).

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Dalton's Atomic Theory

The atomic theory Dalton developed consists of three ideas:

- All substances are made of atoms. Atoms are the smallest particles of matter. They cannot be divided into smaller particles. They also cannot be created or destroyed.

- All atoms of the same element are alike and have the same mass. Atoms of different elements are different and have different masses.
- Atoms join together to form compounds. A given compound always consists of the same kinds of atoms in the same ratio.

Dalton's theory was soon widely accepted. Most of it is still accepted today. The only part that is no longer accepted is his idea that atoms are the smallest particles. Scientists now know that atoms consist of even smaller particles.

Dalton's Atomic Models

Dalton incorrectly thought that atoms are tiny solid particles of matter. He used solid wooden balls to model them. The sketch in the **Figure** 3.9 shows how Dalton's model atoms looked. He made holes in the balls so they could be joined together with hooks. In this way, the balls could be used to model compounds. When later scientists discovered subatomic particles (particles smaller than the atom itself), they realized that Dalton's models were too simple. They didn't show that atoms consist of even smaller particles. Models including these smaller particles were later developed.

FIGURE 3.9
Dalton's model atoms were hard, solid balls. How do they differ from the atomic models you saw in the lesson "Inside the Atom" from earlier in the chapter?

Thomson Adds Electrons

The next major advance in the history of the atom was the discovery of electrons. These were the first subatomic particles to be identified. They were discovered in 1897 by a British physicist named J. J. Thomson. You can learn more about Thomson and his discovery at this online exhibit: http://www.aip.org/history/electron/ .

Thomson's Vacuum Tube Experiments

Thomson was interested in electricity. He did experiments in which he passed an electric current through a vacuum tube. The experiments are described in **Figure** 3.10.

Thomson's experiments showed that an electric current consists of flowing, negatively charged particles. Why was this discovery important? Many scientists of Thomson's time thought that electric current consists of rays, like rays of light, and that it is positive rather than negative. Thomson's experiments also showed that the negative particles are all alike and smaller than atoms. Thomson concluded that the negative particles couldn't be fundamental units of matter because they are all alike. Instead, they must be parts of atoms. The negative particles were later named electrons.

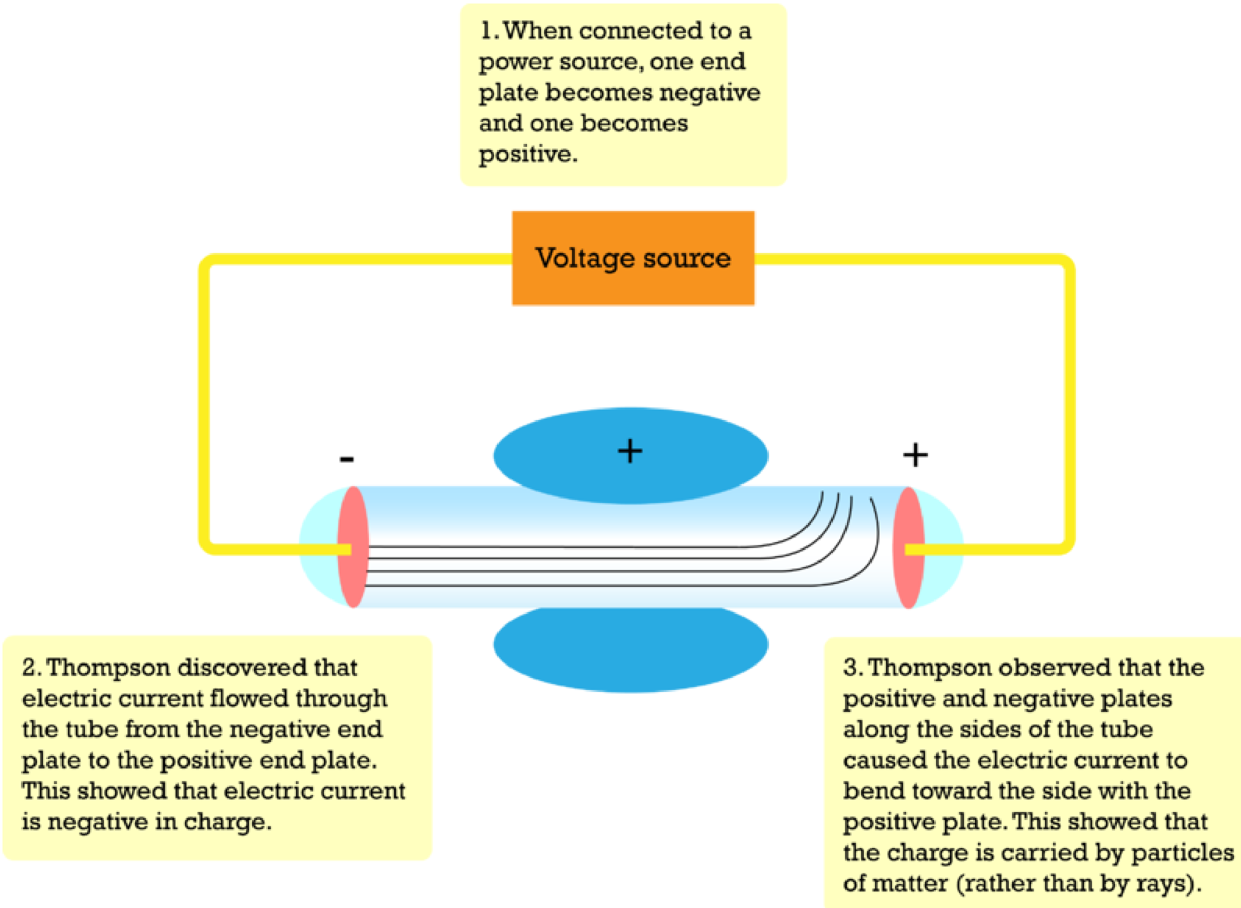

FIGURE 3.10
This sketch shows the basic set up of Thomson's experiments. The vacuum tube is a glass tube that contains very little air. It has metal plates at each end and along the sides.

Thomson's Plum Pudding Model

Thomson knew that atoms are neutral in electric charge. So how could atoms contain negative particles? Thomson thought that the rest of the atom must be positive to cancel out the negative charge. He said that an atom is like a plum pudding, which has plums scattered through it. That's why Thomson's model of the atom is called the plum pudding model. You can see it in **Figure** 3.11. It shows the atom as a sphere of positive charge (the pudding) with negative electrons (the plums) scattered through it.

Rutherford Finds the Nucleus

A physicist from New Zealand named Ernest Rutherford made the next major discovery about atoms. He discovered the nucleus. You can watch a video about Rutherford and his discovery at this URL: http://www.youtube.com/watch?v=wzALbzTdnc8 (3:28).

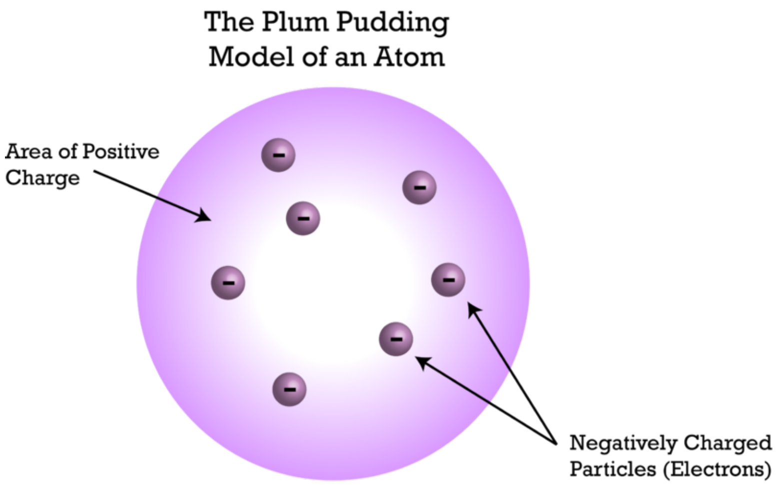

FIGURE 3.11
Thomson's atomic model includes negative electrons in a "sea" of positive charge.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5076

Rutherford's Gold Foil Experiments

In 1899, Rutherford discovered that some elements give off positively charged particles. He named them alpha particles (α). In 1911, he used alpha particles to study atoms. He aimed a beam of alpha particles at a very thin sheet of gold foil. Outside the foil, he placed a screen of material that glowed when alpha particles struck it.

If Thomson's plum pudding model were correct, the alpha particles should be deflected a little as they passed through the foil. Why? The positive "pudding" part of gold atoms would slightly repel the positive alpha particles. This would cause the alpha particles to change course. But Rutherford got a surprise. Most of the alpha particles passed straight through the foil as though they were moving through empty space. Even more surprising, a few of the alpha particles bounced back from the foil as though they had struck a wall. This is called back scattering. It happened only in very small areas at the centers of the gold atoms.

The Nucleus and Its Particles

Based on his results, Rutherford concluded that all the positive charge of an atom is concentrated in a small central area. He called this area the nucleus. Rutherford later discovered that the nucleus contains positively charged particles. He named the positive particles protons. Rutherford also predicted the existence of neutrons in the nucleus. However, he failed to find them. One of his students, a physicist named James Chadwick, went on to discover neutrons in 1932. You learn how at this URL: http://www.light-science.com/chadwick.html .

Rutherford's Atomic Model

Rutherford's discoveries meant that Thomson's plum pudding model was incorrect. Positive charge is not spread out everywhere in an atom. It is all concentrated in the tiny nucleus. The rest of the atom is empty space, except for the electrons moving randomly through it. In Rutherford's model, electrons move around the nucleus in random orbits.

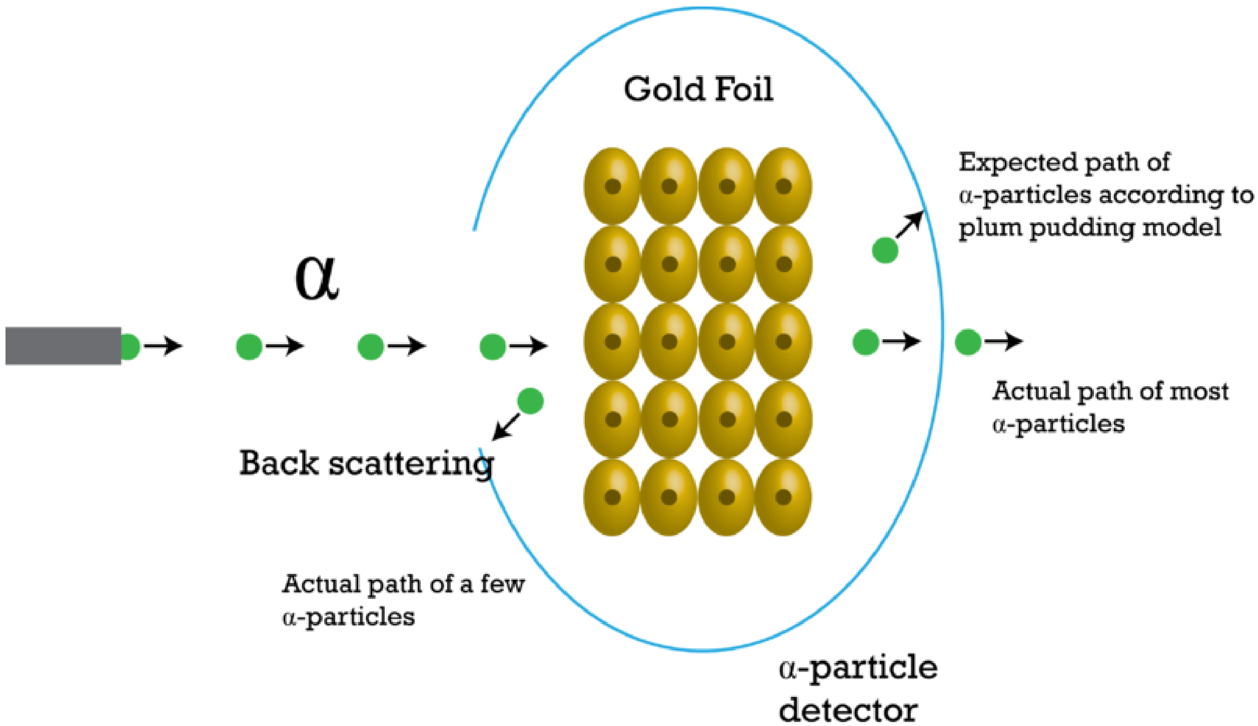

FIGURE 3.12
Rutherford shot a beam of positive alpha particles at thin gold foil.

He compared them to planets orbiting a star. That's why Rutherford's model is called the planetary model. You can see it in **Figure** 3.13.

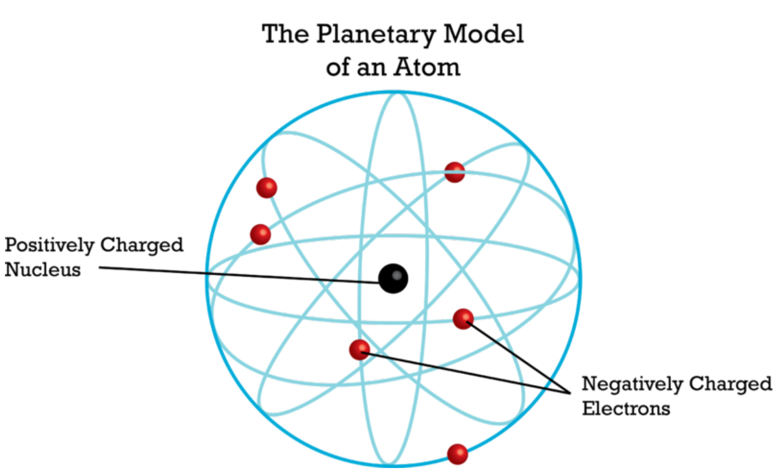

FIGURE 3.13
This model shows Rutherford's idea of the atom. How does it compare with Thomson's plum pudding model?

Lesson Summary

- Around 450 B.C., the Greek philosopher Democritus introduced the idea of the atom. However, the idea was essentially forgotten for more than 2000 years.
- In 1800, John Dalton re-introduced the atom. He provided evidence for atoms and developed atomic theory. His theory is essentially correct. However, he incorrectly thought that atoms are the smallest particles of matter.
- In 1897, J.J. Thomson discovered electrons. He proposed the plum pudding model of the atom. In this model, negative electrons are scattered throughout a "sea" of positive charge.
- In 1911, Ernest Rutherford discovered the nucleus. He later discovered protons as well. Rutherford thought that electrons randomly orbit the nucleus.

Lesson Review Questions

Recall

1. State Democritus's ideas about the atom.
2. What evidence did Dalton use to argue for the existence of atoms?
3. State Dalton's atomic theory.
4. Describe how Thomson discovered electrons.

Apply Concepts

5. Create sketches to compare and contrast Thomson's and Rutherford's models of the atom.

Think Critically

6. Based on Rutherford's work, use evidence and reasoning to argue for the existence of the nucleus.

Points to Consider

In this lesson, you read how models of the atom changed as scientists discovered the particles that make up atoms. In the next lesson, "Modern Atomic Theory," you will read how Rutherford's model was revised as scientists learned even more about electrons. For example, they discovered that electrons do not travel around the nucleus in random orbits as Rutherford thought.

- Can you predict how electrons might move around the nucleus?
- How might Rutherford's model be changed to show this?

3.3 Modern Atomic Theory

Lesson Objectives

- Define energy levels.
- Describe the electron cloud and orbitals.

Vocabulary

- electron cloud
- energy level
- orbital

Introduction

Rutherford's model of the atom was better than earlier models. But it wasn't the last word. Danish physicist Niels Bohr created a more accurate and useful model. Bohr's model was an important step in the development of modern atomic theory. The video at the URL below is a good introduction to modern atomic theory. It also reviews important concepts from the previous two lessons, "Inside the Atom" and "History of the Atom."

http://www.khanacademy.org/video/introduction-to-the-atom?playlist=Chemistry

Bohr's Model of the Atom

Bohr's research focused on electrons. In 1913, he discovered evidence that the orbits of electrons are located at fixed distances from the nucleus. Remember, Rutherford thought that electrons orbit the nucleus at random. **Figure** 3.14 shows Bohr's model of the atom.

Energy Levels

Basic to Bohr's model is the idea of energy levels. **Energy levels** are areas located at fixed distances from the nucleus of the atom. They are the only places where electrons can be found. Energy levels are a little like rungs on a ladder. You can stand on one rung or another but not between the rungs. The same goes for electrons. They can occupy one energy level or another but not the space between energy levels.

The model of an atom in **Figure** 3.15 has six energy levels. The level with the least energy is the one closest to the nucleus. As you go farther from the nucleus, the levels have more and more energy. Electrons can jump from one energy level to another. If an atom absorbs energy, some of its electrons can jump to a higher energy level.

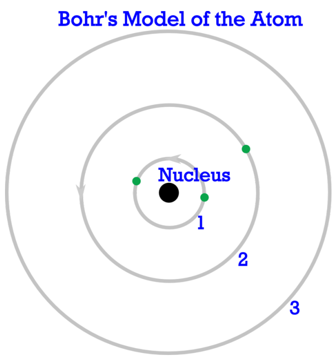

FIGURE 3.14
In Bohr's atomic model, electrons orbit at fixed distances from the nucleus. These distances are called energy levels.

If electrons jump to a lower energy level, the atom emits, or gives off, energy. You can see an animation at this happening at the URL below.

http://cas.sdss.org/dr6/en/proj/advanced/spectraltypes/energylevels.asp

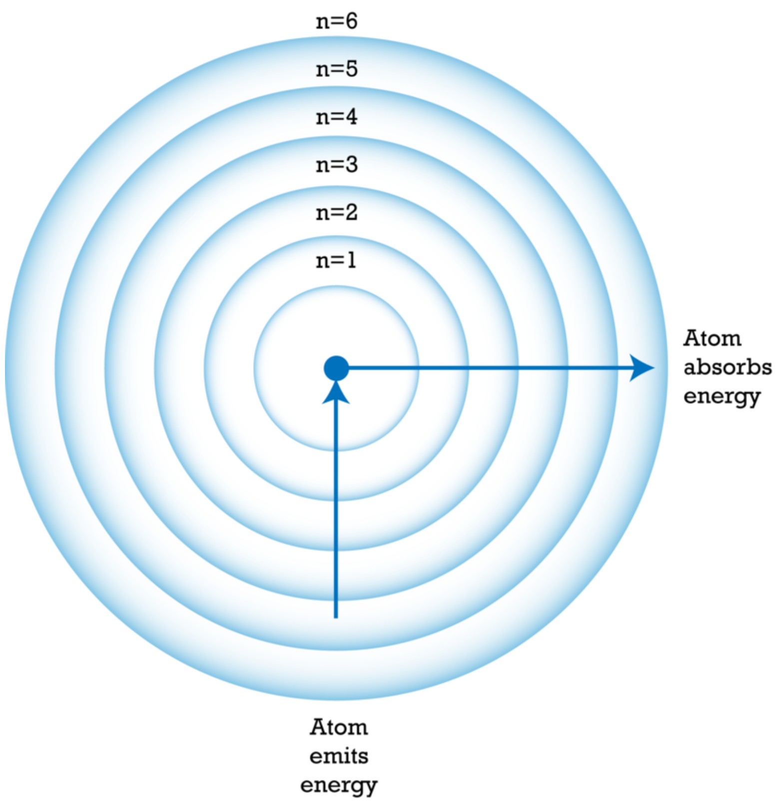

FIGURE 3.15
This model of an atom contains six energy levels (n = 1 to 6). Atoms absorb or emit energy when some of their electrons jump to a different energy level.

Energy Levels in Action

Bohr's idea of energy levels is still useful today. It helps explain how matter behaves. For example, when chemicals in fireworks explode, their atoms absorb energy. Some of their electrons jump to a higher energy level. When the electrons move back to their original energy level, they give off the energy as light. Different chemicals have different arrangements of electrons, so they give off light of different colors. This explains the blue- and purple-colored fireworks in **Figure** 3.16.

FIGURE 3.16
Atoms in fireworks give off light when their electrons jump back to a lower energy level.

Electron Cloud and Orbitals

In the 1920s, physicists discovered that electrons do not travel in fixed paths. In fact, they found that electrons only have a certain chance of being in any particular place. They could only describe where electrons are with mathematical formulas. That's because electrons have wave-like properties as well as properties of particles of matter. It is the "wave nature" of electrons that lets them exist only at certain distances from the nucleus. The negative electrons are attracted to the positive nucleus. However, because the electrons behave like waves, they bend around the nucleus instead of falling toward it. Electrons exist only where the wave is stable. These are the orbitals. They do not exist where the wave is not stable. These are the places between orbitals.

Electron Cloud Model

Today, these ideas about electrons are represented by the electron cloud model. The **electron cloud** is an area around the nucleus where electrons are likely to be. **Figure** 3.17 shows an electron cloud model for a helium atom.

Orbitals

Some regions of the electron cloud are denser than others. The denser regions are areas where electrons are most likely to be. These regions are called **orbitals**. Each orbital has a maximum of just two electrons. Different energy levels in the cloud have different numbers of orbitals. Therefore, different energy levels have different maximum numbers of electrons. **Table** 3.1 lists the number of orbitals and electrons for the first four energy levels. Energy

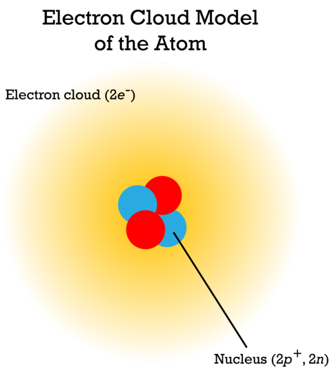

FIGURE 3.17
This sketch represents the electron cloud model for helium. What does the electron cloud represent?

levels farther from the nucleus have more orbitals. Therefore, these levels can hold more electrons.

TABLE 3.1: First Four Energy Levels and Their Orbitals

Energy Level	Number of Orbitals	Max. No. of Electrons (@ 2 per orbital)
1	1	2
2	4	8
3	9	18
4	16	32

Figure 3.18 shows the arrangement of electrons in an atom of magnesium as an example. The most stable arrangement of electrons occurs when electrons fill the orbitals at the lowest energy levels first before more are added at higher levels. You can learn more about orbitals and their electrons at the URL below: http://www.khanacademy.org/video/orbitals?playlist=Chemistry .

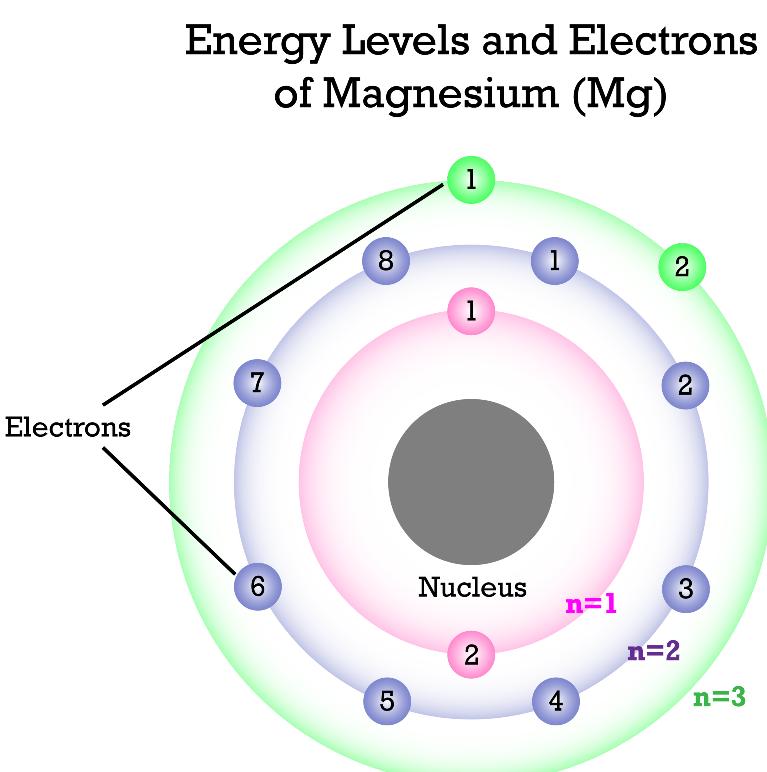

FIGURE 3.18
This model represents an atom of the element magnesium (Mg). How many electrons does the atom have at each energy level? What is the maximum number it could have at each level?

Lesson Review Questions

Recall

1. What are energy levels?
2. Which energy level has the smallest amount of energy?
3. Define orbitals.
4. How many electrons can be found in an orbital?

Apply Concepts

5. A change in energy caused an electron in an atom to jump from energy level 2 to energy level 3. Did the atom gain or lose energy? Explain.
6. Create a sketch to model the concept of the electron cloud.

Think Critically

7. Explain how orbitals are related to energy levels.

Points to Consider

In this chapter, you learned that atoms of each element have a unique number of protons. This is one way that each element differs from all other elements.

- How could the number of protons be used to organize elements?
- If one element has more protons than another element, how do their numbers of electrons compare?

3.4 References

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CHAPTER 4 Periodic Table

Chapter Outline

Imagine going to the library and finding all the books in big messy piles like the one above. It could take a very long time to find the book you wanted. You might give up without even trying. Of course, in most libraries, books are arranged in an orderly way, like the books shown below. For example, novels, like those pictured here, are arranged in alphabetical order by author's last name. Not only can you quickly find the book you want, you can also scan the books nearby to find others by the same author. It's clear that grouping books in an organized way is very useful.

The same is true of chemical elements. For many years, scientists looked for a good way to organize them. This became increasingly important as more and more elements were discovered. In this chapter, you'll read how elements were first organized and how they are organized today. You'll see why an orderly arrangement of elements, like the books in a library, is also very useful.

4.1 How Elements Are Organized

Lesson Objectives

- Describe Mendeleev's periodic table of the elements.
- Give an overview of the modern periodic table of the elements.

Vocabulary

- group
- period
- periodic table

Introduction

Scientists first started looking for a way to organize the elements in the 1700s. They were trying to find a method to group together elements with similar properties. No one could come up with a good solution. It wasn't until the 1860s that a successful method was devised. It was developed by a Russian chemist named Dmitri Mendeleev. He is pictured in **Figure** 4.1. You can learn more about him and his work at this URL: http://videos.howstuffworks.com/science-channel/27862-100-greatest-discoveries-the-periodic-table-video.htm .

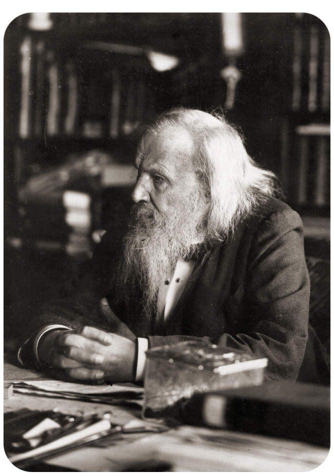


FIGURE 4.1
Dmitri Mendeleev developed the first periodic table of the elements in 1869.

Mendeleev's Periodic Table of the Elements

Mendeleev was a teacher as well as a chemist. He was writing a chemistry textbook and needed a way to organize the elements so it would be easier for students to learn about them. He made a set of cards of the elements, similar to a deck of playing cards, with one element per card. On the card, he wrote the element's name, atomic mass, and known properties. He arranged and rearranged the cards in many different ways, looking for a pattern. He finally found it when he placed the elements in order by atomic mass.

A Repeating Pattern

You can see how Mendeleev organized the elements in **Figure** 4.2. From left to right across each row, elements are arranged by increasing atomic mass. Mendeleev discovered that if he placed eight elements in each row and then continued on to the next row, the columns of the table would contain elements with similar properties. He called the columns **groups**. They are sometimes called families, because elements within a group are similar but not identical to one another, like people in a family.

Reihen	Gruppo I. — R^2O	Gruppo II. — RO	Gruppo III. — R^2O^3	Gruppo IV. RH^4 RO^2	Gruppo V. RH^3 R^2O^5	Gruppo VI. RH^2 RO^3	Gruppo VII. RH R^2O^7	Gruppo VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

FIGURE 4.2

Mendeleev's table of the elements organizes the elements by atomic mass. The table has a repeating pattern.

Mendeleev's table of the elements is called a **periodic table** because of its repeating pattern. Anything that keeps repeating is referred to as periodic. Other examples of things that are periodic include the monthly phases of the moon and the daily cycle of night and day. The term **period** refers to the interval between repetitions. In a periodic table, the periods are the rows of the table. In Mendeleev's table, each period contains eight elements, and then the pattern repeats in the next row.

Predicting Missing Elements

Did you notice the blanks in Mendeleev's table (**Figure** 4.2)? They are spaces that Mendeleev left for elements that had not yet been discovered when he created his table. He predicted that these missing elements would eventually be discovered. Based on their position in the table, he could even predict their properties. For example, he predicted a missing element in row 5 of his group 3. He said it would have an atomic mass of about 68 and be a soft metal like other group 3 elements. Scientists searched for the missing element. They found it a few years later and named it gallium. Scientists searched for the other missing elements. Eventually, all of them were found.

An important measure of a good model is its ability to make accurate predictions. This makes it a useful model. Clearly, Mendeleev's periodic table was a useful model. It helped scientists discover new elements and make sense of those that were already known.

The Modern Periodic Table of the Elements

A periodic table is still used today to classify the elements. **Figure** 4.3 shows the modern periodic table. You can see an interactive version at this URL: http://www.ptable.com/ .

Basis of the Modern Periodic Table

In the modern periodic table, elements are organized by atomic number. The atomic number is the number of protons in an atom of an element. This number is unique for each element, so it seems like an obvious way to organize the elements. (Mendeleev used atomic mass instead of atomic number because protons had not yet been discovered when he made his table.) In the modern table, atomic number increases from left to right across each period. It also increases from top to bottom within each group. How is this like Mendeleev's table?

Reading the Table

Besides atomic number, the periodic table includes each element's chemical symbol and class. Some tables include other information as well.

- The chemical symbol consists of one or two letters that come from the chemical's name in English or another language. The first letter is always written in upper case. The second letter, if there is one, is always written in lower case. For example, the symbol for lead is Pb. It comes from the Latin word *plumbum*, which means "lead." Find lead in **Figure** 4.3. What is its atomic number? You can access videos about lead and other elements in the modern periodic table at this URL: http://www.periodicvideos.com/index.htm .
- The classes of elements are metals, metalloids, and nonmetals. They are color-coded in the table. Blue stands for metals, orange for metalloids, and green for nonmetals. You can read about each of these three classes of elements later in the chapter, in the lesson "Classes of Elements."

Periods

Rows of the modern table are called periods, as they are in Mendeleev's table. From left to right across a period, each element has one more proton than the element before it. In each period, elements change from metals on the left side of the table, to metalloids, and then to nonmetals on the right. **Figure** 4.4 shows this for period 4.

Some periods in the modern periodic table are longer than others. For example, period 1 contains only two elements. Periods 6 and 7, in contrast, are so long that some of their elements are placed below the main part of the table. They

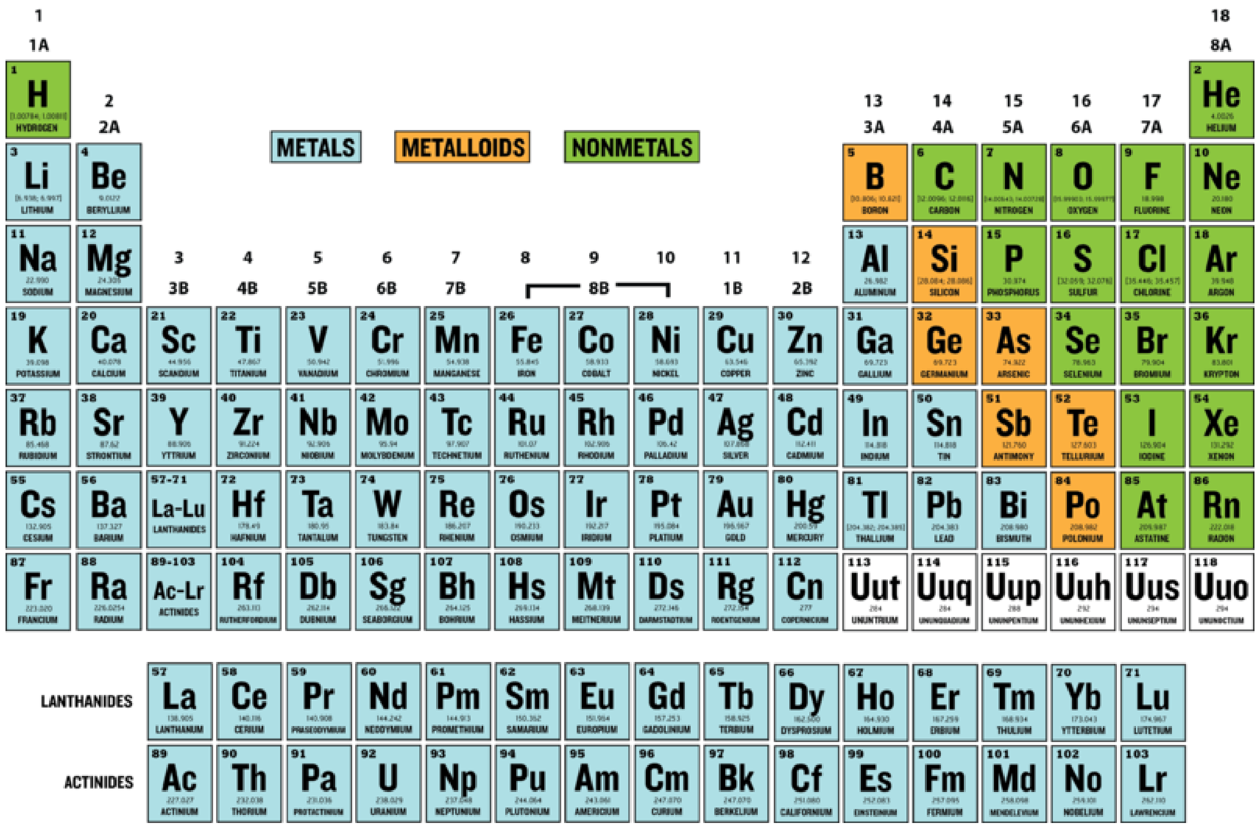


FIGURE 4.3

The modern periodic table of the elements is a lot like Mendeleev's table. But the modern table is based on atomic number instead of atomic mass. It also has more than 110 elements. Mendeleev's table only had about 65 elements.

are the elements starting with lanthanum (La) in period 6 and actinium (Ac) in period 7. Some elements in period 7 have not yet been named. They are represented by temporary symbols, such as Uub.

Groups

Columns of the modern table are called groups, as they are in Mendeleev's table. However, the modern table has many more groups —18 to be exact. Elements in the same group have similar properties. For example, all elements in group 18 are colorless, odorless gases. You can read about the different groups of elements in this chapter's lesson on "Groups of Elements."

Lesson Summary

- Mendeleev developed the first periodic table of the elements in 1869. He organized the elements by increasing atomic mass. He used his table to predict unknown elements. These were later discovered.
- The modern periodic table is based on atomic number. Elements in each period go from metals on the left to

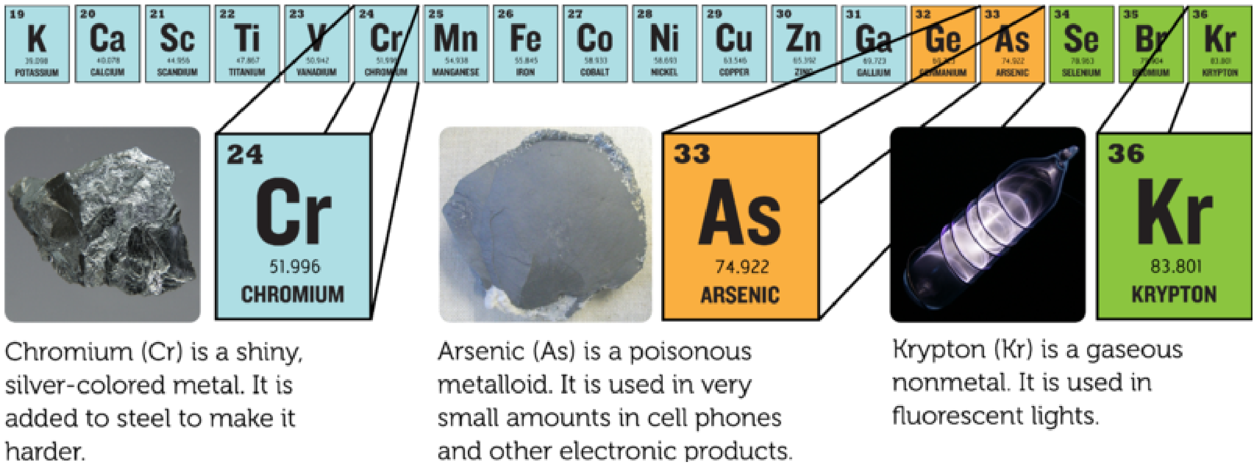


FIGURE 4.4
Like other periods, period 4 changes from metals on the left to metalloids and then nonmetals on the right.

metalloids and then nonmetals on the right. Within groups, elements have similar properties.

Lesson Review Questions

Recall

1. How did Mendeleev organize the elements?
2. How does the modern periodic table differ from Mendeleev's table?
3. What is a period in the periodic table?
4. What is a group in the periodic table?

Apply Concepts

5. An unknown element has an atomic number of 44. Identify the element's symbol and the symbols of two other elements that have similar properties.

Think Critically

6. Mendeleev's table and the modern periodic table organize the elements based on different information, yet most elements are in the same order in both tables. Explain why.

Points to Consider

Elements are classified as metals, metalloids, or nonmetals.

- Do you know some examples of metals?
- How do you think metals might differ from the other two classes of elements?

4.2 Classes of Elements

Lesson Objectives

- Identify properties of metals.
- List properties of nonmetals.
- Describe metalloids.
- Relate valence electrons to reactivity of elements by class.

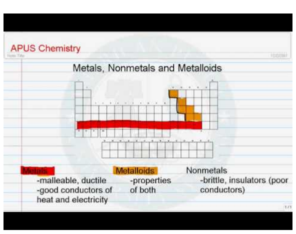
Vocabulary

- metal
- metalloid
- nonmetal
- valence electron

Introduction

Elements in different groups are lumped together in one of three classes, depending on their properties. The classes are metals, nonmetals, and metalloids. Knowing the class of an element lets you predict many of its properties. The video at the URL below is a good introduction to the classes.

http://www.youtube.com/watch?v=ZuQmionhkGU (2:04)



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5077

Metals

Metals are elements that are good conductors of electricity. They are the largest of the three classes of elements. In fact, most elements are metals. Look back at the modern periodic table (**Figure** 4.3) in this chapter's lesson "How Elements Are Organized." Find the metals in the table. They are all the elements that are color-coded blue. Examples include sodium (Na), silver (Ag), and zinc (Zn).

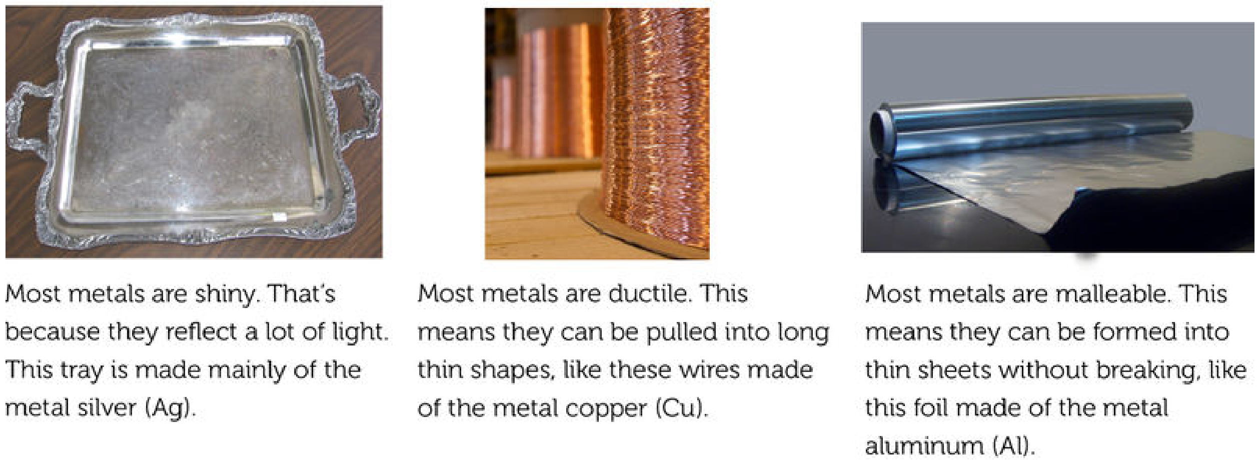


FIGURE 4.5
The three properties described here characterize most metals.

Metals have relatively high melting points, so almost all are solids at room temperature. The only exception is mercury (Hg), which is a liquid. Most metals are also good conductors of heat. That's why they are used for cooking pots and stovetops. Metals have other characteristic properties as well. Most are shiny, ductile, and malleable. These properties are illustrated in **Figure** 4.5. You can dig deeper into the properties of metals at this URL: http://www.bbc.co.uk/schools/gcsebitesize/science/add_gateway/periodictable/metalsrev1.shtml .

Nonmetals

Nonmetals are elements that do not conduct electricity. They are the second largest class of elements. Find the nonmetals in **Figure** 4.3. They are all the elements on the right side of the table that are color-coded green. Examples of nonmetals include helium (He), carbon (C), and oxygen (O).

Nonmetals generally have properties that are the opposite of those of metals. They also tend to vary more in their properties than metals do. For example, nonmetals have relatively low boiling points, so many of them are gases at room temperature. But several nonmetals are solids, including carbon and phosphorus (P). One nonmetal, bromine (Br), is a liquid at room temperature.

Generally, nonmetals are also poor conductors of heat. In fact, they may be used for insulation. For example, the down filling in a down jacket is mostly air, which consists mainly of nitrogen (N) and oxygen (O). These nonmetal gases are poor conductors of heat, so they keep body heat in and cold air out. Solid nonmetals are dull rather than shiny. They are also brittle rather than ductile or malleable. You can see examples of solid nonmetals in **Figure** 4.6. You can learn more about specific nonmetals with the interactive table at this URL: http://library.thinkquest.org/3659/pertable/nonmetal.html .

These yellow piles of powder are sulfur (S), a nonmetal. Sulfur in rocks has been ground up to produce a powder. The powder has been heaped on a dock for shipment.

The "lead" in this pencil is actually graphite, a form of the nonmetal carbon (C). Graphite is brittle. It breaks easily if you put too much pressure on it.

These match heads are coated with the nonmetal phosphorus (P). Phosphorus is not malleable. If you tried to pound it flat, it would crumble into a powder.

FIGURE 4.6

Unlike metals, solid nonmetals are dull and brittle.

Metalloids

Metalloids are elements that fall between metals and nonmetals in the periodic table. Just seven elements are metalloids, so they are the smallest class of elements. In **Figure** 4.3, they are color-coded orange. Examples of metalloids include boron (B), silicon (Si), and germanium (Ge).

Metalloids have some properties of metals and some properties of nonmetals. For example, many metalloids can conduct electricity but only at certain temperatures. These metalloids are called semiconductors. Silicon is an example. It is used in computer chips. It is also the most common metalloid on Earth. It is shiny like a metal but brittle like a nonmetal. You see a sample of silicon in **Figure** 4.7. The figure also shows other examples of metalloids. You can learn more about the properties of metalloids at this URL: http://library.thinkquest.org/3659/pertable/metaloid.html .

Classes of Elements and Electrons

From left to right across the periodic table, each element has one more proton than the element to its left. Because atoms are always electrically neutral, for each added proton, one electron is also added. Electrons are added first to the lowest energy level possible until that level is full. Only then are electrons added to the next higher energy level.

Electrons by Class

The increase in electrons across the periodic table explains why elements go from metals to metalloids and then to nonmetals from left to right across the table. Look at period 2 in **Figure** 4.8 as an example. Lithium (Li) is a metal, boron (B) a metalloid, and fluorine (F) and neon (Ne) are nonmetals. The inner energy level is full for all four elements. This level has just one orbital and can hold a maximum of two electrons. The outer energy level is a different story. This level has four orbitals and can hold a maximum of eight electrons. Lithium has just one electron in this level, boron has three, fluorine has seven, and neon has eight.

Silicon (Si) is a metal that can conduct electricity but not as well as a metal. It is shiny but brittle. It chips easily, like glass.

Antimony (Sb) is a metalloid that is shiny like a metal but brittle like a nonmetal.

Boron (B) is a metalloid that is somewhat shiny. It also conducts electricity like a metal. However, it is brittle like a nonmetal.

FIGURE 4.7

Metalloids share properties with both metals and nonmetals.

Valence Electrons and Reactivity

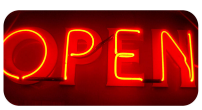
The electrons in the outer energy level of an atom are called **valence electrons**. It is valence electrons that are potentially involved in chemical reactions. The number of valence electrons determines an element's reactivity, or how likely the element is to react with other elements. The number of valence electrons also determines whether the element can conduct electric current. That's because electric current is the flow of electrons. **Table** 4.1 shows how these properties vary in elements from each class.

- Metals such as lithium have an outer energy level that is almost empty. They "want" to give up their few valence electrons so they will have a full outer energy level. As a result, metals are very reactive and good conductors of electricity.
- Metalloids such as boron have an outer energy level that is about half full. These elements need to gain or lose too many electrons for a full outer energy level to come about easily. As a result, these elements are not very reactive. They may be able to conduct electricity but not very well.
- Some nonmetals, such as bromine, have an outer energy level that is almost full. They "want" to gain electrons so they will have a full outer energy level. As a result, these nonmetals are very reactive. Because they only accept electrons and do not give them up, they do not conduct electricity.
- Other nonmetals, such as neon, have a completely full outer energy level. Their electrons are already in the most stable arrangement possible. They are unreactive and do not conduct electricity.

TABLE 4.1: These examples show the relative reactivity of elements in the three classes.

Element	Description

TABLE 4.1: (continued)

Element	Description
Lithium 	Lithium (Li) is a highly reactive metal. It has just one electron in its outer energy level. Lithium reacts explosively with water (see picture). It can react with moisture on skin and cause serious burns.
Boron 	Boron (B) is a metalloid. It has three valence electrons and is less reactive than lithium. Boron compounds dissolved in water form boric acid. Dilute boric acid is weak enough to use as eye wash.
Bromine	Bromine (Br) is an extremely reactive nonmetal. In fact, reactions with fluorine are often explosive, as you can see in the URL below. http://www.youtube.com/watch?v=vtWp45Eewtw
Neon 	Neon (Ne) is a nonmetal gas with a completely filled outer energy level. This makes it unreactive, so it doesn't combine with other elements. Neon is used for lighted signs like this one. You can learn why neon gives off light at this link: http://www.scientificamerican.com/article.cfm?id=how-do-neon-lights-work

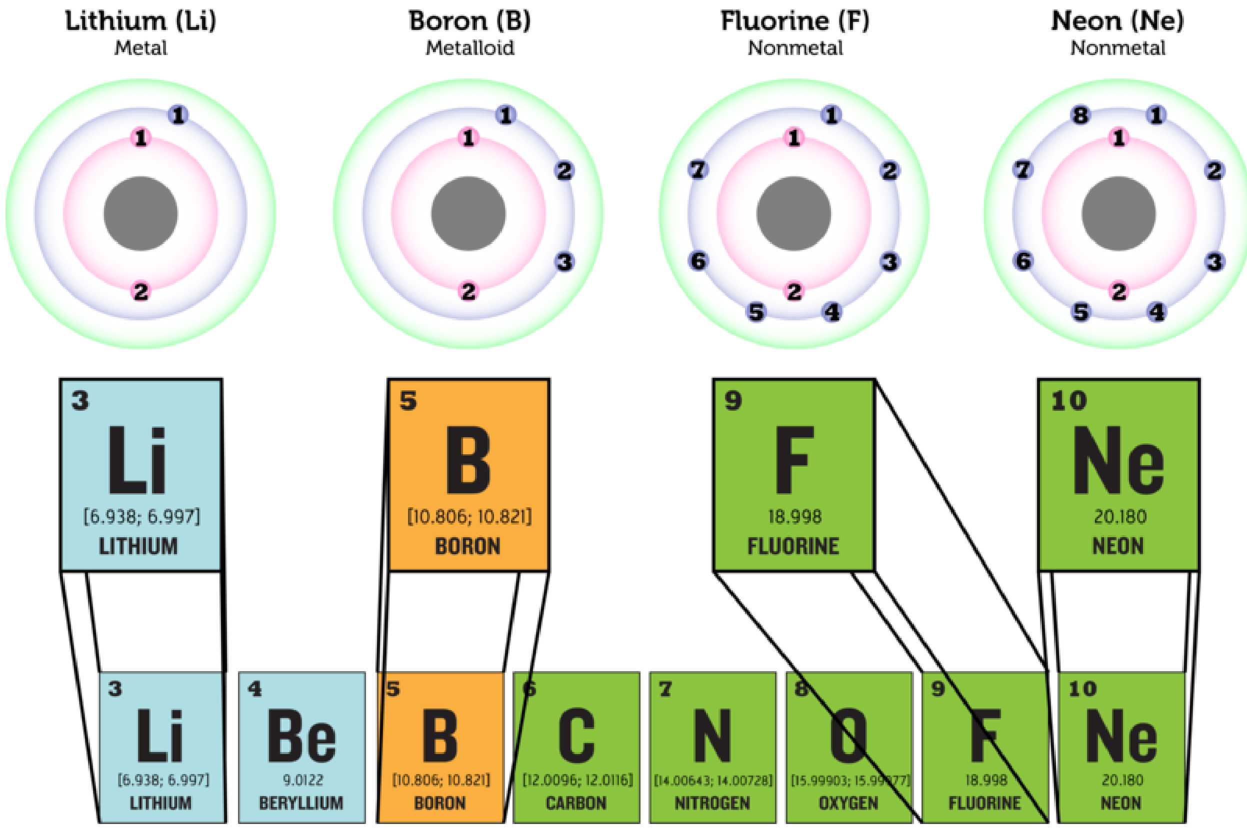


FIGURE 4.8

The number of electrons increases from left to right across each period in the periodic table. In period 2, lithium (Li) has the fewest electrons and neon (Ne) has the most. How do the numbers of electrons in their outer energy levels compare?

Lesson Summary

- Metals are elements that are good conductors of electricity. They are the largest class of elements. Many metals are shiny, ductile, and malleable. They are also good conductors of heat. Almost all metals are solids are room temperature.
- Nonmetals are elements that do not conduct electricity. They are the second largest class of elements. Nonmetals are also poor conductors of heat. The majority of nonmetals are gases. Solid nonmetals are dull and brittle.
- Metalloids are elements that have properties of both metals and nonmetals. Some can conduct electricity but only at certain temperatures. They may be shiny but brittle. All metalloids are solids at room temperature.
- Atoms of elements in different classes vary in their number of valence electrons. This explains their differences in reactivity and conductivity.

Lesson Review Questions

Recall

1. What are metals? Name one example.
2. Define nonmetal, and give an example.
3. State one way that metalloids may be like metals and one way they may be like nonmetals.
4. What are valence electrons?

Apply Concepts

5. A mystery element is a dull, gray solid. It is very reactive with other elements. Classify the mystery element as a metal, nonmetal, or metalloid. Explain your answer.

Think Critically

6. Create a Venn diagram for metals, metalloids, and nonmetals. The diagram should show which properties are different and which, if any, are shared among the three groups of elements.
7. Relate number of valence electrons to reactivity of classes of elements.

Points to Consider

The number of valence electrons increases from left to right across each period of the periodic table. By the end of the period, the outer energy level is full. Moving on to the next period of the table, electrons are added to the next higher energy level. This happens in each row of the periodic table.

- How do you think the number of valence electrons compares in elements within the same column (group) of the periodic table?
- How might this be reflected in the properties of elements within a group?

4.3 Groups of Elements

Lesson Objectives

- Identify hydrogen and alkali metals.
- Describe alkaline Earth metals.
- List properties of transition metals.
- Identify groups containing metalloids.
- Give properties of halogens.
- Describe noble gases.

Vocabulary

- alkali metal
- alkaline Earth metal
- halogen
- noble gas
- transition metal

Introduction

Elements in the same column, or group, of the periodic table have the same number of valence electrons in their outer energy level. This gives them many similar properties. The rest of this chapter describes properties of the different groups of elements. You can watch a video about the groups at this link: http://www.khanacademy.org/video/groups-of-the-periodic-table?playlist=Chemistry .

Group 1: Hydrogen and Alkali Metals

All the elements in group 1 have just one valence electron, so they are highly reactive. Group 1 is shown in **Figure** 4.9. At the top of this group is hydrogen (H), which is a very reactive, gaseous nonmetal. It is the most common element in the universe.

All the other elements in group 1 are **alkali metals**. They are the most reactive of all metals, and along with the elements in group 17, the most reactive elements. Because alkali metals are so reactive, they are only found in nature combined with other elements. The alkali metals are soft. Most are soft enough to cut with a knife. They are also low in density. Some of them even float on water. All are solids at room temperature. You can see a video demonstrating the reactivity of alkali metals with water at this URL: http://www.youtube.com/watch?v=uixxJtJPVXk (2:22).

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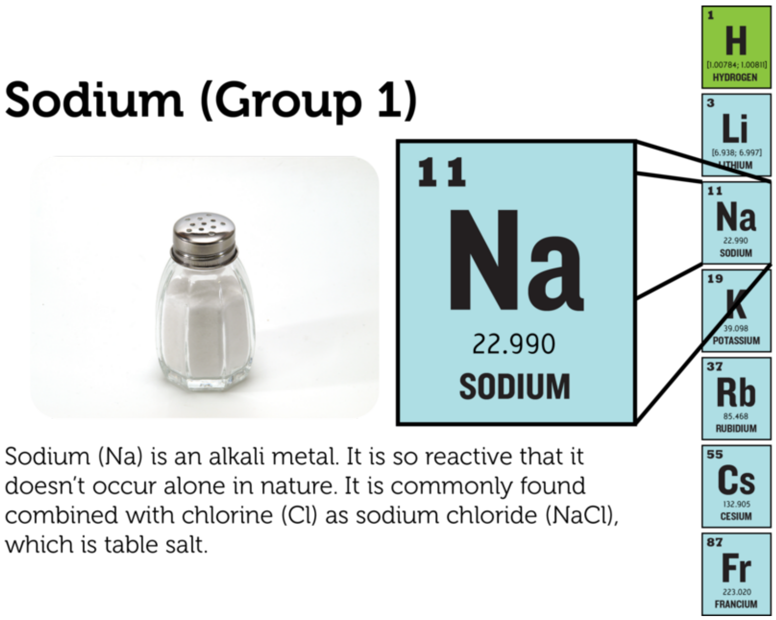

FIGURE 4.9

In group 1 of the periodic table, all the elements except hydrogen (H) are alkali metals.

Group 2: Alkaline Earth Metals

The **alkaline Earth metals** include all the elements in group 2 (see **Figure** 4.10). These metals have just two valence electrons, so they are very reactive, although not quite as reactive as the alkali metals. In nature, they are always found combined with other elements. Alkaline Earth metals are silvery grey in color. They are harder and denser than the alkali metals. All are solids at room temperature.

Groups 3-12: Transition Metals

Groups 3–12 of the periodic table contain **transition metals** (see **Figure** 4.11). Transition metals have more valence electrons and are less reactive than metals in the first two metal groups. The transition metals are shiny. Many are silver colored. They tend to be very hard, with high melting and boiling points. All except mercury (Hg) are solids at room temperature.

Transition metals include the elements that are placed below the periodic table. Those that follow lanthanum (La) are called lanthanides. They are all shiny, relatively reactive metals. Those that follow Actinium (Ac) are called actinides. They are all radioactive metals. This means they are unstable. They break down into different, more stable elements. You can read more about radioactive elements in the chapter *Nuclear Chemistry*. Many of the actinides do not occur in nature but are made in laboratories.

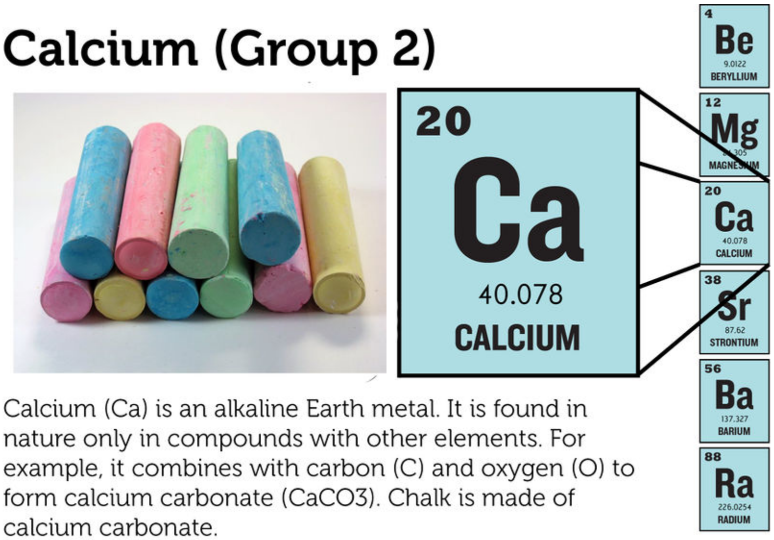

FIGURE 4.10
The alkaline Earth metals make up group 2 of the periodic table.

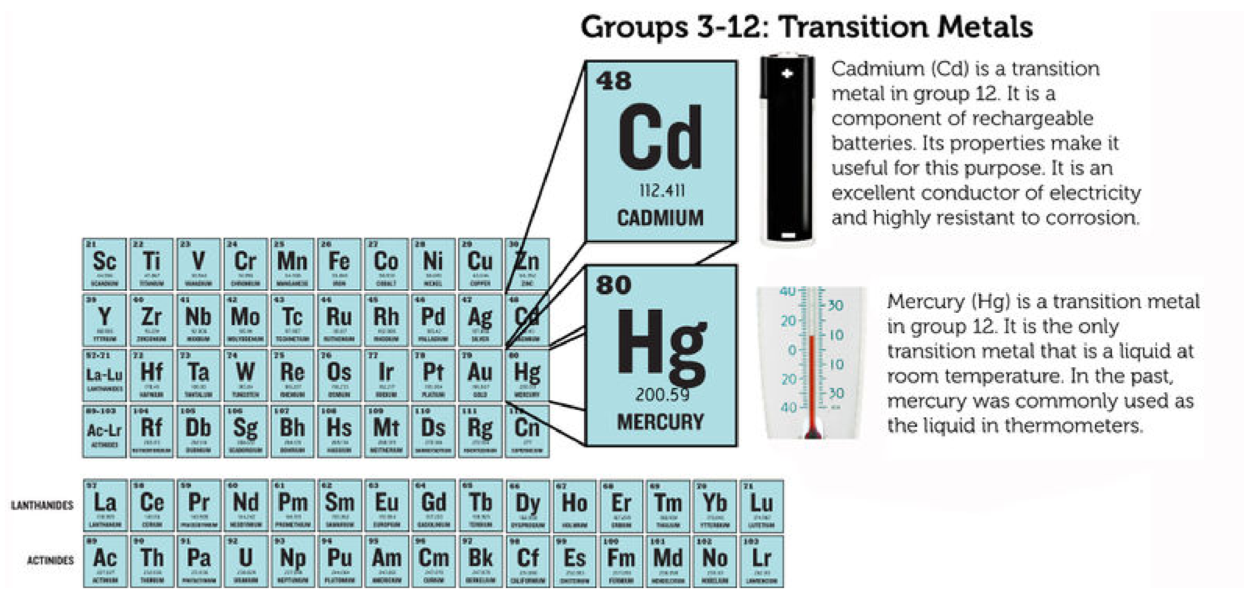

FIGURE 4.11
All the elements in groups 3–12 are transition metals.

Groups 13-16: Groups Containing Metalloids

Groups 13–16 each contain one or more metalloids. These groups are shown in **Figure** 4.12.

- Group 13 is called the boron group. The only metalloid in this group is boron (B). The other four elements are metals. All group 13 elements have three valence electrons and are fairly reactive. All are solids at room

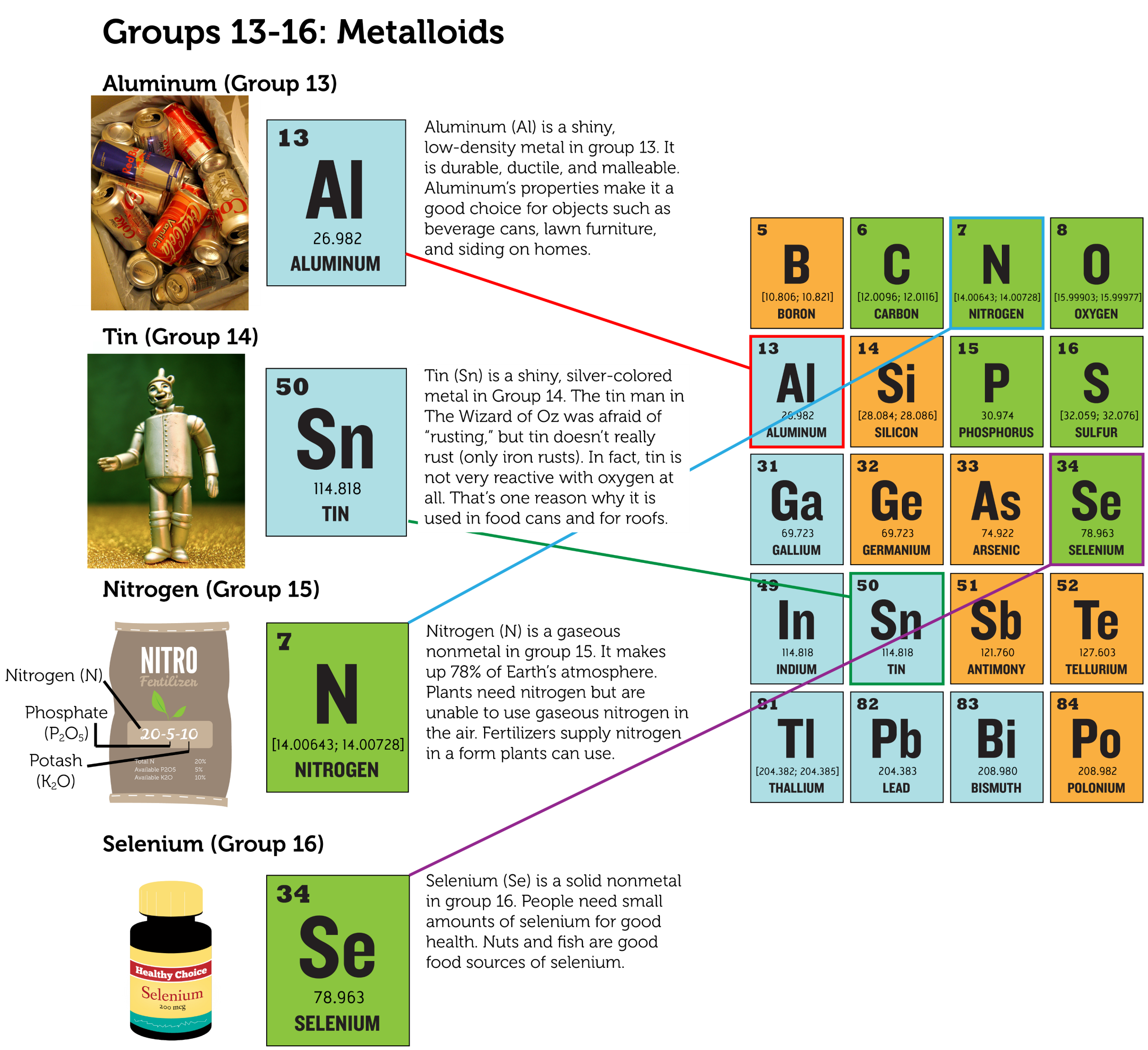

FIGURE 4.12

These groups each contain one or more metalloids.

temperature.

- Group 14 is called the carbon group. Carbon (C) is a nonmetal. The next two elements are metalloids, and the final two are metals. All the elements in the carbon group have four valence electrons. They are not very reactive. All are solids at room temperature.
- Group 15 is called the nitrogen group. The first two elements in this group are nonmetals. These are followed by two metalloids and one metal. All the elements in the nitrogen group have five valence electrons, but they vary in their reactivity. Nitrogen (N) in not reactive at all. Phosphorus (P), in contrast, is quite reactive. In fact, it is found naturally only in combination with other substances. Nitrogen is a gas at room temperature. The other group 15 elements are solids.
- Group 16 is called the oxygen group. The first three elements in this group are nonmetals. They are followed by one metalloid and one metal. All the elements in the oxygen group have six valence electrons, and all are

reactive. Oxygen (O), for example, readily reacts with metals to form compounds such as rust. Oxygen is a gas at room temperature. The other four elements in group 16 are solids.

Group 17: Halogens

Elements in group 17 are called **halogens** (see **Figure** 4.13). They are highly reactive nonmetals with seven valence electrons. The halogens react violently with alkali metals, which have one valence electron. The two elements combine to form a salt. For example, the halogen chlorine (Cl) and the alkali metal sodium (Na) react to form table salt, or sodium chloride (NaCl). The halogen group includes gases, liquids, and solids. For example, chlorine is a gas at room temperature, bromine (Br) is a liquid, and iodine (I) is a solid. You can watch a video demonstrating the reactivity of halogens at this URL: http://www.youtube.com/watch?v=mY7o28-l_WU&feature=related .

Group 18: Noble Gases

Group 18 elements are nonmetals called **noble gases** (see **Figure** 4.14). They are all colorless, odorless gases. Their outer energy level is also full, so they are the least reactive elements. In nature, they seldom combine with other substances. For a short video about the noble gases and their properties, go to this URL: http://www.youtube.com/watch?v=QLrofyj6a2s (1:17).

Lesson Summary

- Group 1 of the periodic table consists of hydrogen and the alkali metals. Hydrogen is a very reactive nonmetal. The alkali metals are the most reactive metals.
- Group 2 consists of the alkaline Earth metals. They are very reactive but less so than the alkali metals.
- Groups 3–12 contain transition metals. They are less reactive than metals in groups 1 and 2.
- Groups 13–16 each contain at least one metalloid. They also contain metals and/or nonmetals. Elements in these groups vary in reactivity and other properties.
- Group 17 contains halogens. They are highly reactive nonmetals.
- Group 18 consists of noble gases. They are unreactive and rarely combine with other elements.

Lesson Review Questions

Recall

1. What are alkali metals? What is one example?
2. Identify an alkaline Earth metal. How reactive is it?
3. Which element is the only transition metal that is a liquid at room temperature?
4. In which groups of the periodic table would you find metalloids?
5. State why halogens are highly reactive.
6. Describe noble gases.

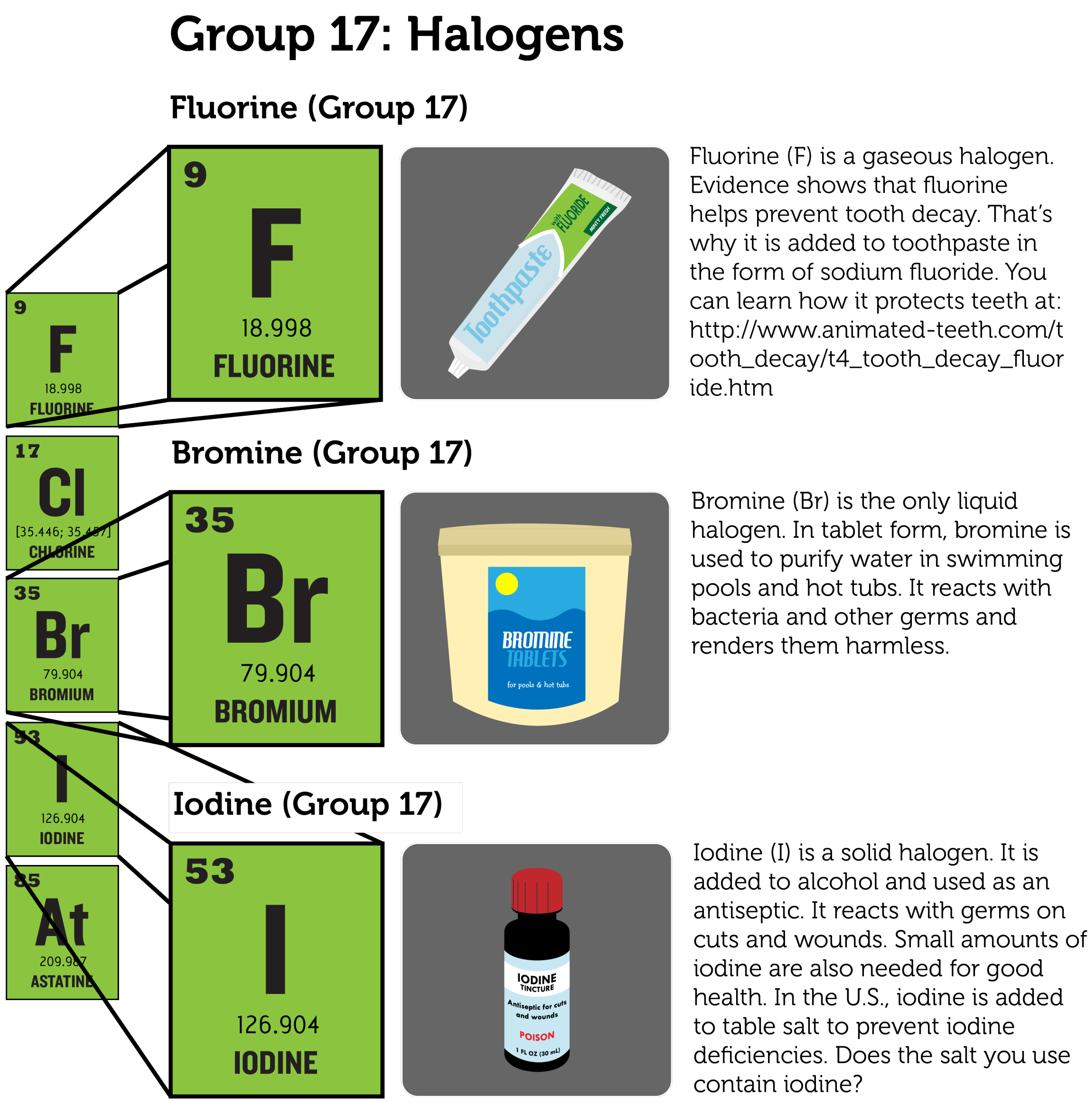

FIGURE 4.13

Group 17 consists of the nonmetals called halogens.

Apply Concepts

7. Assume you have a sample of an unknown element. At room temperature, it is a soft solid. You cut a small piece from the sample with a knife and drop the piece into a container of water. It bursts into flames. Which group of the periodic table does the unknown element belong in?

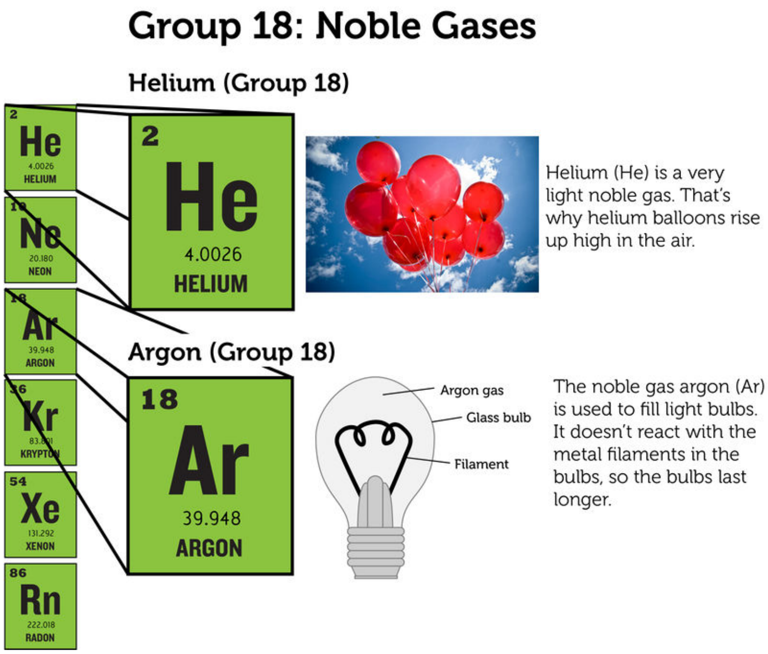

FIGURE 4.14

Noble gases include helium and argon.

Think Critically

8. Both hydrogen (H) and helium (He) are gaseous nonmetals. Why are they placed on opposite sides of the periodic table?

Points to Consider

Reactive elements combine easily with other elements. This explains why they usually exist in nature in compounds rather than in pure form.

- How do you think elements join together to form compounds?
- Do you think this might vary from one group of elements to another?

For **Table** 4.1,

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- Boron: Christopher Auyeung. CC BY-NC 3.0. CK-12 Foundation.
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4. Chromium and krypton: User:Jurii/Wikimedia Commons; Arsenic: Aram Dulyan (Wikimedia: Aramgutang). Chromium: http://commons.wikimedia.org/wiki/File:Chromium.jpg; Arsenic: http://commons.wikimedia.org/wiki/File:Native_arsenic.jpg; Krypton: http://commons.wikimedia.org/wiki/File:Krypton-glow.jpg . Chromium and krypton: CC-BY 3.0; Arsenic: Public Domain
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CHAPTER 5 Chemical Bonding

Chapter Outline

What do this lump of coal, diamond, and pencil "lead" all have in common? All three substances are forms of carbon. Are you surprised that one element can exist in forms that have such different properties? Do you know what explains it? The answer is chemical bonds. Carbon atoms chemically bond together in different ways to form these three substances. What are chemical bonds and how do they form? Read on to find out.

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5.1 Introduction to Chemical Bonds

Lesson Objectives

- Define chemical bond.
- List general properties of compounds.

Lesson Vocabulary

- chemical bond
- chemical formula

Introduction

There is an amazing diversity of matter in the universe, but there are only about 100 elements. How can this relatively small number of pure substances make up all kinds of matter? Elements can combine in many different ways. When they do, they form new substances called compounds. For a video introduction to compounds, go this URL: http://www.youtube.com/watch?v=-HjMoTthEZ0 (3:53).

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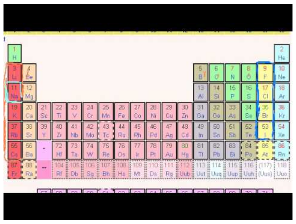
Chemical Bonding

Elements form compounds when they combine chemically. Their atoms join together to form molecules, crystals, or other structures. The atoms are held together by chemical bonds. A **chemical bond** is a force of attraction between atoms or ions. It occurs when atoms share or transfer valence electrons. Valence electrons are the electrons in the outer energy level of an atom. You can learn more about chemical bonds in this video: http://www.youtube.com/watch?v=CGA8sRwqIFg (13:21).



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Look at the example of water in **Figure** 5.1. A water molecule consists of two atoms of hydrogen and one atom of oxygen. Each hydrogen atom has just one electron. The oxygen atom has six valence electrons. In a water molecule, two hydrogen atoms share their two electrons with the six valence electrons of one oxygen atom. By sharing electrons, each atom has electrons available to fill its sole or outer energy level. This gives it a more stable arrangement of electrons that takes less energy to maintain.

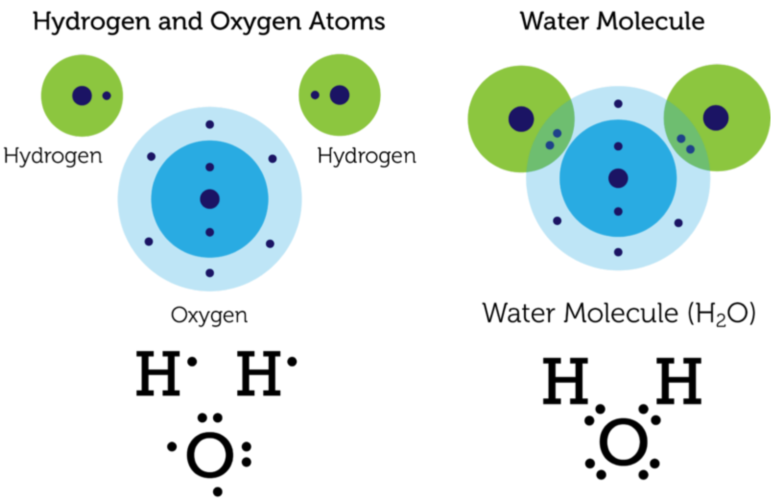


FIGURE 5.1

These diagrams show the valence electrons of hydrogen and water atoms and a water molecule. The diagrams represent electrons with dots, so they are called electron dot diagrams.

Chemical Compounds

Water (H_2O) is an example of a chemical compound. Water molecules always consist of two atoms of hydrogen and one atom of oxygen. Like water, all other chemical compounds consist of a fixed ratio of elements. It doesn't matter how much or how little of a compound there is. It always has the same composition.

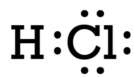
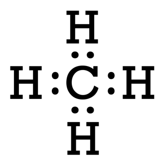
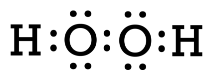
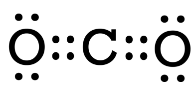
Chemical Formulas

Elements are represented by chemical symbols. Examples are H for hydrogen and O for oxygen. Compounds are represented by **chemical formulas**. You've already seen the chemical formula for water. It's H_2O. The subscript 2 after the H shows that there are two atoms of hydrogen in a molecule of water. The O for oxygen has no subscript. When there is just one atom of an element in a molecule, no subscript is used. **Table** 5.1 shows some other examples of compounds and their chemical formulas.

TABLE 5.1: Examples of Chemical Compounds

Name of Compound	Electron Dot Diagram	Numbers of Atoms	Chemical Formula

TABLE 5.1: (continued)

Name of Compound	Electron Dot Diagram	Numbers of Atoms	Chemical Formula
Hydrogen chloride		H = 1 Cl = 1	HCl
Methane		C = 1 H = 4	CH_4
Hydrogen peroxide		H = 2 O = 2	H_2O_2
Carbon dioxide		C = 1 O = 2	CO_2

Problem Solving

Problem: A molecule of ammonia consists of one atom of nitrogen (N) and three atoms of hydrogen (H). What is its chemical formula?

Solution: The chemical formula is NH_3.

You Try It!

Problem: A molecule of nitrogen dioxide consists of one atom of nitrogen (N) and two atoms of oxygen (O). What is its chemical formula?

Same Elements, Different Compounds

The same elements may combine in different ratios. If they do, they form different compounds. **Figure** 5.2 shows some examples. Both water (H_2O) and hydrogen peroxide (H_2O_2) consist of hydrogen and oxygen. However, they have different ratios of the two elements. As a result, water and hydrogen peroxide are different compounds with different properties. If you've ever used hydrogen peroxide to disinfect a cut, then you know that it is very different from water! Both carbon dioxide (CO_2) and carbon monoxide (CO) consist of carbon and oxygen, but in different ratios. How do their properties differ?

Types of Compounds

There are different types of compounds. They differ in the nature of the bonds that hold their atoms together. The type of bonds in a compound determines many of its properties. Three types of bonds are ionic, covalent, and metallic bonds. You will read about these three types in later lessons. You can also learn more about them by watching this video: http://www.youtube.com/watch?v=hEFeLYWTKX0 (7:18).

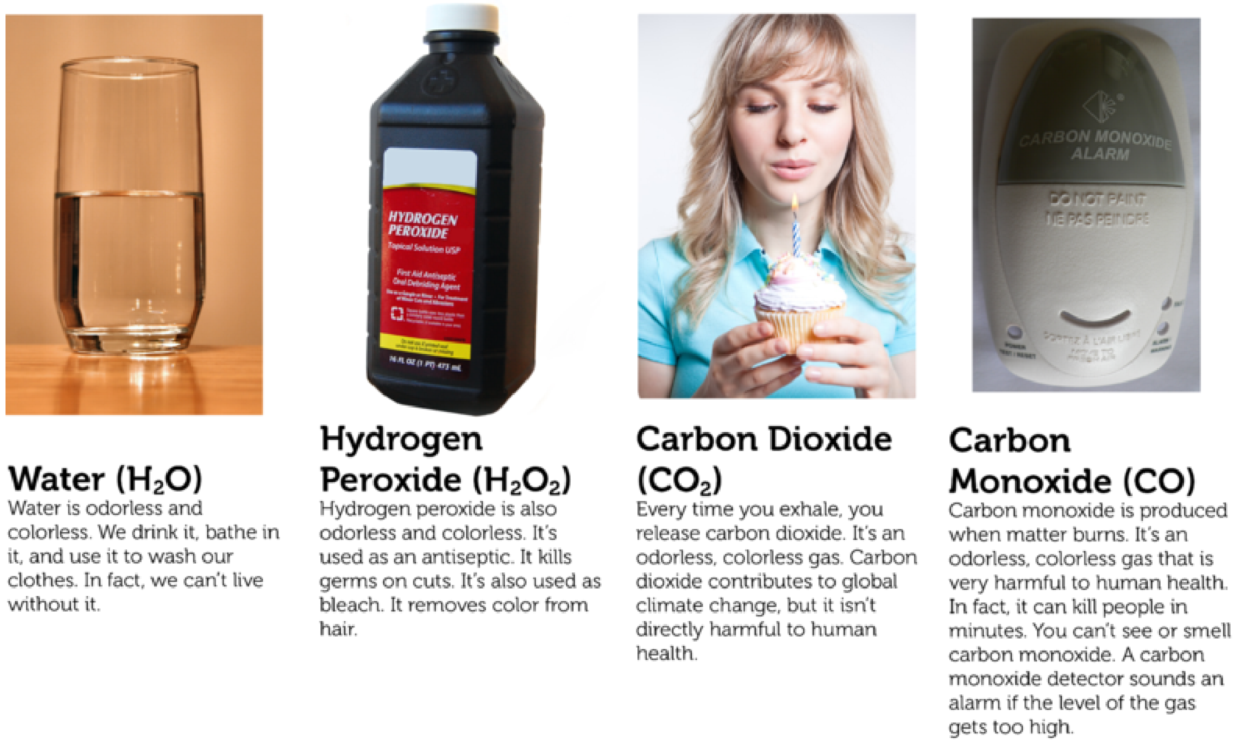
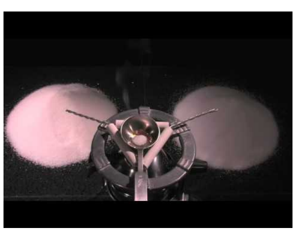


FIGURE 5.2

Different compounds may contain the same elements in different ratios. How does this affect their properties?



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KQED: The Sweet Science of Chocolate

Chocolate: It's been revered for millennia by cultures throughout the world. But while it's easy to appreciate all of its delicious forms, creating this confection is a complex culinary feat. Local chocolate makers explain the elaborate engineering and chemistry behind this tasty treat. And learn why it's actually good for your health! For more information on the science of chocolate, see http://science.kqed.org/quest/video/the-sweet-science-of-chocolate/ .

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Lesson Summary

- A chemical bond is a force of attraction between atoms. It occurs when atoms share or transfer electrons.
- A chemical compound is a new substance that forms when atoms of different elements form chemical bonds. A compound always consists of a fixed ratio of elements.

Lesson Review Questions

Recall

1. What is a chemical bond?
2. Define chemical compound.

Apply Concepts

3. Which atoms and how many of each make up a molecule of sulfur dioxide? Write the chemical formula for this compound.

Think Critically

4. Why does a molecule of water have a more stable arrangement of electrons than do individual hydrogen and oxygen atoms?
5. Explain how the ratio of elements in a compound is related to the compound's properties.

Points to Consider

In this lesson, you learned about chemical bonds in a water molecule. The bonds form between atoms of hydrogen and oxygen when they share electrons. This type of bond is an example of a covalent bond.

- What might be other ways that atoms can bond together?
- How might ions form bonds?

5.2 Ionic Bonds

Lesson Objectives

- Describe how ionic bonds form.
- List properties of ionic compounds.

Lesson Vocabulary

- ionic bond
- ionic compound

Introduction

All compounds form when atoms of different elements share or transfer electrons. In water, the atoms share electrons. In some other compounds, called **ionic compounds**, atoms transfer electrons. The electrons actually move from one atom to another. When atoms transfer electrons in this way, they become charged particles called ions. The ions are held together by ionic bonds.

Formation of Ionic Bonds

An **ionic bond** is the force of attraction that holds together positive and negative ions. It forms when atoms of a metallic element give up electrons to atoms of a nonmetallic element. **Figure** 5.3 shows how this happens.

In row 1 of **Figure** 5.3, an atom of sodium donates an electron to an atom of chlorine (Cl).

- By losing an electron, the sodium atom becomes a sodium ion. It now has one less electron than protons, giving it a charge of +1. Positive ions such as sodium are given the same name as the element. The chemical symbol has a plus sign to distinguish the ion from an atom of the element. The symbol for a sodium ion is Na^+.
- By gaining an electron, the chlorine atom becomes a chloride ion. It now has one more electron than protons, giving it a charge of -1. Negative ions are named by adding the suffix *–ide* to the first part of the element name. The symbol for chloride is Cl^-.

Sodium and chloride ions have equal but opposite charges. Opposites attract, so sodium and chloride ions attract each other. They cling together in a strong ionic bond. You can see this in row 2 of **Figure** 5.3. Brackets separate the ions in the diagram to show that the ions in the compound do not share electrons. You can see animations of sodium chloride forming at these URLs:

- http://web.jjay.cuny.edu/~acarpi/NSC/salt.htm

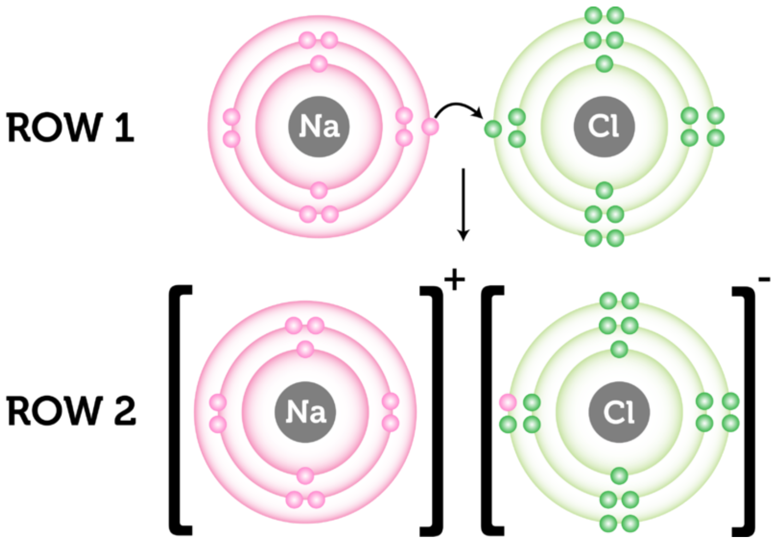


FIGURE 5.3
An ionic bond forms when the metal sodium gives up an electron to the non-metal chlorine.

- http://www.visionlearning.com/library/module_viewer.php?mid=55

Why Ionic Bonds Form

Ionic bonds form only between metals and nonmetals. Metals "want" to give up electrons, and nonmetals "want" to gain electrons. Find sodium (Na) in **Figure** 5.4. Sodium is an alkali metal in group 1. Like other group 1 elements, it has just one valence electron. If sodium loses that one electron, it will have a full outer energy level. Now find fluorine (F) in **Figure** 5.4. Fluorine is a halogen in group 17. It has seven valence electrons. If fluorine gains one electron, it will have a full outer energy level. After sodium gives up its valence electron to fluorine, both atoms have a more stable arrangement of electrons.

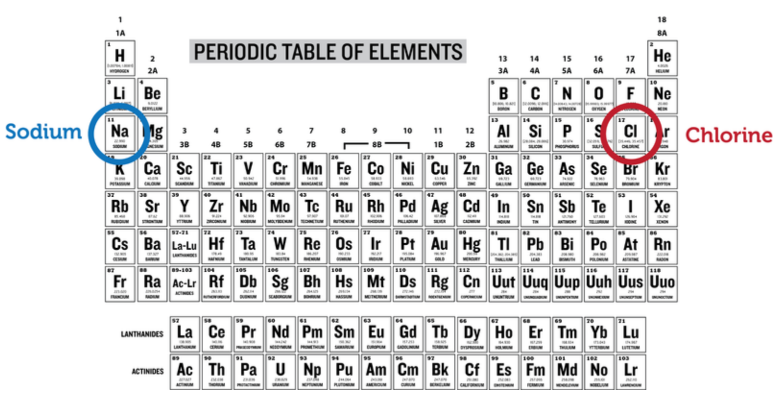


FIGURE 5.4
Sodium and chlorine are on opposite sides of the periodic table. How is this related to their numbers of valence electrons?

Energy and Ionic Bonds

It takes energy to remove valence electrons from an atom. The force of attraction between the negative electrons and positive nucleus must be overcome. The amount of energy needed depends on the element. Less energy is needed to remove just one or a few electrons than many. This explains why sodium and other alkali metals form positive ions so easily. Less energy is also needed to remove electrons from larger atoms in the same group. For example, in group 1, it takes less energy to remove an electron from francium (Fr) at the bottom of the group than from lithium (Li) at the top of the group (see **Figure** 5.4). In bigger atoms, valence electrons are farther from the nucleus. As a result, the force of attraction between the electrons and nucleus is weaker.

What happens when an atom gains an electron and becomes a negative ion? Energy is released. Halogens release the most energy when they form ions. As a result, they are very reactive.

Ionic Compounds

Ionic compounds contain ions of metals and nonmetals held together by ionic bonds. Ionic compounds do not form molecules. Instead, many positive and negative ions bond together to form a structure called a crystal. You can see an example of a crystal in **Figure** 5.5. It shows the ionic compound sodium chloride. Positive sodium ions (Na^+) alternate with negative chloride ions (Cl^-). The oppositely charged ions are strongly attracted to each other.

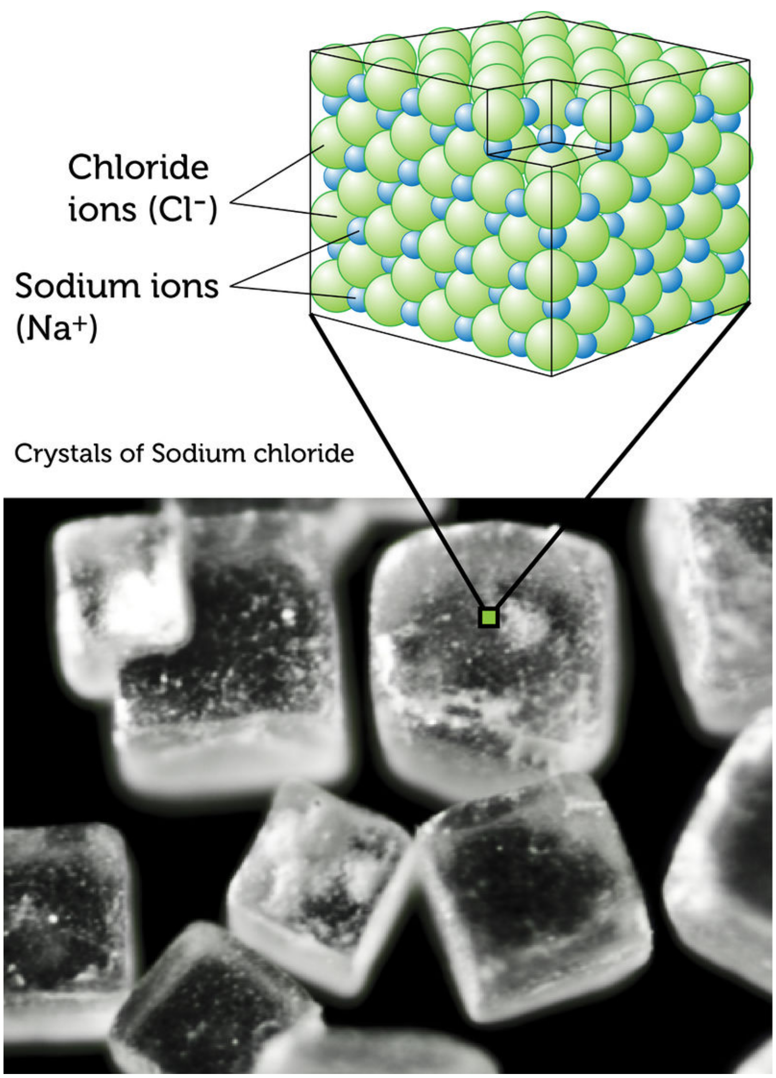


FIGURE 5.5
Sodium chloride crystals are cubic in shape. Other ionic compounds may have crystals with different shapes.

Helpful Hints

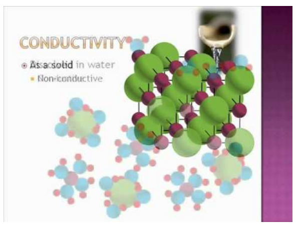
Naming Ionic Compounds Ionic compounds are named for their positive and negative ions. The name of the positive ion always comes first. For example, sodium and chloride ions form the compound named sodium chloride.

You Try It!

Problem: What is the name of the ionic compound composed of positive barium ions and negative iodide ions?

Properties of Ionic Compounds

The crystal structure of ionic compounds is strong and rigid. It takes a lot of energy to break all those strong ionic bonds. As a result, ionic compounds are solids with high melting and boiling points (see **Table** 5.2). The rigid crystals are brittle and more likely to break than bend when struck. As a result, ionic crystals tend to shatter. You can learn more about the properties of ionic compounds by watching the video at this URL: http://www.youtube.com/watch?v=buWrSgs_ZHk (3:34).



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Compare the melting and boiling points of these ionic compounds with those of water (0°C and 100°C), which is *not* an ionic compound.

TABLE 5.2: Melting and Boiling Points of Select Ionic Compounds

Ionic Compound	**Melting Point** (°C)	**Boiling Point** (°C)
Sodium chloride (NaCl)	801	1413
Calcium chloride ($CaCl_2$)	772	1935
Barium oxide (BaO)	1923	2000
Iron bromide ($FeBr_3$)	684	934

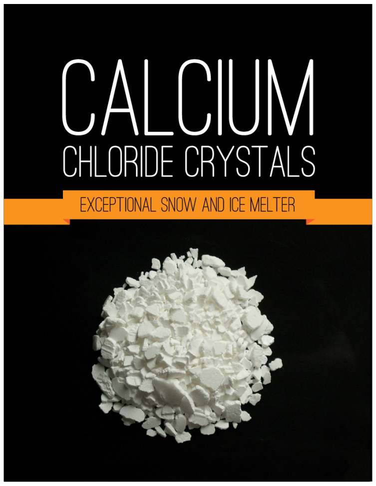
Solid ionic compounds are poor conductors of electricity. The strong bonds between ions lock them into place in the crystal. However, in the liquid state, ionic compounds are good conductors of electricity. Most ionic compounds dissolve easily in water. When they dissolve, they separate into individual ions. The ions can move freely, so they are good conductors of electricity. Dissolved ionic compounds are called electrolytes.

Uses of Ionic Compounds

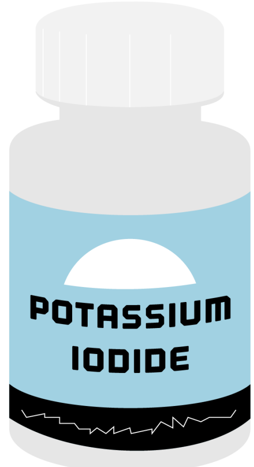
Ionic compounds have many uses. Some are shown in **Figure** 5.6. Many ionic compounds are used in industry. The human body also needs several ions for good health. Having low levels of the ions can endanger important functions such as heartbeat. Solutions of ionic compounds can be used to restore the ions.

Lesson Summary

- An ionic bond is the force of attraction that holds together oppositely charged ions. It forms when atoms of a metal transfer electrons to atoms of a nonmetal. When this happens, the atoms become oppositely charged ions.



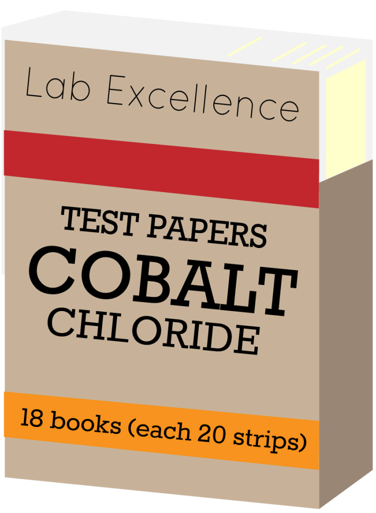
Calcium chloride crystals are used to melt ice and snow. The crystals lower the freezing point of water.



Potassium iodide tablets are given to people who are exposed to high levels of radiation. They protect the thyroid gland from radiation.

Barium chloride is used to make fireworks. It produces green-colored explosions.

Electrolyte solutions are given to children who have lost ions. This can happen with vomiting or diarrhea.



Cobalt chloride test papers are used to detect moisture. They change color when they absorb water.

Lithium iodide is used in batteries. It's an excellent conductor of electricity.

FIGURE 5.6

Have you ever used any of these ionic compounds?

- Ionic compounds form crystals instead of molecules. Ionic bonds are strong and the crystals are rigid. As a result, ionic compounds are brittle solids with high melting and boiling points. In the liquid state or dissolved in water, ionic compounds are good conductors of electricity.

Lesson Review Questions

Recall

1. What is an ionic bond?
2. Outline the role of energy in the formation of an ionic bond.
3. List properties of ionic compounds.

Apply Concepts

4. Create a model to represent the ionic bonds in a crystal of the salt lithium iodide (LiI).
5. A mystery compound is a liquid with a boiling point of 50°C. Is it likely to be an ionic compound? Why or why not?

Think Critically

6. Explain why ionic bonds form only between atoms of metals and nonmetals.

Points to Consider

Bonds form not only between atoms of metals and nonmetals. Nonmetals may also bond with nonmetals.

- How do you think bonds form between atoms of nonmetals?
- Can you think of examples of compounds that consist only of nonmetals?

5.3 Covalent Bonds

Lesson Objectives

- Describe how covalent bonds form.
- Compare properties of polar and nonpolar covalent compounds.

Lesson Vocabulary

- covalent bond
- covalent compound
- hydrogen bond
- nonpolar
- polar

Introduction

Covalent bonds are bonds in which atoms share rather than transfer electrons. Compounds with covalent bonds are called covalent compounds.

Formation of Covalent Bonds

A **covalent bond** is the force of attraction that holds together two atoms that share a pair of electrons. The shared electrons are attracted to the nuclei of both atoms. Covalent bonds form only between atoms of nonmetals. The two atoms may be the same or different elements. If the bonds form between atoms of different elements, a covalent compound forms. Covalent compounds are described in detail later in the lesson. To see a video about covalent bonding, go to this URL: http://www.youtube.com/watch?v=-Eh_0Dseg3E (6:20).

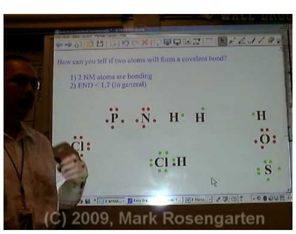


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Figure 5.7 shows an example of a covalent bond forming between two atoms of the same element, in this case two atoms of hydrogen. The two atoms share a pair of electrons. Hydrogen normally occurs in two-atom, or diatomic, molecules like this (*di-* means "two"). Several other elements also normally occur as diatomic molecules: nitrogen, oxygen, and all but one of the halogens (fluorine, chlorine, bromine, and iodine).

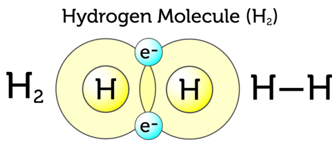

FIGURE 5.7
This figure shows three ways of representing a covalent bond. A dash (-) between two atoms represents one pair of shared electrons.

Why Covalent Bonds Form

Covalent bonds form because they give atoms a more stable arrangement of electrons. Look at the hydrogen atoms in **Figure** 5.7. Alone, each hydrogen atom has just one electron. By sharing electrons with another hydrogen atom, it has two electrons: its own and the one in the other hydrogen atom. The shared electrons are attracted to both hydrogen nuclei. This force of attraction holds the two atoms together as a molecule of hydrogen.

Some atoms need to share more than one pair of electrons to have a full outer energy level. For example, an oxygen atom has six valence electrons. It needs two more electrons to fill its outer energy level. Therefore, it must form two covalent bonds. This can happen in many different ways. One way is shown in **Figure** 5.8. The oxygen atom in the figure has covalent bonds with two hydrogen atoms. This forms the covalent compound water.

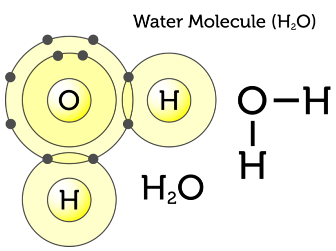

FIGURE 5.8
An oxygen atom has a more stable arrangement of electrons when it forms covalent bonds with two hydrogen atoms.

Polar and Nonpolar Covalent Bonds

In some covalent bonds, electrons are not shared equally between the two atoms. These are called **polar** bonds. **Figure** 5.9 shows this for water. The oxygen atom attracts the shared electrons more strongly because its nucleus has more positively charged protons. As a result, the oxygen atom becomes slightly negative in charge. The hydrogen atoms attract the electrons less strongly. They become slightly positive in charge. For another example of polar bonds, see the video at this URL: http://www.youtube.com/watch?v=1lnjg81daBs (0:52).

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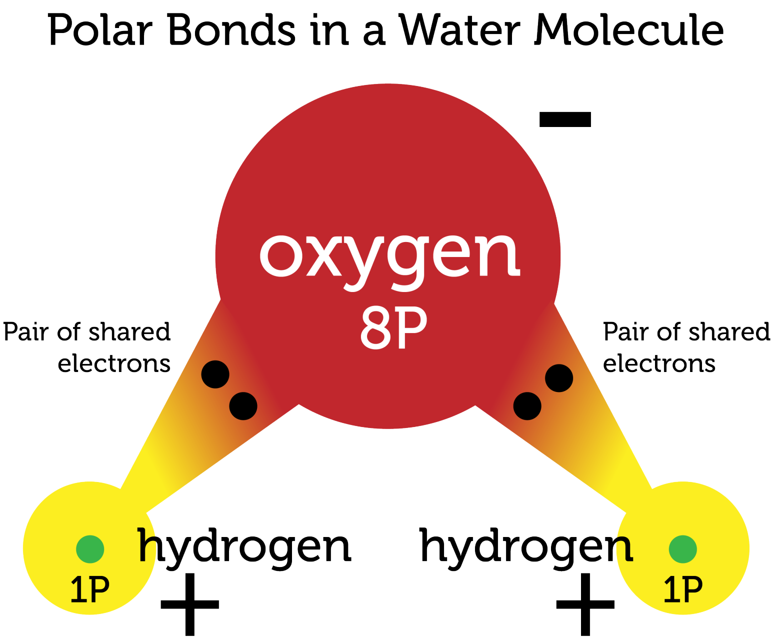


FIGURE 5.9
A water molecule has two polar bonds.

In other covalent bonds, electrons are shared equally. These bonds are called **nonpolar** bonds. Neither atom attracts the shared electrons more strongly. As a result, the atoms remain neutral. **Figure** 5.10 shows an example of nonpolar bonds.

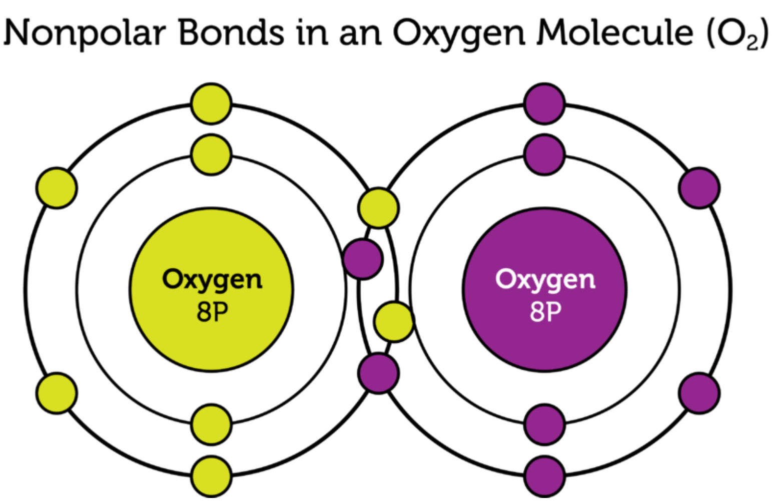


FIGURE 5.10
An oxygen molecule has two nonpolar bonds. This is called a double bond. The two oxygen atoms attract equally the four shared electrons.

Covalent Compounds

Covalent bonds between atoms of different elements form **covalent compounds**. The smallest, simplest covalent compounds have molecules with just two atoms. An example is hydrogen chloride (HCl). It consists of one hydrogen atom and one chlorine atom. The largest, most complex covalent molecules have thousands of atoms. Examples include proteins and carbohydrates. These are compounds in living things.

Helpful Hints

Naming Covalent Compounds Follow these rules in naming simple covalent compounds:

- The element closer to the left of the periodic table is named first.
- The second element gets the suffix *–ide*.
- Prefixes such as *di-* (2) and *tri-* (3) show the number of each atom in the compound. These are written with subscripts in the chemical formula.

Example: The gas that consists of one carbon atom and two oxygen atoms is named carbon dioxide. Its chemical formula is CO_2.

You Try It!

Problem: What is the name of the compound that contains three oxygen atoms and two nitrogen atoms? What is its chemical formula?

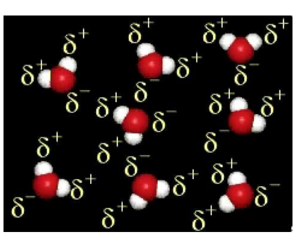
Properties of Covalent Compounds

Covalent compounds have different properties than ionic compounds because of their bonds. Covalent compounds exist as individual molecules rather than crystals. It takes less energy for individual molecules than ions in a crystal to pull apart. As a result, covalent compounds have lower melting and boiling points than ionic compounds. Many are gases or liquids at room temperature. Covalent compounds have shared electrons. These are not free to move like the transferred electrons of ionic compounds. This makes covalent compounds poor conductors of electricity. Many covalent compounds also do not dissolve in water as all ionic compounds do.

Polar and Nonpolar Covalent Compounds

Having polar bonds may make a covalent compound polar. A polar compound is one in which there is a slight difference in charge between opposite ends of the molecule. All polar compounds contain polar bonds. But having polar bonds does not necessarily result in a polar compound. It depends on how the atoms are arranged. This is illustrated in **Figure** 5.11. Both molecules in the figure contain polar bonds, but only formaldehyde is a polar compound. Why is carbon dioxide nonpolar?

The molecules of polar compounds are attracted to each other. You can see this in **Figure** 5.12 for water. A bond forms between the positive hydrogen end of one water molecule and the negative oxygen end of another water molecule. This type of bond is called a **hydrogen bond**. Hydrogen bonds are weak, but they still must be overcome when a polar substance changes from a solid to a liquid or from a liquid to a gas. As a result, polar covalent compounds may have higher melting and boiling points than nonpolar covalent compounds. To learn more about hydrogen bonding and when it occurs, see the video at this URL: http://www.youtube.com/watch?v=lkl5cbfqFRM (0:58).



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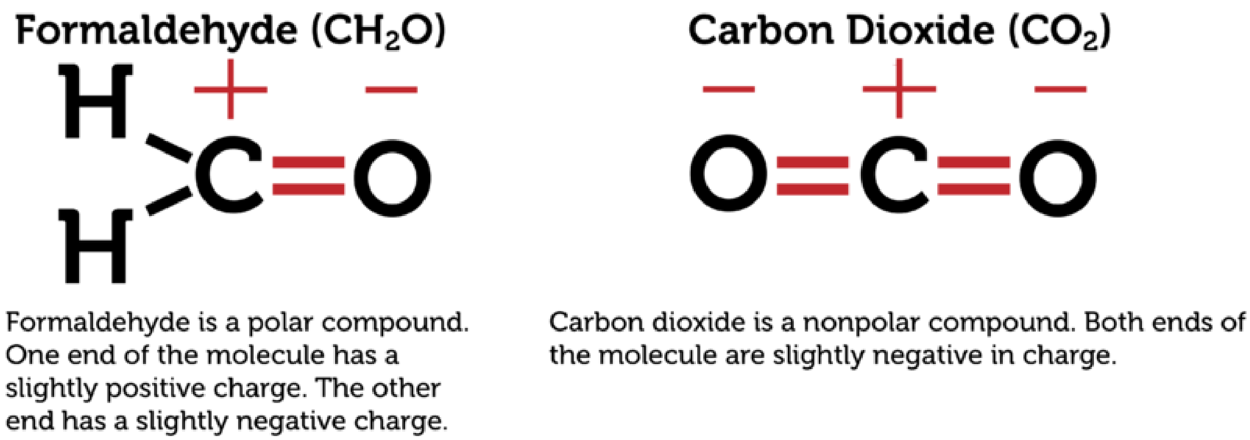


FIGURE 5.11
Covalent compounds may be polar or nonpolar, as these two examples show. In both molecules, the oxygen atoms attract electrons more strongly than the carbon or hydrogen atoms do.

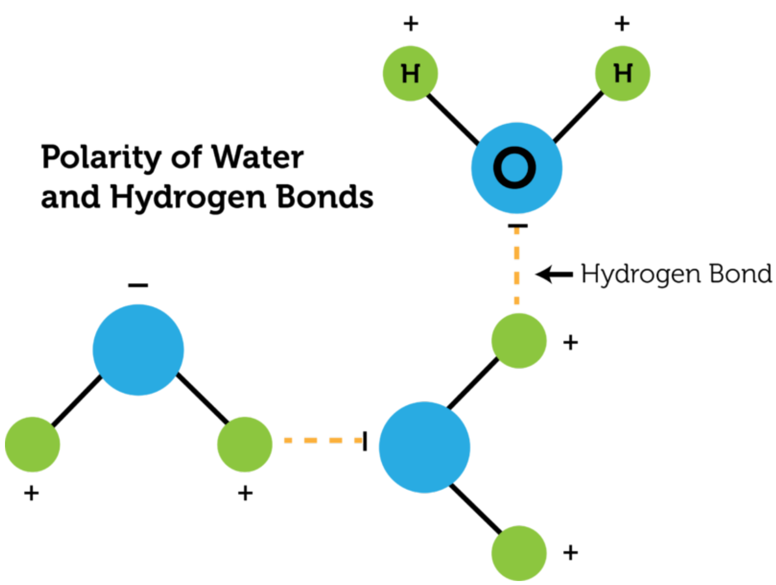


FIGURE 5.12
Water is a polar compound, so its molecules are attracted to each other and form hydrogen bonds.

Lesson Summary

- A covalent bond is the force of attraction that holds together two atoms that share a pair of electrons. It forms between atoms of the same or different nonmetals. In polar covalent bonds, one atom attracts the shared electrons more strongly and becomes slightly negative. The other atom becomes slightly positive.
- Covalent compounds form individual molecules rather than crystals. Compared with ionic compounds, they have low melting and boiling points. They are also poor conductors of electricity. In polar covalent compounds, oppositely charged ends of different molecules attract each other. This affects the properties of polar

compounds.

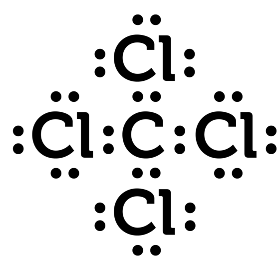
Lesson Review Questions

Recall

1. What is a covalent bond?
2. What is the difference between a polar and nonpolar covalent bond?
3. List general properties of covalent compounds.

Apply Concepts

4. The electron dot diagram below represents a covalent compound. Do you think it is a polar or nonpolar compound? Explain.



Think Critically

5. Explain why covalent bonds form.

Points to Consider

You read in this lesson that covalent bonds may form between atoms of the same nonmetal element. For example, hydrogen atoms (H) commonly form covalent bonds to form hydrogen molecules (H_2).

- Do you think bonds may also form between atoms of the same metallic element?
- Predict what these metallic bonds might be like.

5.4 Metallic Bonds

Lesson Objectives

- Describe how metallic bonds form.
- Relate the nature of metallic bonds to the properties of metals.
- Identify alloys and their uses.

Lesson Vocabulary

- alloy
- metallic bond

Introduction

Special bonds form in metals that do not form in other classes of elements. They are called metallic bonds. The bonds explain some of the unique properties of elements in the metals class.

Formation of Metallic Bonds

A **metallic bond** is the force of attraction between a positive metal ion and the valence electrons it shares with other ions of the metal. The positive ions form a lattice-like structure. You can see an example in **Figure** 5.13. (For an animated version, go to the URL below.) The ions are held together in the lattice by bonds with the valence electrons around them. These valence electrons include their own and those of other ions. Why do metallic bonds form? Recall that metals "want" to give up their valence electrons. This means that their valence electrons move freely. The electrons form a "sea" of negative charge surrounding the positive ions.

http://www.youtube.com/watch?v=c4udBSZfLHY (1:50)

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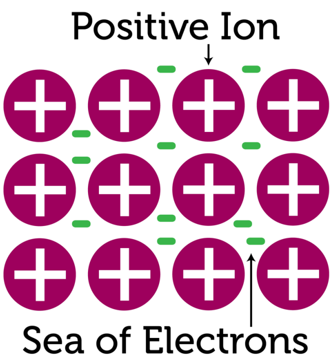
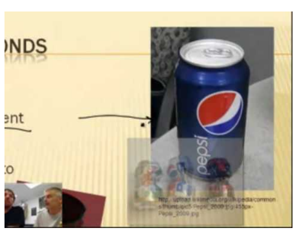


FIGURE 5.13
Positive metal ions and their shared electrons form metallic bonds.

Metallic Bonds and the Properties of Metals

Because of their freely moving electrons, metals are good conductors of electricity. Metals also can be shaped without breaking. They are ductile (can be shaped into wires) and malleable (can be shaped into thin sheets). Metals have these properties because of the nature of their metallic bonds.

A metallic lattice, like the one in **Figure** 5.13, may resemble a rigid ionic crystal. However, it is much more flexible. Look at **Figure** 5.14. It shows a blacksmith hammering a piece of red-hot iron in order to shape it. Why doesn't the iron shatter, as an ionic crystal would? The ions of the metal can move within the "sea" of electrons without breaking the metallic bonds that hold them together. The ions can shift closer together or farther apart. In this way, the metal can change shape without breaking. You can learn more about metallic bonds and the properties of metals at this URL: http://www.youtube.com/watch?v=ap5pHBWwpu4 (6:12).



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Alloys

Metals are useful for many purposes because of their unique properties. However, pure metals may be less useful than mixtures of metals. For example, iron is not as strong as steel, which is a mixture of iron and small amounts of carbon. Steel is so strong that it can hold up huge bridges, like the one **Figure** 5.15. Steel is also used to make skyscrapers, cargo ships, cars, and trains.

Steel is an example of an alloy. An **alloy** is a mixture of a metal with one or more other elements. The other elements may be metals, nonmetals, or both. An alloy is a solid solution. It is formed by melting a metal and dissolving the other elements in it. The molten solution is then allowed to cool and harden. Several other examples of alloys and their uses are shown in **Figure** 5.16. You can learn more about an amazing alloy called memory wire at the URL below. If you have braces on your teeth, you may even have this alloy in your mouth!

http://www.youtube.com/watch?v=LSNRwtTMH6w

FIGURE 5.14
A blacksmith shapes a piece of iron.

FIGURE 5.15
The girders of this bridge are made of steel.

Lesson Summary

- A metallic bond is the force of attraction between a positively charged metal ion and the valence electrons it shares with other ions of the metal. The electrons move freely around the positive ions, which form a lattice-like structure.
- With freely moving electrons, metals are good conductors of electricity. The positive ions of metals can also move within the "sea" of electrons without breaking the metallic bonds that hold them together. This allows metals to change shape without breaking.
- Pure metals may be less useful than mixtures of metals, called alloys. Examples of alloys include steel, bronze, and brass.

FIGURE 5.16
Most metal objects are made of metal alloys rather than pure metals.

Lesson Review Questions

Recall

1. What is a metallic bond?
2. Define alloy and give three examples.

Apply Concepts

3. Create a model to represent the metallic bonds in solid iron (Fe).

Think Critically

4. Relate metallic bonds to the properties of metals.
5. Compare and contrast metallic and ionic bonds.

Points to Consider

Compounds form when atoms of different elements combine. This process is a chemical reaction.

- How would you define chemical reaction?
- How do you think chemical reactions are related to chemical changes in matter, such as wood burning and iron rusting?

5.5 References

1. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
2. Water: Derek Jensen (Wikimedia: Tysto); Hydrogen peroxide: Robert Lopez; Girl blowing out candle: Image copyright arek_malang, 2013; Carbon monoxide detector: User:Sideroxylon/Wikimedia Commons. Water: http://commons.wikimedia.org/wiki/File:Glass-of-water.jpg; Hydrogen peroxide: CK-12; Girl blowing out candle: http://www.shutterstock.com; Carbon monoxide detector: http://commons.wikimedia.org/wiki/File:CO_detector.JPG . Water: Public Domain; Hydrogen peroxide: CC BY-NC; Girl blowing out candle: Used under licenses from Shutterstock.com; Carbon monoxide detector: Public Domain
3. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
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5. Salt: Tony L Wong; Illustration: Christopher Auyeung (CK-12 Foudnation). http://www.flickr.com/photos/tonylwong/3954263897/ . CC BY 2.0
6. Fireworks:Epic Fireworks; Battery: Lukas A, CZE; Others: Christopher Auyeung (CK-12 Foundation). Fireworks: http://www.flickr.com/photos/epicfireworks/8838128619/; Battery: http://commons.wikimedia.org/wiki/File:Energizer_lithium.jpg . Fireworks: CC BY 2.0; Battery: Public Domain; Others: CC BY-NC 3.0
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16. Saxophone: Thor (Flickr:Geishaboy500); Sink: Granite Charlotte Countertops; Bracelet: Maegan Tintari; Status: Elliot Brown. Statue: http://www.flickr.com/photos/geishaboy500/1103796516/; Sink: http://www.flickr.com/photos/46317749@N02/4403383547/; Bracelet: http://www.flickr.com/photos/lovemaegan/6877739921/; Status: http://www.flickr.com/photos/ell-r-brown/6277693589/ . CC BY 2.0

CHAPTER 6 Chemical Reactions

Chapter Outline

The puffy white fibers on this plant look like cotton balls. In fact, that's just what they are! The plant is a cotton plant, and the white fibers enclose the seeds of the plant. The fibers are used to make cotton fabrics, so if you have a cotton T-shirt, this is where the fabric came from. Cotton fibers —and most other plant fibers —consist of one of the most common compounds on Earth, the compound named cellulose.

Cellulose is a compound found in plants. The chief component of cellulose is carbon. Cellulose is one of many carbon-based compounds that make up living things. In fact, carbon-based compounds are the most common type of compound on Earth. More than 90 percent of all known compounds contain carbon. Do you know why carbon is found in so many compounds? Read on to find out.

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6.1 Introduction to Chemical Reactions

Lesson Objectives

- Describe how chemical reactions occur.
- List signs that a chemical reaction has occurred.

Lesson Vocabulary

- chemical reaction
- equilibrium
- product
- reactant

Introduction

No doubt you've seen changes like those pictured in **Figure** 6.1. What do all these changes have in common? They are all chemical changes in matter. In a chemical change, matter changes into a different substance with different properties. Chemical changes occur because of chemical reactions. You can see more examples of chemical changes at this URL: http://www.youtube.com/watch?v=66kuhJkQCVM (2:05).

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What Is a Chemical Reaction?

A **chemical reaction** is a process in which some substances change into different substances. Substances that start a chemical reaction are called **reactants**. Substances that are produced in the reaction are called **products**. Reactants and products can be elements or compounds. A chemical reaction can be represented by this general equation:

$$\text{Reactants} \rightarrow \text{Products}$$

FIGURE 6.1
Each of these pictures shows a chemical change taking place.

The arrow (→) shows the direction in which the reaction occurs. The reaction may occur quickly or slowly. For example, foam shoots out of a fire extinguisher as soon as the lever is pressed. But it might take years for metal to rust.

Breaking and Reforming Chemical Bonds

In chemical reactions, bonds break in the reactants and new bonds form in the products. The reactants and products contain the same atoms, but they are rearranged during the reaction. As a result, the atoms are in different combinations in the products than they were in the reactants.

Look at the example in **Figure** 6.2. It shows how water forms. Bonds break in molecules of hydrogen and oxygen. Then new bonds form in molecules of water. In both reactants and products, there are four hydrogen atoms and two oxygen atoms. But the atoms are combined differently in water. You can see another example at this URL: http://www.avogadro.co.uk/h_and_s/bondenthalpy/bondenthalpy.htm .

Reaction Direction and Equilibrium

The arrow in **Figure** 6.2 shows that the reaction goes from left to right, from hydrogen and oxygen to water. The reaction can also go in the reverse direction. If an electric current passes through water, water molecules break down into molecules of hydrogen and oxygen. This reaction would be represented by a right-to-left arrow (←) in **Figure** 6.2.

Many other reactions can also go in both forward and reverse directions. Often, a point is reached at which the forward and reverse reactions occur at the same rate. When this happens, there is no overall change in the amount of reactants and products. This point is called **equilibrium**, which refers to a balance between any opposing changes. You can see an animation of a chemical reaction reaching equilibrium at this URL: http://www.tutorvista.com/content/chemistry/chemistry-ii/chemical-equilibrium/chemical-equilibrium-animation.php .

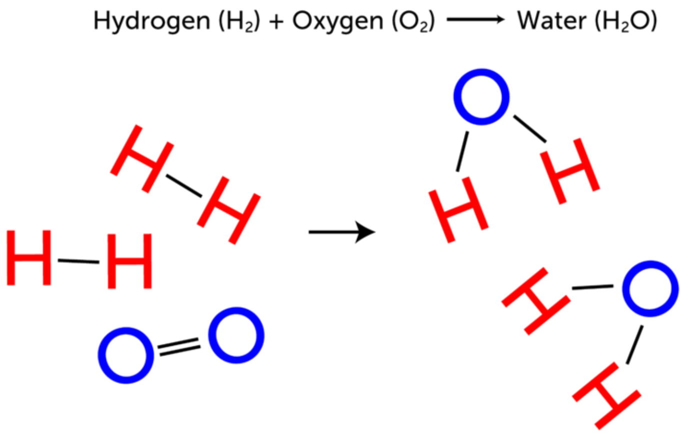


FIGURE 6.2
A chemical reaction changes hydrogen and oxygen to water.

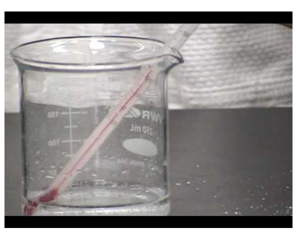
Evidence of Chemical Reactions

Not all changes in matter involve chemical reactions. For example, there are no chemical reactions involved in changes of state. When liquid water freezes or evaporates, it is still water. No bonds are broken and no new products are formed.

How can you tell whether a change in matter involves a chemical reaction? Often, there is evidence. Four common signs that a chemical reaction has occurred are:

- Change in color: the products are a different color than the reactants.
- Change in temperature: heat is released or absorbed during the reaction.
- Production of a gas: gas bubbles are released during the reaction.
- Production of a solid: a solid settles out of a liquid solution. The solid is called a precipitate.

You can see examples of each type of evidence in **Figure** 6.3 and at this URL: http://www.youtube.com/watch?v=gs0j1EZJ1Uc (9:57).



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Lesson Summary

- A chemical reaction is a process in which some substances change into different substances. In a chemical reaction, bonds break in reactants and new bonds form in products.
- Evidence that a chemical reaction has occurred include a change in color, a change in temperature, the production of a gas, or the formation of a precipitate.

FIGURE 6.3
Can you think of other examples of changes like these? If so, they probably indicate that a chemical reaction has occurred.

Lesson Review Questions

Recall

1. Define chemical reaction.
2. What are the reactants and products in a chemical reaction?
3. Describe what happens to the atoms involved in a chemical reaction.
4. List four common signs that a chemical reaction has occurred.

Apply Concepts

5. Tina made a "volcano" by pouring vinegar over a "mountain" of baking soda. The wet baking soda bubbled and foamed. Did a chemical reaction occur? How do you know?

Think Critically

6. Explain the meaning of the term "equilibrium" as it applies to a chemical reaction. How can you tell when a chemical reaction has reached equilibrium?

Points to Consider

In **Figure** 6.2, you saw how hydrogen and oxygen combine chemically to form water.

- How could you use chemical symbols and formulas to represent this reaction?
- How many molecules of hydrogen and oxygen are involved in this reaction? How many molecules of water are produced? How could you include these numbers in your representation of the reaction?

6.2 Chemical Equations

Lesson Objectives

- Describe how to write chemical equations.
- Demonstrate how to balance chemical equations.
- Relate the law of conservation of mass to balancing chemical equations.

Lesson Vocabulary

- chemical equation

Introduction

Chemists use a standard method to represent chemical reactions. It includes chemical symbols and formulas to stand for reactants and products. The symbols and formulas are used to write chemical equations.

Writing Chemical Equations

A **chemical equation** is a symbolic representation of a chemical reaction. It is a shorthand way of showing how atoms are rearranged in the reaction. The general form of a chemical equation was introduced in this chapter's lesson "Introduction to Chemical Reactions." It is:

$$\text{Reactants} \rightarrow \text{Products}$$

Consider the simple example in **Figure** 6.4. When carbon (C) reacts with oxygen (O_2), it produces carbon dioxide (CO_2). The chemical equation for this reaction is:

$$C + O_2 \rightarrow CO_2$$

The reactants are one atom of carbon and one molecule of oxygen. When there is more than one reactant, they are separated by plus signs (+). The product is one molecule of carbon dioxide. If more than one product were produced, plus signs would be used between them as well.

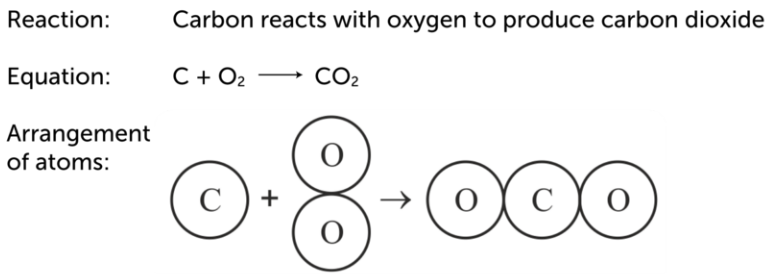


FIGURE 6.4
This figure shows a common chemical reaction. The drawing below the equation shows how the atoms are rearranged in the reaction. What chemical bonds are broken and what new chemical bonds are formed in this reaction?

Balancing Chemical Equations

Some chemical equations are more challenging to write. Consider the reaction in which hydrogen (H_2) and oxygen (O_2) combine to form water (H_2O). Hydrogen and oxygen are the reactants, and water is the product. To write a chemical equation for this reaction, you would start by writing symbols for the reactants and products:

Equation 1: $H_2 + O_2 \rightarrow H_2O$

Like equations in math, equations in chemistry must balance. There must be the same number of each type of atom in the products as there is in the reactants. In equation 1, count the number of hydrogen and oxygen atoms on each side of the arrow. There are two hydrogen atoms in both reactants and products. There are two oxygen atoms in the reactants but only one in the product. Therefore, equation 1 is not balanced.

Using Coefficients

Coefficients are used to balance chemical equations. A coefficient is a number placed in front of a chemical symbol or formula. It shows how many atoms or molecules of the substance are involved in the reaction. For example, two molecules of hydrogen would be written as $2H_2$. A coefficient of 1 usually isn't written.

Coefficients can be used to balance equation 1 (above) as follows:

Equation 2: $2H_2 + O_2 \rightarrow 2H_2O$

Equation 2 shows that two molecules of hydrogen react with one molecule of oxygen to produce two molecules of water. The two molecules of hydrogen each contain two hydrogen atoms. There are now four hydrogen atoms in both reactants and products. Is equation 2 balanced? Count the oxygen atoms to find out.

Steps in Balancing a Chemical Equation

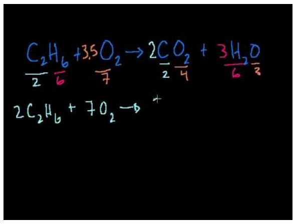
Balancing a chemical equation involves a certain amount of trial and error. In general, however, you should follow these steps:

1. Count the number of each type of atom in reactants and products. Does the same number of each atom appear on both sides of the arrow? If not, the equation is not balanced, and you need to go to step 2.
2. Add coefficients to increase the number of atoms or molecules of reactants or products. Use the smallest coefficients possible.
3. Repeat steps 1 and 2 until the equation is balanced.

Helpful Hint

When you balance chemical equations, never change the subscripts in chemical formulas. Changing subscripts changes the substances involved in the reaction. Change only the coefficients.

Work through the **Problem Solving** examples below. Then do the **You Try It!** problems to check your understanding. If you need more help, go to this URL: http://www.youtube.com/watch?v=RnGu3xO2h74 (14:28).



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Problem Solving

Problem: Balance this chemical equation: $N_2 + H_2 \rightarrow NH_3$

Hints for balancing

1. Two N are needed in the products to match the two N (N_2) in the reactants. Add the coefficient 2 in front of NH_3. Now N is balanced.
2. Six H are now needed in the reactants to match the six H in the products. Add the coefficient 3 in front of H_2. Now H is balanced.

Solution: $N_2 + 3H_2 \rightarrow 2NH_3$

Problem: Balance this chemical equation: $CH_4 + O_2 \rightarrow CO_2 + H_2O$

Solution: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

You Try It!

Problem: Balance these chemical equations:

$$Zn + HCl \rightarrow ZnCl_2 + H_2$$
$$Cu + O_2 \rightarrow CuO$$

Conserving Mass

Why must chemical equations be balanced? It's the law! Matter cannot be created or destroyed in chemical reactions. This is the law of conservation of mass. In every chemical reaction, the same mass of matter must end up in the products as started in the reactants. Balanced chemical equations show that mass is conserved in chemical reactions.

How do scientists know that mass is always conserved in chemical reactions? Careful experiments in the 1700s by a French chemist named Antoine Lavoisier led to this conclusion. For this and other contributions, Lavoisier has been called the father of modern chemistry.

Lavoisier carefully measured the mass of reactants and products in many different chemical reactions. He carried out the reactions inside a sealed jar, like the one in **Figure** 6.5. As a result, any gases involved in the reactions were captured and could be measured. In every case, the total mass of the jar and its contents was the same after the reaction as it was before the reaction took place. This showed that matter was neither created nor destroyed in the reactions. Another outcome of Lavoisier's research was his discovery of oxygen. You can learn more about Lavoisier and his important research at: http://www.youtube.com/watch?v=x9iZq3ZxbO8

FIGURE 6.5
Lavoisier carried out several experiments inside a sealed glass jar. Why was sealing the jar important for his results?

Lesson Summary

- A chemical equation is a symbolic representation of a chemical reaction. It shows how atoms are rearranged in the reaction.
- Equations in chemistry must balance. There must be the same number of each type of atom in the products as there is in the reactants. Coefficients are used to balance chemical equations. They show how many atoms or molecules of a substance are involved in a reaction.
- Chemical equations must be balanced because matter cannot be created or destroyed. This is the law of conservation of mass. Experiments by Antoine Lavoisier led to this law.

Lesson Review Questions

Recall

1. What is a chemical equation? Give an example.
2. What is a coefficient? How are coefficients used in chemistry?
3. Describe how Antoine Lavoisier showed matter is conserved in chemical reactions.

Apply Concepts

4. Draw a sketch that shows how atoms are rearranged in the chemical reaction represented by equation 2.
5. Balance this chemical equation: $Hg + O_2 \rightarrow HgO$.

Think Critically

6. Explain why it is necessary to balance chemical equations.

Points to Consider

In this lesson, you saw examples of chemical reactions in which two reactants combine to yield a single product. This is called a synthesis reaction. It is just one type of chemical reaction.

- What might be other types of chemical reactions?
- How might one reactant produce more than one product?

6.3 Types of Chemical Reactions

Lesson Objectives

- Explain how synthesis reactions occur.
- Describe how decomposition reactions occur.
- Describe single and double replacement reactions.
- Explain how combustion reactions occur.

Lesson Vocabulary

- combustion reaction
- decomposition reaction
- replacement reaction
- synthesis reaction

Introduction

Most of the chemical reactions you have seen so far in this chapter are synthesis reactions. In this type of reaction, two or more reactants combine to synthesize a product. There are several other types of chemical reactions, including decomposition, replacement, and combustion reactions. You will read about all four types of reactions in this lesson. **Table** 6.1 summarizes the four types of chemical reactions you will read about in the rest of the lesson. You can see demonstrations of each type at this URL: http://www.youtube.com/watch?v=nVysOW0Lb8U .

TABLE 6.1: Four Types of Chemical Reactions

Type of Reaction	General Equation	Example
Synthesis	$A+B \rightarrow C$	$2Na+Cl_2 \rightarrow 2NaCl$
Decomposition	$AB \rightarrow A+B$	$2H_2O \rightarrow 2H_2+O_2$
Replacement	$A+BC \rightarrow B+AC$	$2K+2H_2O \rightarrow 2KOH+H_2$
Single	$AB+CD \rightarrow AD+CB$	$NaCl+AgF \rightarrow NaF+AgCl$
Double		
Combustion	fuel + oxygen $\rightarrow$ carbon dioxide + water	$CH_4+2O_2 \rightarrow CO_2+2H_2O$

Synthesis Reactions

A **synthesis reaction** occurs when two or more reactants combine to form a single product. A synthesis reaction can be represented by the general equation:

$$A + B \rightarrow C$$

In this general equation (and others like it in this lesson), the letters A, B, C, and so on represent atoms or ions of elements. The arrow shows the direction of the reaction. The letters on the left side of the arrow are the reactants that begin the chemical reaction. The letters on the right side of the arrow are the product of the reaction. Two examples of synthesis reactions are described below. You can see more examples at this URL: http://www.youtube.com/watch?v=dxlWtsFinTM .

Synthesis Example 1

An example of a synthesis reaction is the combination of sodium (Na) and chlorine (Cl) to produce sodium chloride (NaCl). This reaction is represented by the chemical equation:

$$2Na + Cl_2 \rightarrow 2NaCl$$

Sodium is a highly reactive metal, and chlorine is a poisonous gas (see **Figure** 6.6). The compound they synthesize has very different properties. It is table salt, which is neither reactive nor poisonous. In fact, salt is a necessary component of the human diet.

FIGURE 6.6
Sodium and chlorine combine to synthesize table salt.

Synthesis Example 2

Another example of a synthesis reaction is illustrated in **Figure** 6.7. The brown haze in the air over the city of Los Angeles is smog. A major component of smog is nitrogen dioxide (NO_2). It forms when nitric oxide (NO), from sources such as car exhaust, combines with oxygen (O_2) in the air. The equation for this reaction is:

$$2NO + O_2 \rightarrow 2NO_2$$

Nitrogen dioxide is a toxic gas with a sharp odor. It can irritate the eyes and throat and trigger asthma attacks. It is a major air pollutant.

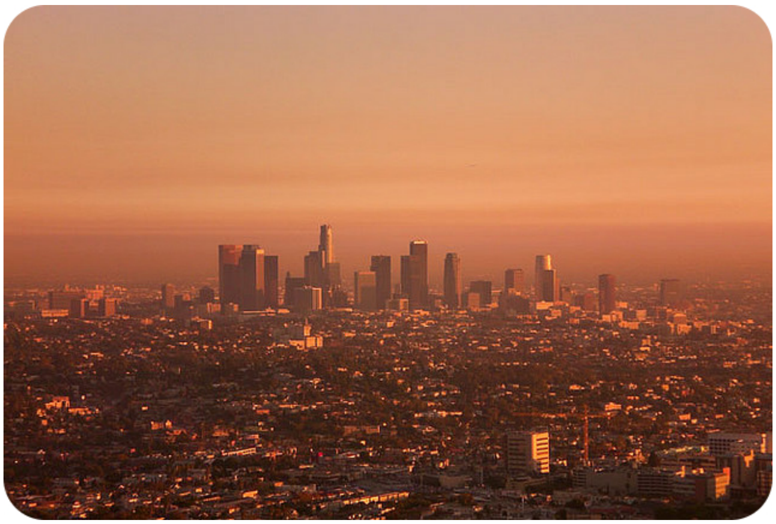

FIGURE 6.7
In this photo, the air over Los Angeles, California is brown with smog.

Decomposition Reactions

A decomposition reaction is the reverse of a synthesis reaction. In a **decomposition reaction**, one reactant breaks down into two or more products. This can be represented by the general equation:

$$AB \rightarrow A + B$$

Two examples of decomposition reactions are described below. You can see other examples at this URL: http://www.youtube.com/watch?v=dxlWtsFinTM .

Decomposition Example 1

An example of a decomposition reaction is the breakdown of carbonic acid (H_2CO_3) to produce water (H_2O) and carbon dioxide (CO_2). The equation for this reaction is:

$$H_2CO_3 \rightarrow H_2O + CO_2$$

Carbonic acid is synthesized in the reverse reaction. It forms when carbon dioxide dissolves in water. For example, some of the carbon dioxide in the atmosphere dissolves in the ocean and forms carbonic acid. The amount of carbon dioxide in the atmosphere has increased over recent decades (see **Figure** 6.8). As a result, the acidity of ocean water is also increasing. How do you think this might affect ocean life?

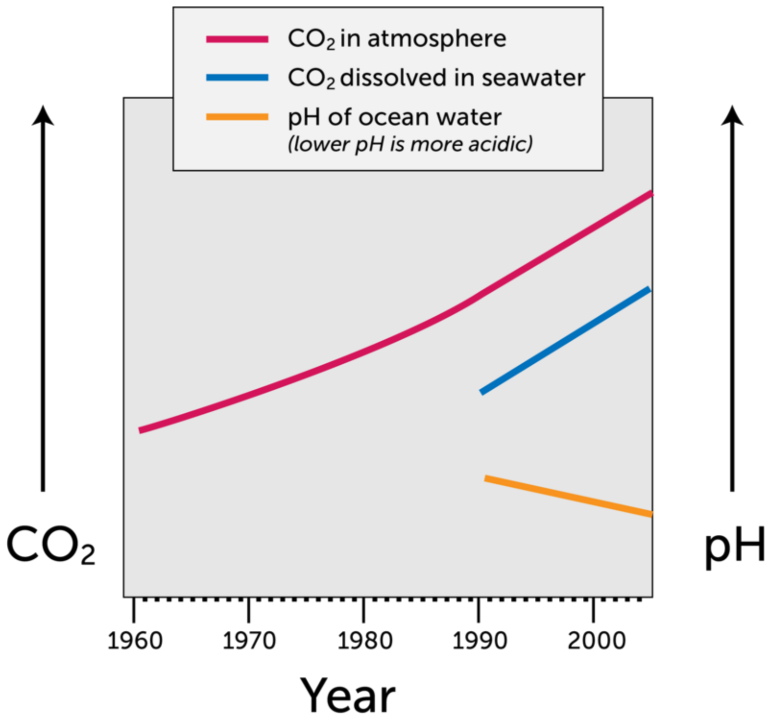

FIGURE 6.8
As carbon dioxide increases in the atmosphere, more carbon dioxide dissolves in ocean water.

Decomposition Example 2

Another example of a decomposition reaction is illustrated in **Figure** 6.9. Water (H_2O) decomposes to hydrogen (H_2) and oxygen (O_2) when an electric current passes through it. This reaction is represented by the equation:

$$2H_2O \rightarrow 2H_2 + O_2$$

What is the reverse of this decomposition reaction? (*Hint*: How is water synthesized? You can look at this chapter's "Introduction to Chemical Reactions" lesson to find out.)

Replacement Reactions

Replacement reactions involve ions. They occur when ions switch places in compounds. There are two types of replacement reactions: single and double. Both types are described below.

Single Replacement Reactions

A single replacement reaction occurs when one ion takes the place of another in a single compound. This type of reaction has the general equation:

$$A + BC \rightarrow B + AC$$

Do you see how *A* has replaced *B* in the compound? The compound *BC* has become the compound *AC*.

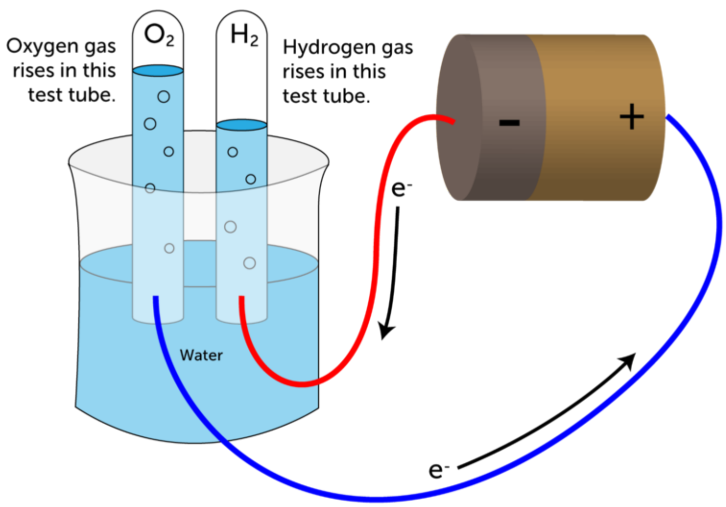

FIGURE 6.9
A decomposition reaction occurs when an electric current passes through water.

An example of a single replacement reaction occurs when potassium (K) reacts with water (H_2O). A colorless solid called potassium hydroxide (KOH) forms, and hydrogen gas (H_2) is released. The equation for the reaction is:

$$2K + 2H_2O \rightarrow 2KOH + H_2$$

Potassium is a highly reactive group 1 alkali metal, so its reaction with water is explosive. You can actually watch this reaction occurring at: http://commons.wikimedia.org/wiki/File:Potassium_water_20.theora.ogv .

Double Replacement Reactions

A double replacement reaction occurs when two compounds exchange ions. This produces two new compounds. A double replacement reaction can be represented by the general equation:

$$AB + CD \rightarrow AD + CB$$

Do you see how *B* and *D* have changed places? Both reactant compounds have changed.

An example of a double replacement reaction is sodium chloride (NaCl) reacting with silver fluoride (AgF). This reaction is represented by the equation:

$$NaCl + AgF \rightarrow NaF + AgCl$$

Cl and F have changed places. Can you name the products of this reaction?

Combustion Reactions

A **combustion reaction** occurs when a substance reacts quickly with oxygen (O_2). You can see an example of a combustion reaction in **Figure** 6.10. Combustion is commonly called burning. The substance that burns is usually referred to as fuel. The products of a combustion reaction include carbon dioxide (CO_2) and water (H_2O). The reaction typically gives off heat and light as well. The general equation for a combustion reaction can be represented by:

$$\text{Fuel} + O_2 \rightarrow CO_2 + H_2O$$

FIGURE 6.10
The burning of charcoal is an example of a combustion reaction.

Combustion Example 1

The fuel that burns in a combustion reaction is often a substance called a hydrocarbon. A hydrocarbon is a compound that contains only carbon (C) and hydrogen (H). Fossil fuels, such as natural gas, consist of hydrocarbons. Natural gas is a fuel that is commonly used in home furnaces and gas stoves (see **Figure** 6.11). The main component of natural gas is the hydrocarbon called methane (CH_4). The combustion of methane is represented by the equation:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Combustion Example 2

Your own body cells burn fuel in combustion reactions. The fuel is glucose ($C_6H_{12}O_6$), a simple sugar. The process in which combustion of glucose occurs in body cells is called cellular respiration. This combustion reaction provides energy for life processes. Cellular respiration can be summed up by the equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Where does glucose come from? It is produced by plants during photosynthesis. In this process, carbon dioxide and water combine to form glucose. Which type of chemical reaction is photosynthesis?

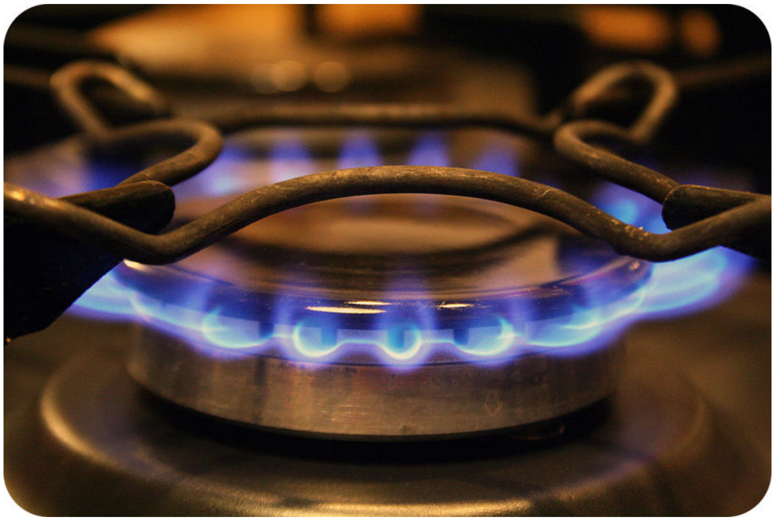

FIGURE 6.11
The blue flame on this gas stove is produced when natural gas burns.

Lesson Summary

- A synthesis reaction occurs when two or more reactants combine to form a single product.
- In a decomposition reaction, one reactant breaks down into two or more products. This is the reverse of a synthesis reaction.
- Replacement reactions occur when elements switch places in compounds. In a single replacement reaction, one element takes the place of another in a single compound. In a double replacement reaction, two compounds exchange elements.
- A combustion reaction occurs when a substance reacts quickly with oxygen. Combustion is commonly called burning. Carbon dioxide, water, and heat and light are products of combustion.

Lesson Review Questions

Recall

1. Write an equation for the chemical reaction in which hydrogen reacts with oxygen to form water. What type of reaction is this?
2. Write an equation for the reverse of the reaction in question 1. What type of reaction is this?
3. Name the type of reaction represented by this general equation: $AB + CD \rightarrow AD + CB$
4. In the general equation in question 3, what do the individual letters represent?
5. What are the reactants and products in a combustion reaction?

Apply Concepts

6. Apply lesson concepts to classify the following chemical reactions:

   a. $\mathrm{Zn + 2HCl \rightarrow H_2 + ZnCl_2}$
   b. $\mathrm{2KClO_3 \rightarrow 2KCl + 3O_2}$
   c. $\mathrm{2KI + Cl_2 \rightarrow 2KCl + I_2}$

d. $AgNO_3 + KCl \rightarrow AgCl + KNO_3$

Think Critically

7. Compare and contrast the four types of reactions described in this lesson. Include an example of each type of reaction.

Points to Consider

Combustion reactions release energy. Some other types of reactions absorb energy. They need a continuous supply of energy to occur.

- Can you think of any chemical changes that might absorb energy?
- What might be different about reactions that need energy to keep going?

6.4 Chemical Reactions and Energy

Lesson Objectives

- Describe endothermic reactions.
- Describe exothermic reactions.
- Relate the law of conservation of energy to chemical reactions.
- Define activation energy.
- Identify factors that affect the rates of chemical reactions.

Lesson Vocabulary

- activation energy
- catalyst
- concentration
- endothermic reaction
- exothermic reaction
- law of conservation of energy
- reaction rate

Introduction

All chemical reactions involve energy. Energy is needed to break bonds in reactants. These bonds may be very strong. Energy is released when new bonds form in the products. That's because the atoms now have a more stable arrangement of electrons. Which energy is greater: that needed for breaking bonds in reactants or that released by bonds forming in products? It depends on the type of reaction. When it comes to energy, chemical reactions may be endothermic or exothermic.

Endothermic Reactions

In an **endothermic reaction**, it takes more energy to break bonds in the reactants than is released when new bonds form in the products. The word "endothermic" literally means "taking in heat." A constant input of energy, often in the form of heat, is needed in an endothermic reaction. Not enough energy is released when products form to break more bonds in the reactants. Additional energy is needed to keep the reaction going. The general equation for an endothermic reaction is:

$$\text{Reactants} + \text{Energy} \rightarrow \text{Products}$$

In many endothermic reactions, heat is absorbed from the surroundings. As a result, the temperature drops. The drop in temperature may be great enough to cause liquid products to freeze. That's what happens in the endothermic reaction at this URL: http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa/chemreac/energychangesrev1.shtml .

One of the most important endothermic reactions is photosynthesis. In this reaction, plants synthesize glucose ($C_6H_{12}O_6$) from carbon dioxide (CO_2) and water (H_2O). They also release oxygen (O_2). The energy for photosynthesis comes from light (see **Figure** 6.12). Without light energy, photosynthesis cannot occur. The chemical equation for photosynthesis is:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

FIGURE 6.12
Plants can get the energy they need for photosynthesis from either sunlight or artificial light.

Exothermic Reactions

In an **exothermic reaction**, it takes less energy to break bonds in the reactants than is released when new bonds form in the products. The word "exothermic" literally means "turning out heat." Energy, often in the form of heat, is released as an exothermic reaction occurs. The general equation for an exothermic reaction is:

$$\text{Reactants} \rightarrow \text{Products} + \text{Energy}$$

If the energy is released as heat, an exothermic reaction results in a rise in temperature. That's what happens in the exothermic reaction at the URL below.

http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa/chemreac/energychangesrev1.shtml

Combustion reactions are examples of exothermic reactions. When substances burn, they usually give off energy as heat and light. Look at the big bonfire in **Figure** 6.13. You can see the light energy it is giving off. If you were standing near the fire, you would also feel its heat.

Conservation of Energy

Whether a reaction absorbs energy or releases energy, there is no overall change in the amount of energy. Energy cannot be created or destroyed. This is the **law of conservation of energy**. Energy can change form —for example, from electricity to light —but the same amount of energy always remains.

FIGURE 6.13
The combustion of wood is an exothermic reaction that releases energy as heat and light.

If energy cannot be destroyed, what happens to the energy that is absorbed in an endothermic reaction? The energy is stored in the chemical bonds of the products. This form of energy is called chemical energy. In an endothermic reaction, the products have more stored chemical energy than the reactants. In an exothermic reaction, the opposite is true. The products have less stored chemical energy than the reactants. The excess energy in the reactants is released to the surroundings when the reaction occurs. The graphs in **Figure** 6.14 show the chemical energy of reactants and products in each type of reaction.

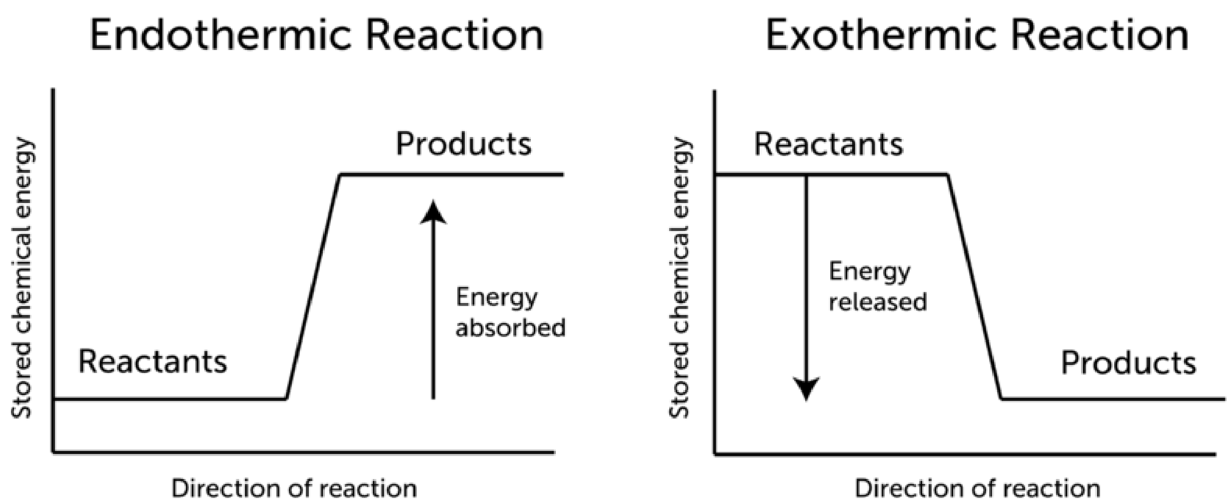

FIGURE 6.14
These graphs compare the energy changes in endothermic and exothermic reactions. What happens to the energy that is absorbed in an endothermic reaction?

Activation Energy

All chemical reactions, even exothermic reactions, need a certain amount of energy to get started. This energy is called **activation energy**. For example, activation energy is needed to start a car. Turning the key causes a spark that activates the burning of gasoline in the engine. The combustion of gas won't occur without the spark of energy to begin the reaction.

Why is activation energy needed? A reaction won't occur unless atoms or molecules of reactants come together.

This happens only if the particles are moving, and movement takes energy. Often, reactants have to overcome forces that push them apart. This takes energy as well. Still more energy is needed to start breaking bonds in reactants. The graphs in **Figure** 6.15 show the changes in energy in endothermic and exothermic reactions. Both reactions need the same amount of activation energy in order to begin.

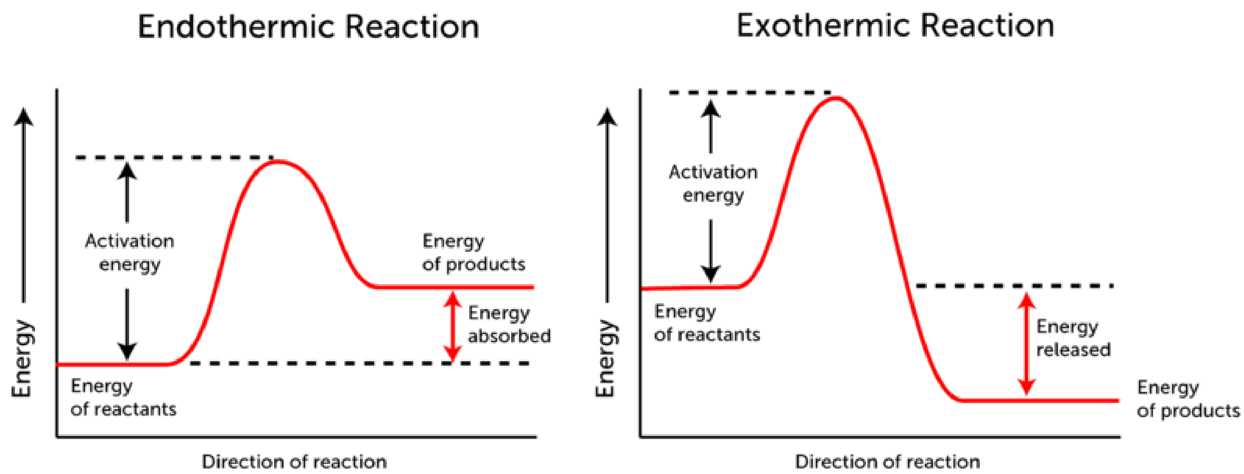

FIGURE 6.15

Even exothermic reactions need activation energy to get started.

You have probably used activation energy to start a chemical reaction. For example, if you've ever used a match to light a campfire, then you provided the activation energy needed to start a combustion reaction. Combustion is exothermic. Once a fire starts to burn, it releases enough energy to activate the next reaction, and the next, and so on. However, wood will not burst into flames on its own.

Reaction Rate

Any factor that helps reactants come together so they can react lowers the amount of activation energy needed to start the reaction. If the activation energy is lowered, more reactant particles can react, and the reaction occurs more quickly. How fast a reaction occurs is called the **reaction rate**. Factors that affect the reaction rate include:

- temperature of reactants
- concentration of reactants
- surface area of reactants
- presence of catalysts

Temperature of Reactants

When the temperature of reactants is higher, the rate of the reaction is faster. At higher temperatures, particles of reactants have more energy, so they move faster. They are more likely to bump into one another and to collide with greater force. For example, when you fry an egg, turning up the heat causes the egg to cook faster. The same principle explains why storing food in a cold refrigerator reduces the rate at which food spoils (see **Figure** 6.16). Both food frying and food spoiling are chemical reactions that happen faster at higher temperatures.

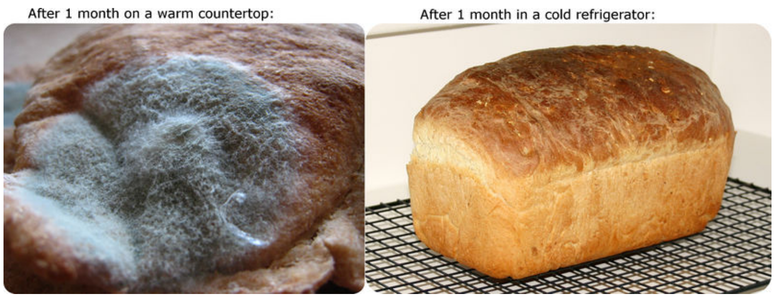

FIGURE 6.16
The chemical reactions that spoil food occur faster at higher temperatures.

Concentration of Reactants

Concentration is the number of particles of a substance in a given volume. When the concentration of reactants is higher, the reaction rate is faster. At higher concentrations, particles of reactants are crowded closer together, so they are more likely to collide and react. Did you ever see a sign like the one in **Figure** 6.17? You might see it where someone is using a tank of pure oxygen for a breathing problem. The greater concentration of oxygen in the air makes combustion rapid if a fire starts burning.

FIGURE 6.17
It's dangerous to smoke or use open flames when oxygen is in use. Can you explain why?

Surface Area of Reactants

When a solid substance is involved in a chemical reaction, only the matter at the surface of the solid is exposed to other reactants. If a solid has more surface area, more of it is exposed and able to react. Therefore, increasing the surface area of solid reactants increases the reaction rate. For example, crushing a solid into a powder exposes more of the substance to other reactants. This may greatly speed up the reaction. You can see another example in **Figure** 6.18. Iron rusts when it combines with oxygen in the air. The iron hammer head and iron nails will both rust eventually. Which will rust faster?

FIGURE 6.18
The nails have more surface area exposed to the air than the head of the hammer. How does this affect the rate at which they rust?

Presence of a Catalyst

Some reactions need extra help to occur quickly. They need another substance, called a catalyst. A **catalyst** is a substance that increases the rate of a chemical reaction but is not changed or used up in the reaction. The catalyst can go on to catalyze many more reactions.

Catalysts are not reactants, but they help reactants come together so they can react. You can see one way this happens in the animation at the URL below. By helping reactants come together, a catalyst decreases the activation energy needed to start a chemical reaction. This speeds up the reaction.

http://www.saskschools.ca/curr_content/chem30/modules/module4/lesson5/explainingcatalysts.htm

Living things depend on catalysts to speed up many chemical reactions inside their cells. Catalysts in living things are called enzymes. Enzymes may be extremely effective. A reaction that takes a split second to occur with an enzyme might take billions of years without it!

Lesson Summary

- In an endothermic reaction, it takes more energy to beak bonds in the reactants than is released when new bonds form in the products. Therefore, an endothermic reaction needs a constant input of energy to keep going.
- In an exothermic reaction, it takes less energy to break bonds in the reactants than is released when new bonds form in the products. Therefore, an exothermic reaction releases enough energy to keep going.
- In any chemical reaction, there is no overall change in the amount of energy. Energy cannot be created or destroyed. This is the law of conservation of energy.
- All chemical reactions, even exothermic reactions, need activation energy to get started. Activation energy is needed to bring reactants together so they can react.
- How fast a reaction occurs is called the reaction rate. Factors that affect the reaction rate include catalysts and the temperature, concentration, and surface area of reactants. A catalyst is a substance that increases the rate of a chemical reaction but is not changed or used up in the reaction.

Lesson Review Questions

Recall

1. What form of energy is needed for the endothermic reaction called photosynthesis?
2. What evidence shows that combustion reactions are exothermic?

3. What happens to the energy that is absorbed in an endothermic reaction?
4. In an exothermic reaction, which has more stored chemical energy: the reactants or the products?
5. Define activation energy.
6. List four factors that affect the rates of chemical reactions.

Apply Concepts

7. Suppose you put a whole antacid tablet in one glass of water and a crushed antacid tablet in another glass containing the same amount of water. Both tablets would start reacting and producing bubbles of gas. Use lesson concepts to predict which tablet would stop producing bubbles first. Explain your prediction. Then, with the permission of an adult, do the activity. Do your results agree with your prediction?
8. Sketch a simple graph to show how energy changes in an exothermic reaction. Include activation energy in your graph.

Think Critically

9. Compare and contrast endothermic and exothermic chemical reactions.

Points to Consider

You read in this chapter that most fuels contain carbon. In the next chapter, "Chemistry of Carbon," you will learn much more about carbon.

- What do you already know about carbon?
- Based on carbon's position in the periodic table, predict how it reacts and the type of bonds it forms.

6.5 References

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11. Flickr:sunshinecity. http://www.flickr.com/photos/sunshinecity/5437195934/ . CC BY 2.0
12. Sunflower: Greg O'Beirne (Wikimedia: Gobeirne); Plants under light: Josh Kelahan. Sunflower: http://commons.wikimedia.org/wiki/File:SunflowerMountLawley2_gobeirne.jpg; Plants under light: http://www.flickr.com/photos/jdkc4d . Sunflower: CC BY 2.5; Plants under light: CC BY 2.0
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18. Left: Flickr:thefixer; Right: Flickr:internets_dairy. Left: http://www.flickr.com/photos/fixersphotos/3199566032/; Right: http://www.flickr.com/photos/16339684@N00/3625223334/ . CC BY 2.0

CHAPTER 7 Chemistry of Carbon

Chapter Outline

The puffy white fibers on this plant look like cotton balls. In fact, that's just what they are! The plant is a cotton plant, and the white fibers enclose the seeds of the plant. The fibers are used to make cotton fabrics, so if you have a cotton T-shirt, this is where the fabric came from. Cotton fibers —and most other plant fibers —consist of one of the most common compounds on Earth, the compound named cellulose.

Cellulose is a compound found in plants. The chief component of cellulose is carbon. Cellulose is one of many carbon-based compounds that make up living things. In fact, carbon-based compounds are the most common type of compound on Earth. More than 90 percent of all known compounds contain carbon. Do you know why carbon is found in so many compounds? Read on to find out.

7.1 Properties of Carbon

Lesson Objectives

- Explain how carbon forms bonds.
- Define monomer and polymer.
- Describe forms of carbon.

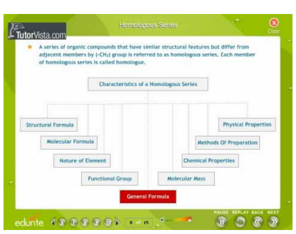
Lesson Vocabulary

- monomer
- polymer

Introduction

Carbon is a very common "ingredient" of matter. The reason? Carbon can combine with itself and with many other elements to form a great diversity of compounds. The compounds can also range in size from just a few atoms to thousands. There are millions of known carbon compounds. Carbon is the only element that can form so many different compounds. You can find a good introduction to carbon and its chemistry at these URLs:

- http://www.youtube.com/watch?v=HJnlNpMStbs
- http://www.youtube.com/watch?v=Kjn5Ht0Vn30 (9:27)



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URL: http://www.ck12.org/flx/render/embeddedobject/5088

Valence Electrons and Bonding in Carbon

Carbon is a nonmetal in group 14 of the periodic table. Like other group 14 compounds, carbon has four valence electrons. Valence electrons are the electrons in the outer energy level of an atom that are involved in chemical bonds. The valence electrons of carbon are shown in **Figure** 7.1.

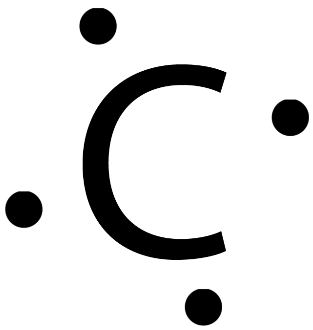

FIGURE 7.1
The dots in this diagram represent the four valence electrons of carbon.

Carbon Bonding

Because it has four valence electrons, carbon needs four more electrons to fill its outer energy level. It can achieve this by forming four covalent bonds. Covalent bonds are chemical bonds that form between nonmetals. In a covalent bond, two atoms share a pair of electrons. By forming four covalent bonds, carbon shares four pairs of electrons, thus filling its outer energy level.

A carbon atom can form bonds with other carbon atoms or with the atoms of other elements. Carbon often forms bonds with hydrogen. You can see an example in **Figure** 7.2. The compound represented in the figure is methane (CH_4). The carbon atom in a methane molecule forms bonds with four hydrogen atoms. The diagram on the left shows all the shared electrons. The diagram on the right represents each pair of shared electrons with a dash (–). This type of diagram is called a structural formula.

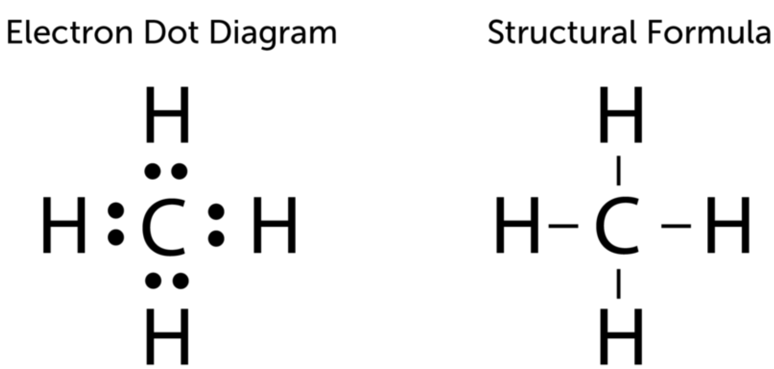

FIGURE 7.2
Methane is one of the simplest carbon compounds. At room temperature, it exists as a gas. It is a component of natural gas. These diagrams show two ways of representing the covalent bonds in methane.

How Many Bonds?

Carbon can form single, double, or even triple bonds with other carbon atoms. In a single bond, two carbon atoms share one pair of electrons. In a double bond, they share two pairs of electrons, and in a triple bond they share three pairs of electrons. Examples of compounds with these types of bonds are shown in **Figure** 7.3.

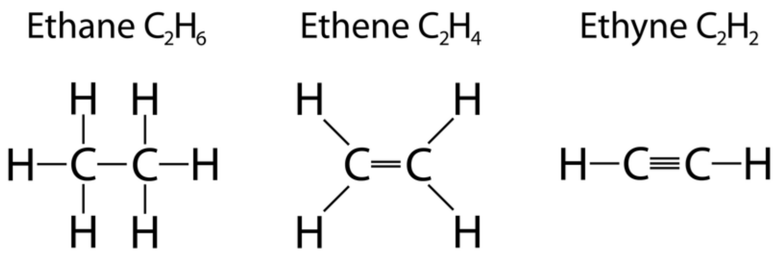

FIGURE 7.3
Carbon atoms can form single, double, or triple bonds with each other. How many bonds do the carbon atoms share in each compound shown here?

Monomers and Polymers of Carbon

Because of carbon's ability to form so many covalent bonds, it often forms polymers. A **polymer** is a large molecule that consists of many smaller molecules joined together by covalent bonds. The smaller molecules are called **monomers**. (The prefix *mono* means "one," and the prefix *poly* means "many.") Polymers may consist of just one type of monomer or of more than one type. Polymers are a little like the strings of beads in **Figure** 7.4. What do the individual beads represent?

FIGURE 7.4
A string of beads serves as a simple model of a polymer. Like monomers making up a polymer, the beads in a string may be all the same or different from one another.

Many polymers occur naturally. You will read about natural polymers in this chapter's "Hydrocarbons" and "Carbon and Living Things" lessons. Other polymers are synthetic. This means that they are produced in labs or factories. Synthetic polymers are created in synthesis reactions in which monomers bond together to form much larger compounds. Plastics are examples of synthetic polymers. The plastic items in **Figure** 7.5 are all made of polythene (also called polyethylene). It consists of repeating monomers of ethene (C_2H_4). To learn more about polymers and how they form, go to this URL: http://www.youtube.com/watch?v=7nCfbZwGWK8 (2:13).

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URL: http://www.ck12.org/flx/render/embeddedobject/5089

FIGURE 7.5

Many common products are made of the plastic known as polyethylene.

KQED: Properties of Plastic

Exploratorium Staff Scientist Julie Yu changes and manipulates the physical and chemical properties of plastic bottles by exposing them to heat. This is how plastic bags and bottles can be recycled and used over and over again. For more information on properties of plastic, see http://science.kqed.org/quest/video/quest-lab-properties-of-plastic/ .

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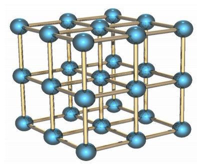
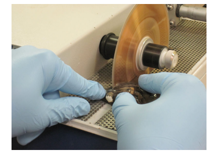
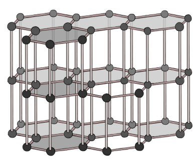
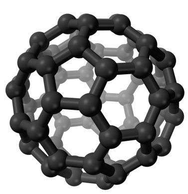
Forms of Carbon

Pure carbon can exist in different forms, depending on how its atoms are arranged. The forms include diamond, graphite, and fullerenes. All three forms exist as crystals, but they have different structures. Their different structures, in turn, give them different properties. You can learn more about them in **Table** 7.1.

TABLE 7.1: Carbon atoms can be arranged in any of these three ways. How does the arrangement of atoms affect the properties of the substances formed?

Structure	Description	
 Diamond crystal	**Diamond** Diamond is a form of carbon in which each carbon atom is bonded to four other carbon atoms. This forms a strong, rigid, three-dimensional structure. Diamond is the hardest natural substance. It is used for cutting and grinding tools as well as for rings and other pieces of jewelry.	 This metal cutter has a diamond blade.
	**Graphite** Graphite is a form of carbon in which carbon atoms are arranged in layers. Bonds are strong between carbon atoms within each layer but relatively weak between atoms in different layers. The weak bonds between layers allow the layers to slide over one another. This makes graphite relatively soft and slippery. It is used as a lubricant. It also makes up the "lead" in pencils.	
	**Fullerene** A fullerene (also called a bucky-ball) is a form of carbon in which carbon atoms are arranged in hollow spheres. Each carbon atom is bonded to three others by single covalent bonds. The pattern of atoms resembles the pattern on the surface of a soccer ball. Fullerenes were first discovered in 1985. They have been found in soot and meteorites. Possible commercial uses of fullerenes are under investigation. To learn how this form of carbon got its funny names, go to this URL: http://www.universetoday.com/83106/fullerene/ .	

Lesson Summary

- Carbon is a nonmetal with four valence electrons. Each carbon atom forms four covalent bonds. Atoms of carbon can bond with each other or with atoms of other elements. The bonds may be single, double, or triple bonds.
- Because of carbon's ability to form so many covalent bonds, it often forms polymers. A polymer is a large molecule that consists of many smaller molecules, called monomers.
- Pure carbon can form different types of crystals. Crystalline forms of carbon include diamond, graphite, and fullerenes.

Lesson Review Questions

Recall

1. Describe the type of bonds that carbon forms.
2. How many bonds does a single carbon atom form?
3. What are polymers and monomers?
4. Name three forms of pure carbon. How do they differ?

Apply Concepts

5. A certain compound consists of two carbon atoms and two hydrogen atoms. Each carbon atom is bonded with one hydrogen atom and also with the other carbon atom. How many bonds do the two carbon atoms share? Draw the structural formula for this compound.

Think Critically

6. Explain why carbon is a component of most compounds.
7. Relate the properties of graphite and diamond to the arrangement of their atoms.

Points to Consider

The carbon compounds represented in **Figure** 7.2 and **Figure** 7.3 contain only carbon and hydrogen. You will read more about this type of carbon compound in the next lesson, "Hydrocarbons."

- What might be some general properties of compounds that consist only of carbon and hydrogen? (*Hint*: What is methane used for?)
- Do you know other examples of this type of compound?

7.2 Hydrocarbons

Lesson Objectives

- Define hydrocarbon.
- Describe and give examples of saturated hydrocarbons.
- Describe and give examples of unsaturated hydrocarbons.
- Identify uses and sources of hydrocarbons.

Lesson Vocabulary

- alkane
- alkene
- alkyne
- aromatic hydrocarbon
- hydrocarbon
- isomer
- saturated hydrocarbon
- unsaturated hydrocarbon

Introduction

Look at the pictures in **Figure** 7.6. Each one shows an item that you might have used or seen used by someone else. All of the items have something in common. Can you guess what it is? They all depend on carbon compounds known as hydrocarbons.

What Are Hydrocarbons?

Hydrocarbons are compounds that contain only carbon and hydrogen. Hydrocarbons are the simplest type of carbon-based compounds. Nonetheless, they can vary greatly in size. The smallest hydrocarbons have just one or two carbon atoms, but large hydrocarbons may have hundreds. The size of hydrocarbon molecules influences their properties. For example, it influences their boiling and melting points. As a result, some hydrocarbons are gases at room temperature, while others are liquids or solids. Hydrocarbons are generally nonpolar and do not dissolve in water. In fact, they tend to repel water. That's why they are used in floor wax and similar products.

Hydrocarbons can be classified in two basic classes. The classes are saturated hydrocarbons and unsaturated hydrocarbons. This classification is based on the number of bonds between carbon atoms. You can learn more about both types of hydrocarbons at this URL: http://www.youtube.com/watch?v=l9ZieYdLwfo (6:41).

A canister of the hydrocarbon named propane provides fuel or this camp stove.

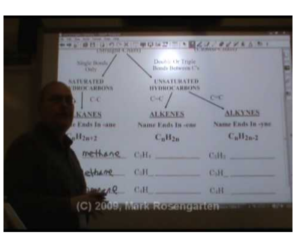
This lawn mower runs on a mixture of hydrocarbons commonly named gasoline.

The main ingredient in nail polish remover is a hydrocarbon named acetone. Acetone is also found in paint thinner.

The strongly scented vapor given off by mothballs repels insects. The main ingredient of mothballs is a hydrocarbon named naphthalene.

FIGURE 7.6

Each of these pictures shows a use of hydrocarbons.



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Saturated Hydrocarbons

Saturated hydrocarbons contain only single bonds between carbon atoms. They are the simplest hydrocarbons. They are called saturated because each carbon atom is bonded to as many hydrogen atoms as possible. In other words, the carbon atoms are saturated with hydrogen. You can see an example of a saturated hydrocarbon in **Figure** 7.7. Each carbon atom is bonded to three hydrogen atoms in this compound, which is named ethane.

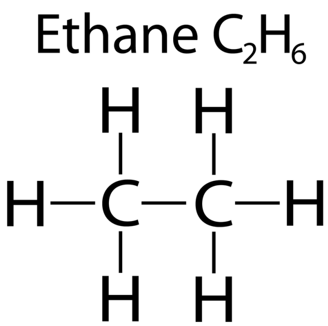


FIGURE 7.7
Ethane is a saturated hydrocarbon. What is its chemical formula?

Saturated hydrocarbons are given the general name of **alkanes**. The name of specific alkanes always ends in *-ane*. The first part of the name indicates how many carbon atoms each molecule of the alkane has. The smallest alkane is methane. It has just one carbon atom. The next largest is ethane, with two carbon atoms. The chemical formulas and properties of methane, ethane, and several other alkanes are listed in **Table** 7.2. The boiling and melting points of alkanes are determined mainly by the number of carbon atoms they have. Alkanes with more carbon atoms generally have higher boiling and melting points.

This table shows only alkanes with relatively few carbon atoms. Some alkanes have many more carbon atoms. What properties might larger alkanes have? For example, do you think that any of them might be solids?

TABLE 7.2: Small Alkanes

Alkane	Chemical Formula	Boiling Point (°C)	Melting Point (°C)	State (at 20°C)
Methane	CH_4	-162	-183	gas
Ethane	C_2H_6	-89	-172	gas
Propane	C_3H_8	-42	-188	gas
Butane	C_4H_{10}	0	-138	gas
Pentane	C_5H_{12}	36	-130	liquid
Hexane	C_6H_{14}	69	-95	liquid
Heptane	C_7H_{16}	98	-91	liquid
Octane	C_8H_{18}	126	-57	liquid

Shapes of Alkanes

Structural formulas are often used to represent hydrocarbon compounds because the molecules can have different shapes, or structures. Hydrocarbons may form straight chains, branched chains, or rings. **Figure** 7.8 shows an example of an alkane with each shape.

- In straight-chain molecules, all the carbon atoms are lined up in a row like cars of a train. They form what is called the backbone of the molecule.

- In branched-chain molecules, at least one of the carbon atoms branches off to the side from the backbone.
- In cyclic molecules, the chain of carbon atoms is joined at the two ends to form a ring.

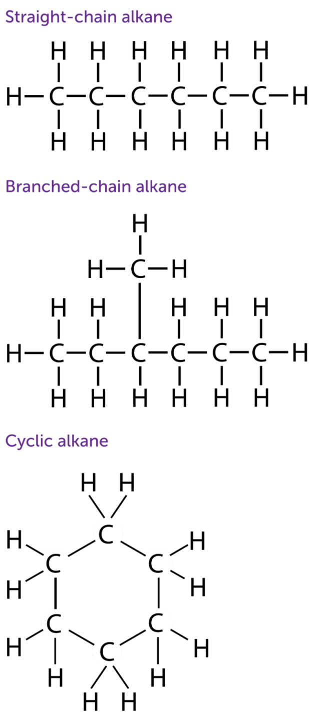


FIGURE 7.8
Alkanes may have any of these three shapes.

Isomers

Even compounds with the same number of carbon and hydrogen atoms can have different shapes. These compounds are called **isomers**. Look at the examples in **Figure** 7.9. The figure shows the structural formulas of butane and its isomer *iso*-butane. Both molecules have four carbon atoms and ten hydrogen atoms (C_4H_{10}), but the atoms are arranged differently. Butane is a straight-chain molecule. *Iso*-butane is branched. You can see three-dimensional models of these two isomers at the URLs below. You can rotate the molecule models to get a better idea of their shapes.

http://www.worldofmolecules.com/3D/butane_3d.htm

http://www.chemspider.com/Chemical-Structure.6120.html

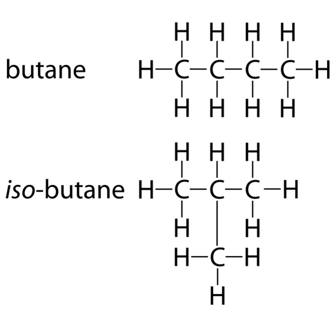


FIGURE 7.9
Butane and isobutane have the same atoms but different shapes.

Isomers usually have somewhat different properties. For example, straight-chain molecules generally have higher boiling and melting points than their branched-chain isomers. The boiling and melting points of *iso*-butane are -12°C and -160°C, respectively. Compare these values with the boiling and melting points of butane in **Table** 7.2. Do these two compounds follow the general trend?

Cycloalkanes

Ring-shaped alkanes are called cycloalkanes. They usually contain just five or six carbon atoms because larger rings are not very stable. However, rings can join together to create larger molecules consisting of two or more rings. Compared with the straight- and branched-chain alkanes, cycloalkanes have higher boiling and melting points.

Unsaturated Hydrocarbons

Unsaturated hydrocarbons contain at least one double or triple bond between carbon atoms. As a result, the carbon atoms are unable to bond with as many hydrogen atoms as they would if they were joined only by single bonds. This makes them unsaturated with hydrogen. Unsaturated hydrocarbons are classified on the basis of their bonds as alkenes, alkynes, or aromatic hydrocarbons.

Alkenes

Unsaturated hydrocarbons that contain at least one double bond are called **alkenes**. The name of a specific alkene always ends in *–ene*, with a prefix indicating the number of carbon atoms. **Figure** 7.10 shows the structural formula for the smallest alkene. It has just two carbon atoms and is named ethene. Ethene is produced by most fruits and vegetables. It speeds up ripening and also rotting. **Figure** 7.11 shows the effects of ethene on bananas.

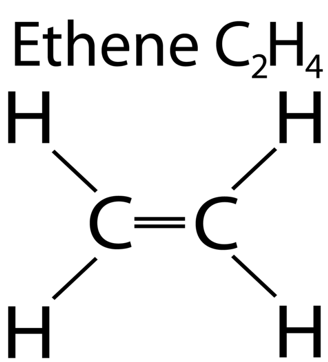


FIGURE 7.10
Ethene is the smallest alkene.

Like alkanes, alkenes can have different shapes. They can form straight chains, branched chains, or rings. Alkenes can also form isomers, or compounds with the same atoms but different shapes. Generally, the physical properties of alkenes are similar to those of alkanes. Smaller alkenes, such as ethene, have relatively high boiling and melting points. They are gases at room temperature. Larger alkenes have lower boiling and melting points. They are liquids or waxy solids at room temperature.

Alkynes

Unsaturated hydrocarbons that contain at least one triple bond are called **alkynes**. The name of specific alkynes always end in *–yne*, with a prefix for the number of carbon atoms. **Figure** 7.12 shows the smallest alkyne, called

FIGURE 7.11

These two bunches of bananas were stored in different ways. The bananas on the right were stored in the open air. The bananas on the left were stored in a special bag that absorbs the ethene they release. The bananas in the bag have not yet turned brown because they were not exposed to ethene.

ethyne, which has just two carbon atoms. Ethyne is also called acetylene. It is burned in acetylene torches, like the one in **Figure** 7.13. Acetylene produces so much heat when it burns that it can melt metal. Breaking all those bonds between carbon atoms releases a lot of energy.

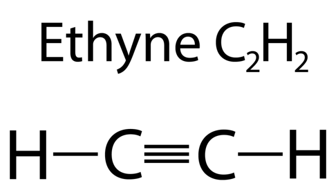


FIGURE 7.12

Ethyne is the smallest alkyne.

FIGURE 7.13

This acetylene torch is being used to cut metal.

Alkynes may form straight or branched chains. They rarely occur as cycloalkynes. In fact, alkynes of all shapes are relatively rare, at least in nature.

Aromatic Hydrocarbons

Unsaturated cyclic hydrocarbons are called **aromatic hydrocarbons**. That's because they have a strong aroma, or scent. Their molecules consist of six carbon atoms in a ring shape, connected by alternating single and double bonds. Aromatic hydrocarbons may have a single ring or multiple rings joined together by bonds between their carbon atoms.

Benzene is the smallest aromatic hydrocarbon. It has just one ring. You can see its structural formula in **Figure** 7.14. Benzene has many uses. For example, it is used in air fresheners and mothballs because of its strong scent.

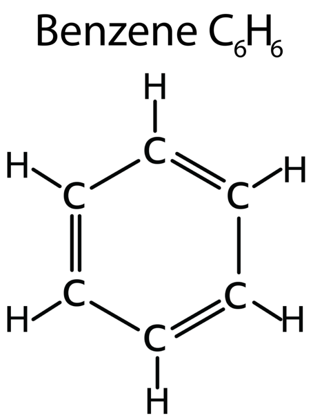
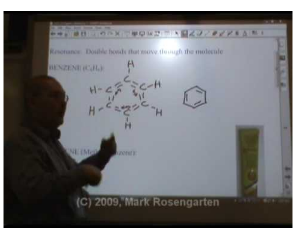


FIGURE 7.14

Benzene is an aromatic hydrocarbon. Does each carbon atom in benzene have a total of four bonds? Count them to find out.

You can learn more about benzene and other aromatic hydrocarbons at this URL: http://www.youtube.com/watch?v=8gW7H0ReN5g (4:54).



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Uses and Sources of Hydrocarbons

It is hard to overstate the importance of hydrocarbons to modern life. Hydrocarbons have even been called the driving force of western civilization. You saw some ways they are used in **Figure** 7.6. Several other ways are illustrated in **Figure** 7.15. Their most important use is as fuels. Gasoline, natural gas, fuel oil, diesel fuel, jet fuel, coal, kerosene, and propane are just some of the hydrocarbon compounds that are burned for fuel. Hydrocarbons are also used to manufacture many products, including plastics and synthetic fabrics such as polyester.

The main source of hydrocarbons is fossil fuels —coal, petroleum, and natural gas. Fossil fuels form over hundreds of millions of years when dead organisms are covered with sediments and put under great pressure. Giant ferns in ancient swamps turned into coal deposits. Dead organisms in ancient seas gradually formed deposits of petroleum and natural gas. You can read more about these sources of hydrocarbons in the chapter *Introduction to Energy* and at the URL below.

http://www.energyquest.ca.gov/story/chapter08.html

FIGURE 7.15

These photos show just a few of the many uses of hydrocarbons.

Lesson Summary

- Hydrocarbons are compounds that contain only carbon and hydrogen. They are the simplest type of carbon-based compounds.
- Saturated hydrocarbons contain only single bonds between carbon atoms. They are also called alkanes. They may form straight-chain, branched-chain, or cyclic molecules. Compounds with the same number of atoms but different shapes are called isomers.
- Unsaturated hydrocarbons contain at least one double or triple bond between carbon atoms. Hydrocarbons with double bonds are called alkenes. Those with triple bonds are called alkynes. Aromatic hydrocarbons consist of six carbon atoms in a ring shape, connected by alternating single and double bonds.
- Hydrocarbons are extremely important to modern life. Their most important use is as fuels. Hydrocarbons are also used to manufacture many products including plastics. The main source of hydrocarbons is fossil fuels.

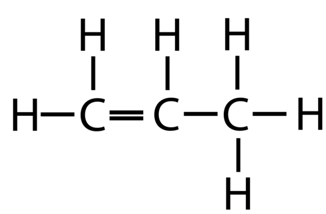
Lesson Review Questions

Recall

1. What are hydrocarbons?
2. Describe how the boiling point of alkanes changes as the number of carbon atoms per molecule increases.
3. Identify and describe the three basic shapes of alkane molecules.
4. What are isomers?
5. Define alkene and alkyne.
6. Describe aromatic hydrocarbons.

Apply Concepts

7. Which type of hydrocarbon is represented by this structural formula? What is the compound's chemical formula? What shape does it have?



Think Critically

8. Compare and contrast saturated and unsaturated hydrocarbons. Give an example of each.
9. Explain the relationship between plastics and fossil fuels.

Points to Consider

In this lesson, you read that fossil fuels form from the remains of dead organisms. As you will read in the next lesson, "Carbon and Living Things," organisms are made of carbon-based compounds.

- Do you know the names of any of the carbon compounds in living things? (*Hint*: Many of them are found in food.)
- How might these carbon compounds be different from hydrocarbons?

7.3 Carbon and Living Things

Lesson Objectives

- Give an overview of biochemical compounds.
- Identify the structure and functions of carbohydrates.
- Describe protein structure, and list functions of proteins.
- Outline the structure and functions of lipids.
- Identify the structure of nucleic acids and their functions.

Lesson Vocabulary

- biochemical compound
- carbohydrate
- lipid
- nucleic acid
- protein

Introduction

Carbon is the most important element in living things. Carbon-based compounds in living things are generally called biochemical compounds. The prefix *bio* comes from the Greek word that means "life." Many of the same biochemical compounds are found in all forms of life, despite life's great diversity.

Biochemical Compounds

A **biochemical compound** is any carbon-based compound found in living things. Like hydrocarbons, all biochemical compounds contain hydrogen as well as carbon. However, biochemical compounds also contain other elements, such as oxygen and nitrogen. Almost all biochemical compounds are polymers. They consist of many, smaller monomer molecules. Biochemical polymers are referred to as macromolecules. The prefix *macro* means "large," and many biochemical molecules are very large indeed. They may contain thousands of monomer molecules.

Biochemical compounds make up the cells and tissues of organisms. They are also involved in life processes, such as making and using food for energy. Given their diversity of functions, it's not surprising that there are millions of different biochemical compounds. However, they can be grouped into just four main classes: carbohydrates, proteins, lipids, and nucleic acids. The classes are summarized in **Table** 7.3 and described in the rest of this lesson.

TABLE 7.3: Classes of Biochemical Compounds

Class	Elements	Examples	Functions
Carbohydrates	carbon hydrogen oxygen	sugars starches cellulose	provide energy to cells store energy in plants makes up the cell walls of plants
Proteins	carbon hydrogen oxygen nitrogen sulfur	enzymes hormones	speed up biochemical reactions regulate life processes
Lipids	carbon hydrogen oxygen	fats oils	store energy in animals store energy in plants
Nucleic acids	carbon hydrogen oxygen nitrogen phosphorus	DNA RNA	stores genetic information in cells helps cells make proteins

Carbohydrates

Carbohydrates are biochemical compounds that include sugars, starches, and cellulose. They contain oxygen in addition to carbon and hydrogen. Organisms use carbohydrates mainly for energy.

Sugars

Sugars are simple carbohydrates. Molecules of sugar have just a few carbon atoms. The simplest sugar is glucose ($C_6H_{12}O_6$). Glucose is the sugar that the cells of living things use for energy. Plants and some other organisms make glucose in the process of photosynthesis. Living things that cannot make glucose obtain it by consuming plants or these other organisms.

You can see the structural formula of glucose and two other sugars in **Figure** 7.16. The other sugars in the figure are fructose and sucrose. Fructose is an isomer of glucose. It is found in fruits. It has the same atoms as glucose, but they are arranged differently. Sucrose is table sugar. It consists of one molecule of glucose and one molecule of fructose.

Starches

Starches are complex carbohydrates. They are polymers of glucose. They consist of hundreds of glucose monomers bonded together. Plants make starch to store extra sugars. Consumers get starch from plants. Common sources of starch in the human diet are pictured in **Figure** 7.17. Our digestive system breaks down starch to simple sugars, which our cells use for energy.

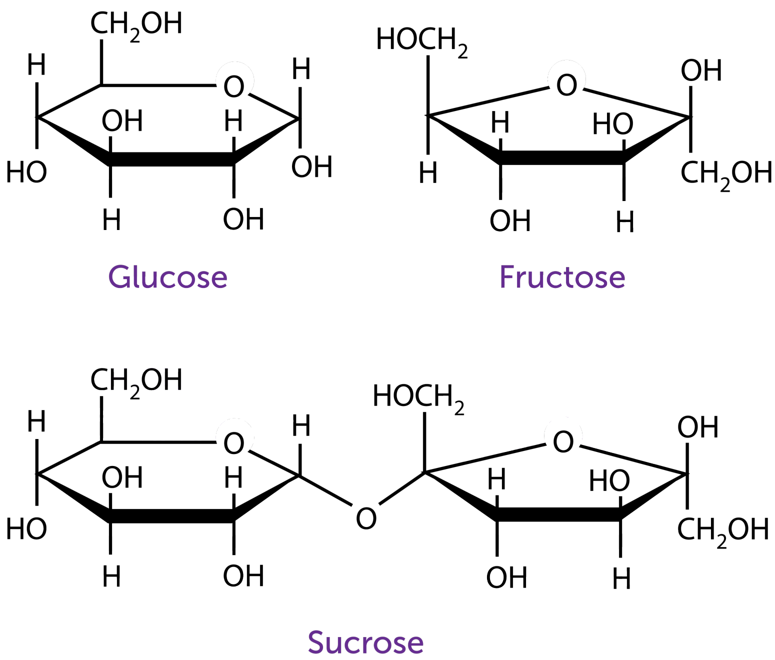


FIGURE 7.16
Glucose and fructose are isomers. Sucrose contains a molecule of each.

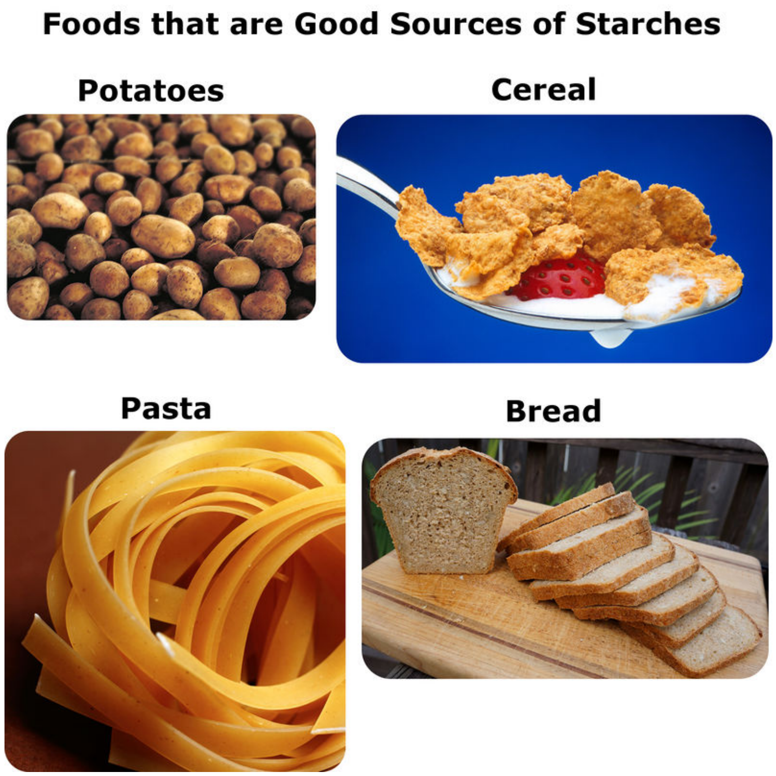


FIGURE 7.17
These foods are all good sources of starch.

Cellulose

Cellulose is another complex carbohydrate that is a polymer of glucose. However, the glucose molecules are bonded together differently in cellulose than they are in starches. Cellulose molecules bundle together to form long, tough fibers (see **Figure** 7.18). Have you ever eaten raw celery? If you have, then you probably noticed that the stalks contain long, stringy fibers. The fibers are mostly cellulose.

Cellulose is the most abundant biochemical compound. It makes up the cell walls of plants and gives support to trunks and stems. Cellulose also provides needed fiber in the human diet. We can't digest cellulose, but it helps keep food wastes moving through the digestive tract.

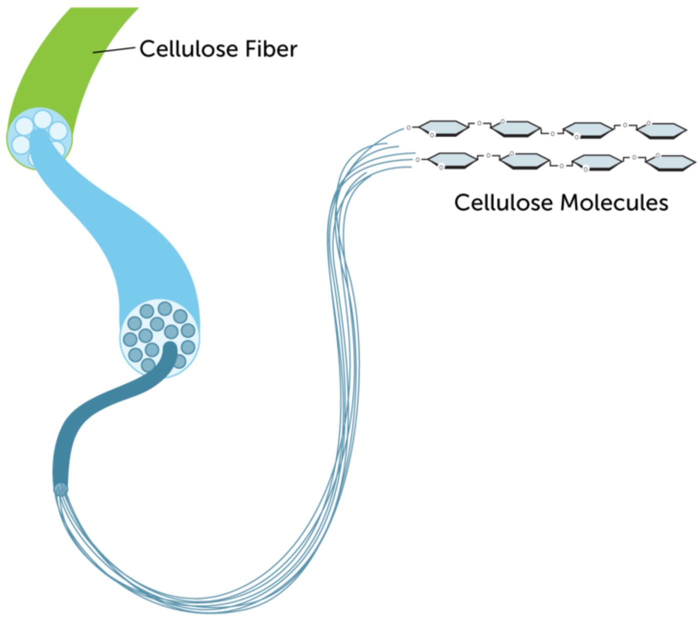


FIGURE 7.18
Cellulose molecules form large cellulose fibers.

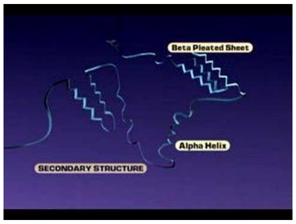
Proteins

Proteins are biochemical compounds that contain oxygen, nitrogen, and sulfur in addition to carbon and hydrogen. Protein molecules consist of one or more chains of small molecules called amino acids.

Protein Structure

Amino acids are the "building blocks" of proteins. There are 20 different common amino acids. The structural formula of the simplest amino acid, called glycine, is shown in **Figure** 7.19. Other amino acids have a similar structure. The sequence of amino acids and the number of amino acid chains in a protein determine the protein's shape. The shape of a protein, in turn, determines its function. Shapes may be very complex. You can learn more about the structure of proteins at the URL below.

http://www.youtube.com/watch?v=lijQ3a8yUYQ (0:52)



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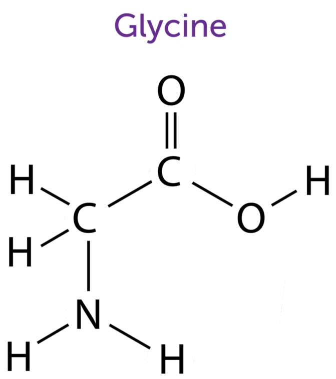


FIGURE 7.19

Glycine is one of 20 common amino acids that make up the proteins of living things.

Protein Functions

Proteins are the most common biochemicals. They have many different functions, including:

- making up tissues as components of muscle.
- speeding up biochemical reactions as enzymes.
- regulating life processes as hormones.
- helping defend against infections as antibodies.
- transporting materials as components of the blood (see the example in **Figure** 7.20).

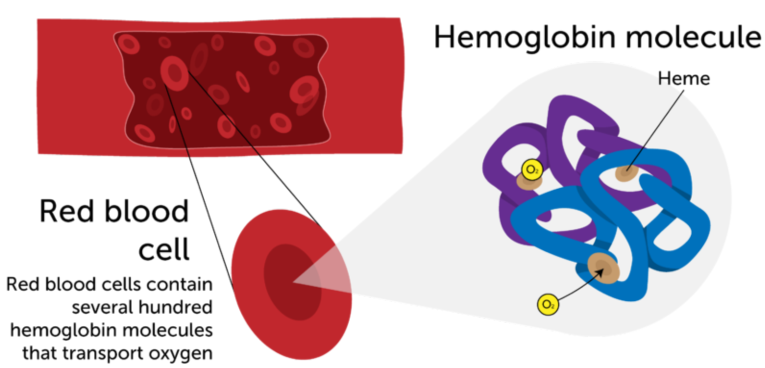


FIGURE 7.20

The blood protein hemoglobin binds with oxygen and carries it from the lungs to cells throughout the body. Heme is a small molecule containing iron that is part of the larger hemoglobin molecule. Oxygen binds to the iron in heme.

Lipids

Lipids are biochemical compounds such as fats and oils. Organisms use lipids to store energy. In addition to carbon and hydrogen, lipids contain oxygen.

Fatty Acids

Lipids are made up of long carbon chains called fatty acids. Like hydrocarbons, fatty acids may be saturated or unsaturated. **Figure** 7.21 shows structural formulas for two small fatty acids. One is saturated and one is unsaturated.

- In saturated fatty acids, there are only single bonds between carbon atoms. As a result, the carbons are saturated with hydrogen atoms. Saturated fatty acids are found in fats. Fats are solid lipids that animals use to store energy.
- In unsaturated fatty acids, there is at least one double bond between carbon atoms. As a result, some carbons are not bonded to as many hydrogen atoms as possible. Unsaturated fatty acids are found in oils. Oils are liquid lipids that plants use to store energy.

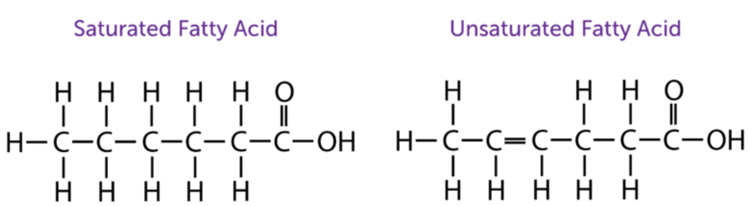


FIGURE 7.21
Both of these fatty acid molecules have six carbon atoms and two oxygen atoms. How many hydrogen atoms does each fatty acid have?

Phospholipids

Some lipids contain the element phosphorus as well as oxygen, carbon, and hydrogen. These lipids are called phospholipids. Two layers of phospholipid molecules make up most of the cell membrane in the cells of living things.

Figure 7.22 shows how phospholipid molecules are arranged in a cell membrane. One end (the head) of each phospholipid molecule is polar and attracts water. This end is called hydrophilic ("water loving"). The other end (the tail) is nonpolar and repels water. This end is called hydrophobic ("water hating"). The nonpolar tails are on the inside of the membrane. The polar heads are on the outside of the membrane. These differences in polarity allow some molecules to pass through the membrane while keeping others out. You can see how this works in the video at the URL below.

http://www.beyondbooks.com/lif71/4b.asp

Nucleic Acids

Nucleic acids are biochemical molecules that contain oxygen, nitrogen, and phosphorus in addition to carbon and hydrogen. There are two main types of nucleic acids. They are DNA (deoxyribonucleic acid) and RNA (ribonucleic acid).

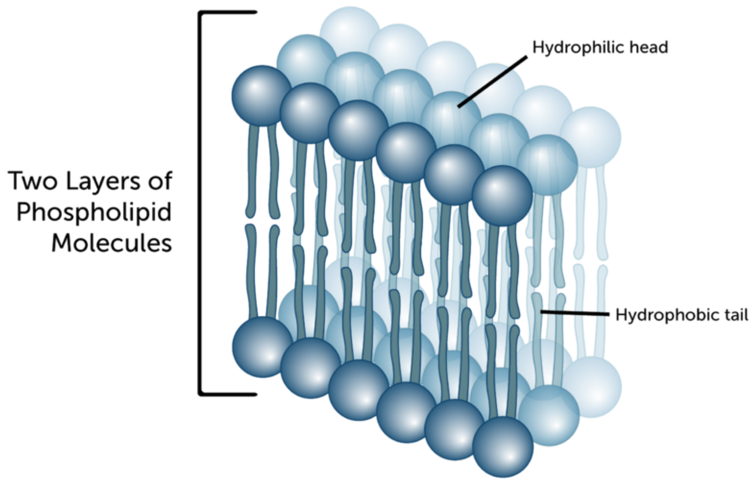


FIGURE 7.22
The arrangement of phospholipid molecules in a cell membrane allows the membrane to control what enters and leaves the cell.

Structure of Nucleic Acids

Nucleic acids consist of chains of small molecules called nucleotides. The structure of a nucleotide is shown in **Figure** 7.23. Each nucleotide contains a phosphate group (PO_4), a sugar ($C_5H_8O_4$) in DNA, and a nitrogen-containing base. (A base is a compound that is not neither acidic nor neutral.) There are four different nitrogenous bases in DNA. They are adenine, thymine, guanine, and cytosine. In RNA, the only difference is that thymine is replaced with a different base, uracil.

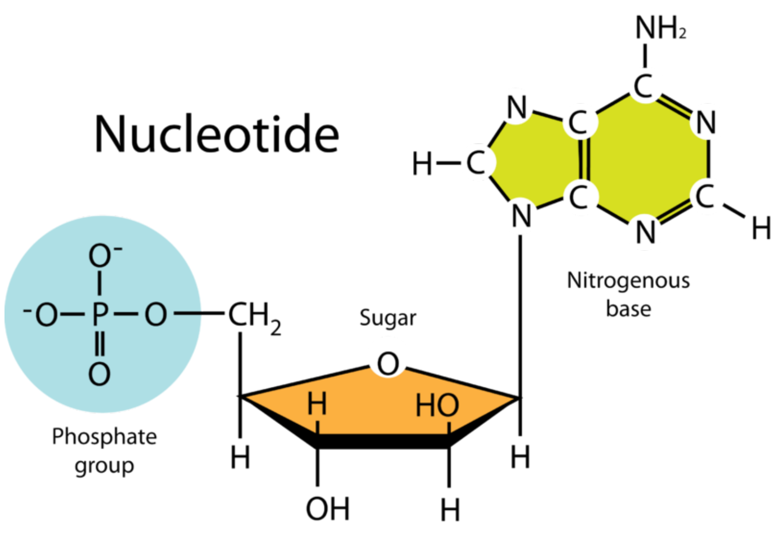


FIGURE 7.23
Each nucleotide contains these three components.

DNA consists of two long chains of nucleotides. Nitrogen bases on the two chains form hydrogen bonds with each other. Adenine always bonds with thymine, and guanine always bonds with cytosine. These bonds hold the two chains together and give DNA is characteristic double helix, or spiral, shape. You can see the shape of the DNA molecule in **Figure** 7.24. Sugars and phosphate groups form the "backbone" of each chain of DNA. The bonded bases are called base pairs. RNA, in contrast to DNA, consists of just one chain of nucleotides. Determining the structure of DNA was a big scientific breakthrough. You can read the interesting story of its discovery at the URL below.

http://nobelprize.org/educational/medicine/dna_double_helix/readmore.html

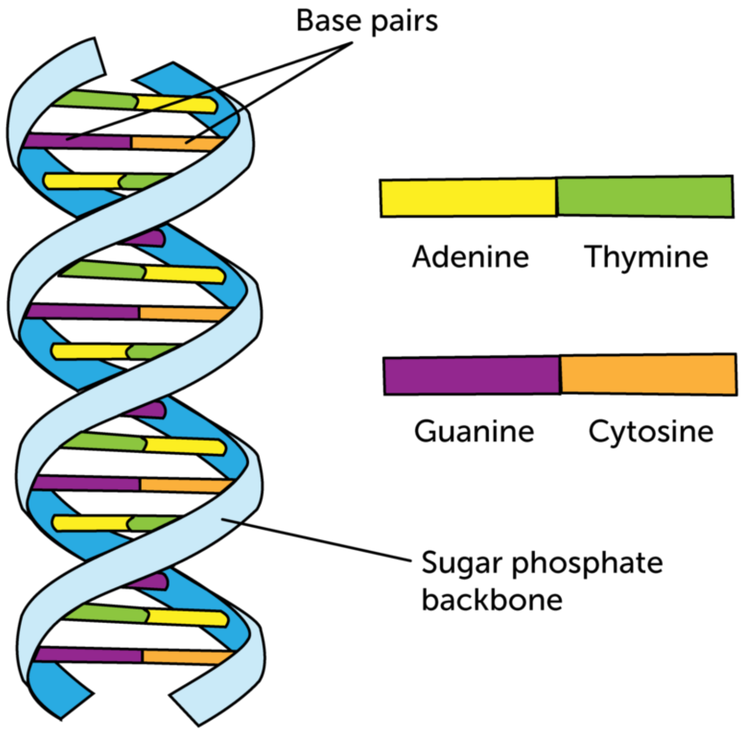
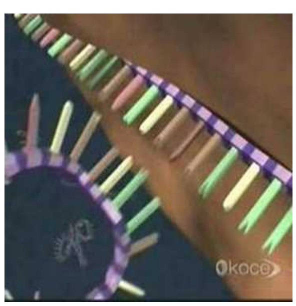


FIGURE 7.24
DNA has the shape of a double helix because of hydrogen bonds between nitrogen bases.

Functions of Nucleic Acids

DNA stores genetic information in the cells of all living things. It contains the genetic code. This is the code that instructs cells how to make proteins. The instructions are encoded in the sequence of nitrogen bases in the nucleotide chains of DNA. RNA "reads" the genetic code in DNA and is involved in the synthesis of proteins based on the code. This video shows how: http://www.youtube.com/watch?v=NJxobgkPEAo (2:51).



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Lesson Summary

- A biochemical compound is any carbon-based compound found in living things. Most biochemical compounds are polymers that contain oxygen, nitrogen, or other elements in addition to carbon and hydrogen.

- Carbohydrates are biochemical compounds that include sugars, starches, and cellulose. Their functions include providing or storing energy and making up plant cell walls.
- Proteins are biochemical compounds that consist of one or more chains of amino acids. Proteins have many different functions. For example, some are enzymes, and some are hormones.
- Lipids are biochemical compounds such as fats and oils. They consist of fatty acids, which may saturated or unsaturated. Lipids are used to store energy. They also make up cell membranes.
- Nucleic acids are biochemical compounds that include DNA and RNA. They consist of chains of smaller molecules called nucleotides. DNA stores the genetic code for proteins. RNA helps make proteins.

Lesson Review Questions

Recall

1. Name the four classes of biochemical compounds.
2. What are sugars and starches? How are they used?
3. Describe the structure of proteins. List three functions of proteins.
4. Describe the structure of nucleic acids. What components are found in each nucleotide?

Apply Concepts

5. A mystery biochemical compound contains only carbon, hydrogen, and oxygen. It is made by both plants and animals. In which class of biochemical compounds should it be placed?

Think Critically

6. Use structural formulas to illustrate the difference between fatty acids in oils and fatty acids in fats.
7. Explain the relationship between DNA and RNA.

Points to Consider

Biochemical compounds are involved in almost all life processes. One of the most important life processes is photosynthesis.

- What is photosynthesis?
- Why is photosynthesis so important to living things?

7.4 Biochemical Reactions

Lesson Objectives

- Describe photosynthesis.
- Outline cellular respiration.
- Explain the role of enzymes in biochemical reactions.

Lesson Vocabulary

- cellular respiration
- enzyme
- photosynthesis

Introduction

All living things need energy. From running a marathon to just taking a breath, energy is required. Where does the energy come from? The answer is chemical reactions. Reactions that take place within living things are called biochemical reactions. Two of the most important are photosynthesis and cellular respiration. Together, these two processes provide energy to almost all of Earth's organisms. **Figure** 7.25 and the video at the URL below show how the two processes are related.

http://www.youtube.com/watch?v=NJxobgkPEAo

Photosynthesis

Most of the energy used by living things comes either directly or indirectly from the sun. Sunlight provides the energy for **photosynthesis**. This is the process in which plants and certain other organisms (see **Figure** 7.26) synthesize glucose ($C_6H_{12}O_6$). The process uses carbon dioxide and water and also produces oxygen. The overall chemical equation for photosynthesis is:

$$6CO_2 + 6H_2O + \text{ Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Photosynthesis changes light energy to chemical energy. The chemical energy is stored in the bonds of glucose molecules. Glucose is used for energy by the cells of almost all living things. Plants make their own glucose. Other organisms get glucose by consuming plants (or organisms that consume plants). How do living things get energy from glucose? The answer is cellular respiration.

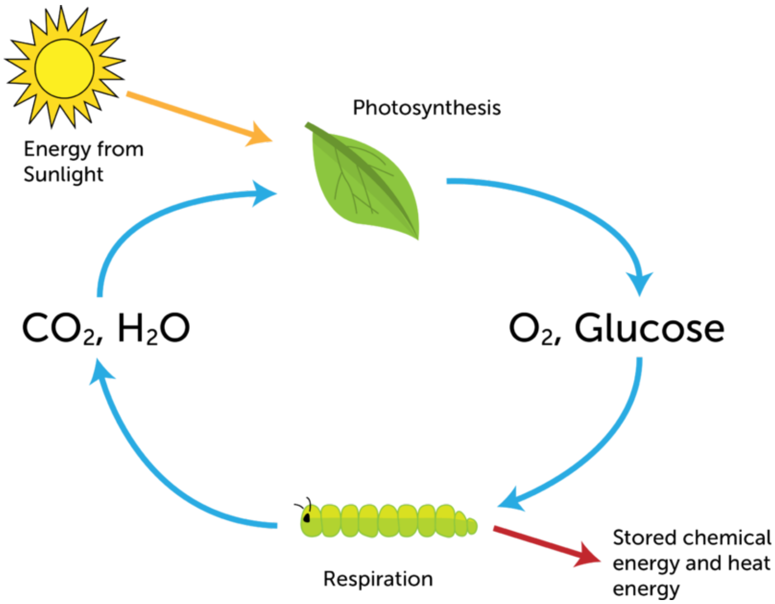


FIGURE 7.25
Photosynthesis and cellular respiration are closely related. What are the products and reactants of each process?

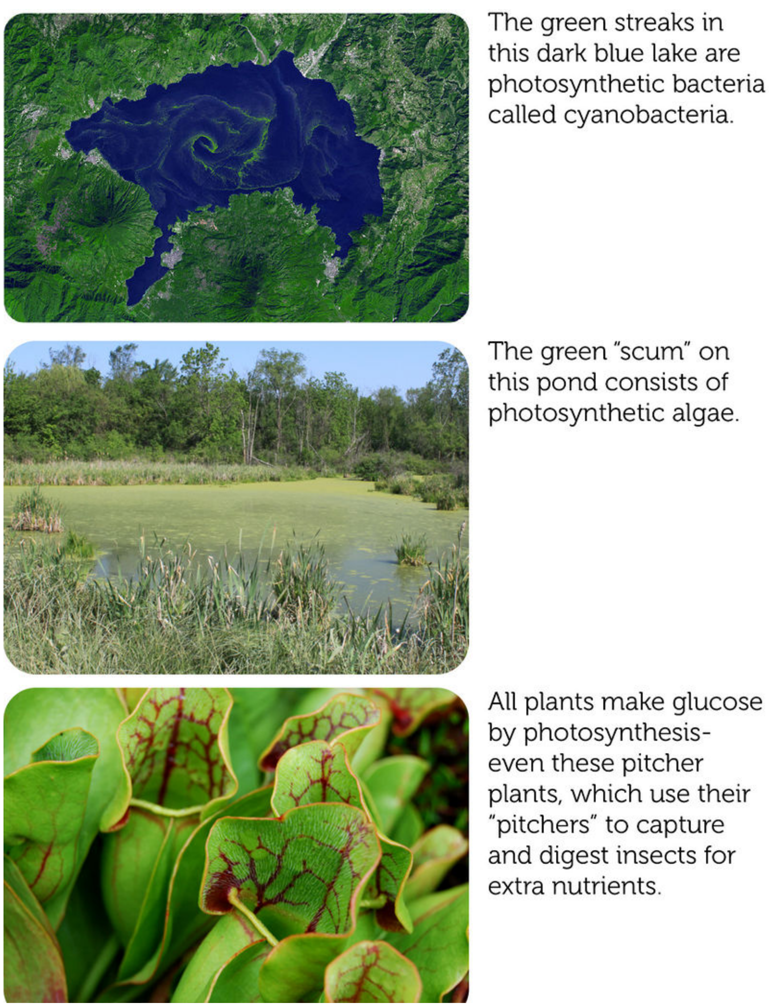


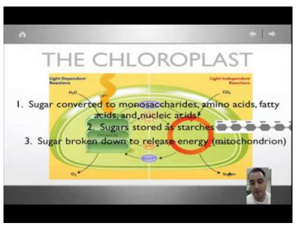
FIGURE 7.26
These organisms use sunlight to make glucose in the process of photosynthesis. All of them contain the green pigment chlorophyll, which is needed to capture light energy.

Cellular Respiration

Cellular respiration is the process in which the cells of living things break down glucose with oxygen to produce carbon dioxide, water, and energy. The overall chemical equation for cellular respiration is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Heat and Chemical Energy}$$

Cellular respiration releases some of the energy in glucose as heat. It uses the rest of the energy to form many, even smaller molecules. The smaller molecules contain just the right amount of energy to power chemical reactions inside cells. You can look at cellular respiration in more detail at this URL: http://www.youtube.com/watch?v=JyMfKP1D7OE (12:38).



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Enzymes and Biochemical Reactions

Human body temperature must remain within a narrow range around 37°C (98.6°F). At this temperature, most biochemical reactions would occur too slowly to keep us alive. That's where enzymes come in. **Enzymes** are biochemical catalysts. They speed up biochemical reactions, not only in humans but in virtually all living things. Most enzymes are proteins. Two are described in **Figure** 7.27.

Lesson Summary

- Biochemical reactions are chemical reactions that take place inside living things. Two of the most important biochemical reactions are photosynthesis and cellular respiration.
- Photosynthesis is the process in which plants and certain other organisms synthesize glucose from carbon dioxide and water using light energy. Oxygen is also produced.
- Cellular respiration is the process in which the cells of living things break down glucose with oxygen to produce carbon dioxide, water, and energy.
- Enzymes are biochemical catalysts that speed up biochemical reactions. Without enzymes, most chemical reactions in living things would occur too slowly to keep organisms alive.

Lesson Review Questions

Recall

1. What is photosynthesis? Write the overall chemical equation for this process.

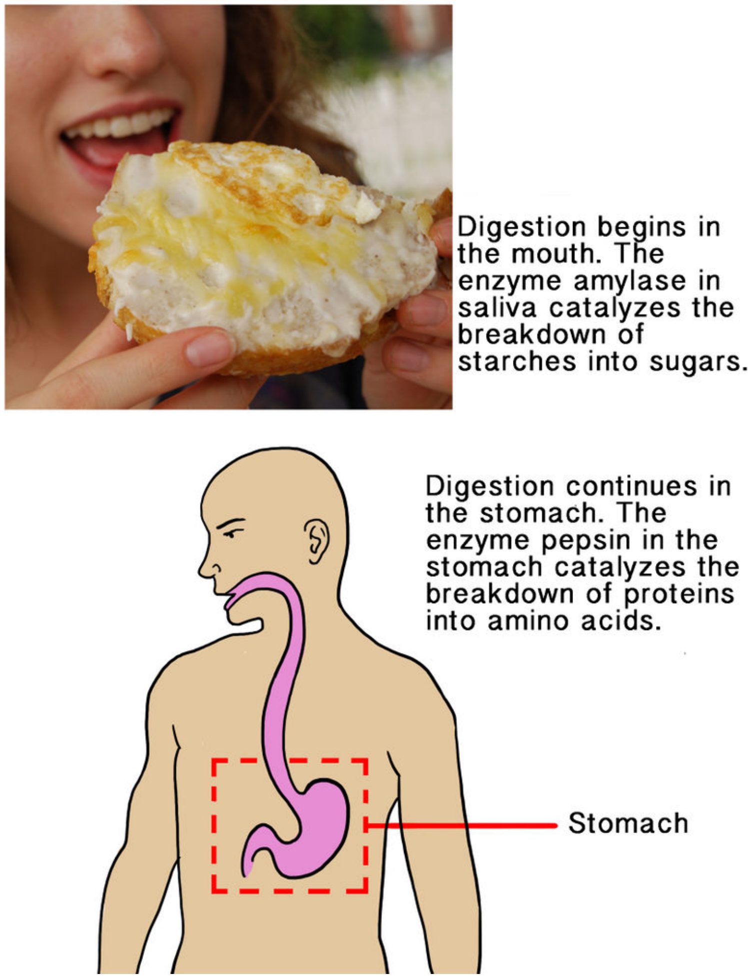

FIGURE 7.27
The human body produces many enzymes that help digest food. Here are just two examples.

2. What types of organisms undergo photosynthesis?
3. What is cellular respiration? Write the overall chemical equation for this process.
4. Define enzyme, and give an example.

Apply Concepts

5. Create a cycle diagram to show how photosynthesis and cellular respiration are related.

Think Critically

6. Classify photosynthesis and cellular respiration as endothermic or exothermic reactions. Explain your classification.

Points to Consider

The enzyme pepsin works only in the presence of acid. A strong acid is secreted into the stomach. It provides the acid that pepsin needs. You will learn about acids in the next chapter, "Chemistry of Solutions." Vinegar and lemon juice are two common acids.

- What do you think are properties of acids?
- What other foods might contain acids?

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26. Blue lake: Courtesy of NASA Earth Observatory; Algae pond: Dwight Burdette; Pitcher plant: Geoff Gallice (Flickr:ggalice). Blue lake: http://commons.wikimedia.org/wiki/File:Harmful_Bloom_in_Lake_Atitl%C3%A1n,_Guatemala.jpg; Algae pond: http://commons.wikimedia.org/wiki/File:Algae_Covered_Pond_Cherry_Hill_Road_Superior_Township_Michigan.JPG; Pitcher plant: http://www.flickr.com/photos/11014423@N07/2916359254 . Blue lake: Public Domain; Algae pond: CC BY 3.0; Pitcher plant: CC BY 2.0
27. Top: Flickr:LearningLark; Bottom: Laura Guerin (CK-12 Foundation). Top: http://www.flickr.com/photos/44282411@N04/7610164322/ . Top: CC BY 2.0; Bottom: CC BY-NC 3.0

CHAPTER 8 Chemistry of Solutions

Chapter Outline

It can be really exciting to explore a big underground cave like the one in this picture. Do you know how caves form? Believe it or not, water is the answer. Water slowly dissolves rocks, especially certain types of rocks such as limestone. How does something as mild and harmless as water cause hard rocks to dissolve? In this chapter, you'll find out.

8.1 Introduction to Solutions

Lesson Objectives

- Explain how solutions form.
- Identify properties of solutions.

Lesson Vocabulary

- insoluble
- soluble
- solute
- solvent

Introduction

When rocks or other substances dissolve in water, they form a solution. A solution is a homogeneous mixture of two or more substances. The particles of a solution are mixed evenly throughout it. The particles are too small to be seen or to settle out. An example of a solution is salt water.

Solutes and Solvents

A solution forms when one substance dissolves in another. The substance that dissolves is called the **solute**. The substance it dissolves in is called the **solvent**. For example, ocean water is a solution in which the solute is salt and the solvent is water. In this example, a solid (salt) is dissolved in a liquid (water). However, matter in any state can be the solute or solvent in a solution. Solutions may be gases, liquids, or solids. In **Table** 8.1 and the video at the URL below, you can learn about solutions involving other states of matter.

http://www.youtube.com/watch?v=NsdBUWnG2cQ

TABLE 8.1: Solutions and States of Matter

Solution	Solute	Solvent
Gas dissolved in gas *Example*: Earth's atmosphere	oxygen (and other gases)	nitrogen
Gas dissolved in liquid *Example*: carbonated water	carbon dioxide	water
Liquid dissolved in gas *Example*: moist air	water	air

TABLE 8.1: (continued)

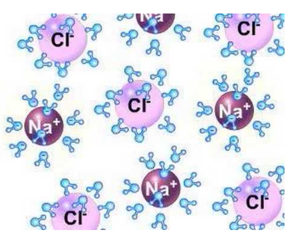
Solution	Solute	Solvent
Liquid dissolved in liquid *Example*: vinegar	acetic acid	water
Solid dissolved in liquid *Example*: sweet tea	sugar	tea
Solid dissolved in solid *Example*: bronze	copper	tin

When a solute dissolves in a solvent, it changes to the same state as the solvent. For example, when solid salt dissolves in liquid water, it becomes part of the liquid solution, salt water. If the solute and solvent are already in the same state, the substance present in greater quantity is considered to be the solvent. For example, nitrogen is the solvent in Earth's atmosphere because it makes up 78 percent of air.

How a Solute Dissolves

When a solute dissolves, it separates into individual particles that spread evenly throughout the solvent. Exactly how this happens depends on the type of bonds the solute contains. Solutes with ionic bonds, such as table salt (NaCl), separate into individual ions (Na^+ and Cl^-). Solutes with covalent bonds, such as glucose ($H_6C_{12}O_6$), separate into individual molecules. In either case, the individual ions or molecules spread apart and are surrounded by molecules of the solvent. This is illustrated in **Figure** 8.1 and in the videos at the URLs below.

http://www.youtube.com/watch?v=gN9euz9jzwc (0:47)



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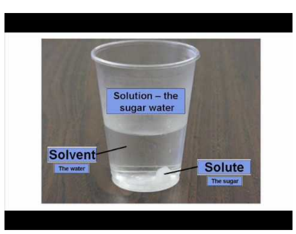
http://www.youtube.com/watch?v=hydUVGUbyvU (1:38)



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Rate of Dissolving

When you add sugar to a cold drink, you may stir it to help the sugar dissolve. If you don't stir, the sugar may eventually dissolve, but it will take much longer. Stirring is one of several factors that affect how fast a solute dissolves in a solvent. Temperature is another factor. A solid solute dissolves faster at a higher temperature. For example, sugar dissolves faster in hot tea than in ice tea. A third factor that affects the rate of dissolving is the surface area of the solute. For example, if you put granulated sugar in a glass of ice tea, it will dissolve more quickly than

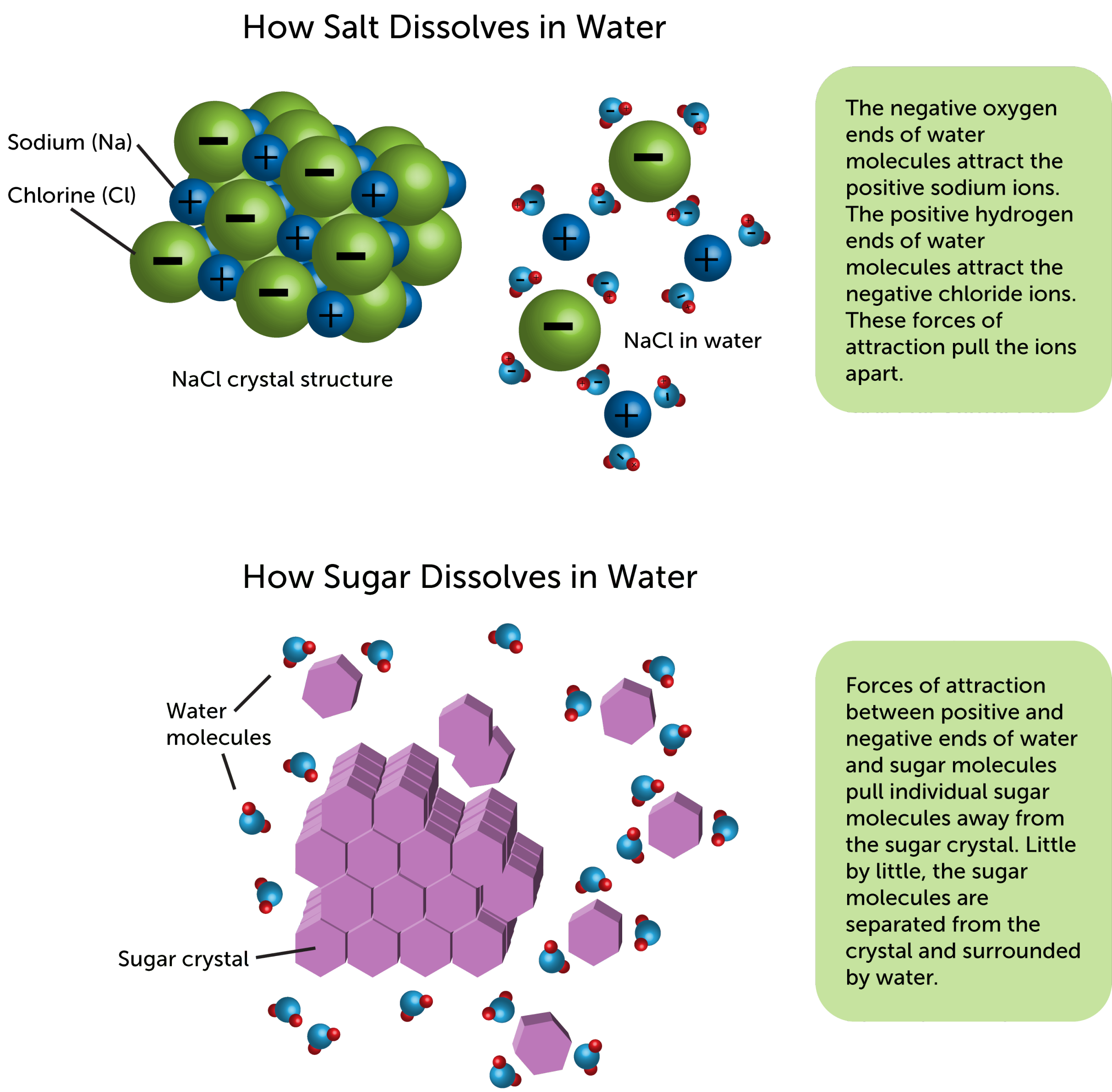

FIGURE 8.1

These two diagrams show how an ionic compound (salt) and a covalent compound (sugar) dissolve in a solvent (water).

the same amount of sugar in a cube. That's because granulated sugar has much more surface area than a cube of sugar. You can see videos of all three factors at these URLs:

http://www.youtube.com/watch?v=cF55VAk1Nlk (1:04)

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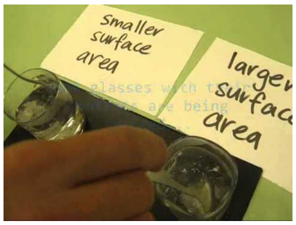
http://www.youtube.com/watch?v=Yb-TdSqmIvc (1:04)



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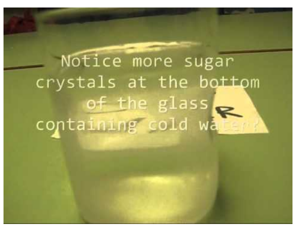
http://www.youtube.com/watch?v=TO42FOay7rg (1:38)



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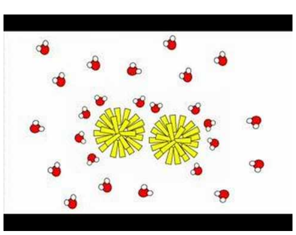
The Almost-Universal Solvent

Water is a polar compound. This means it has positively and negatively charged ends. This is why it is so good at dissolving ionic compounds such as salt and polar covalent compounds such as sugar. Solutes that can dissolve in a given solvent, such as water, are said to be **soluble** in that solvent. So many solutes are soluble in water that water is called the universal solvent.

However, there are substances that don't dissolve in water. Did you ever try to clean a paintbrush after painting with an oil-based paint? It doesn't work. Oil-based paint is nonpolar, so it doesn't dissolve in water. In other words, it is **insoluble** in water. Instead, a nonpolar solvent such as paint thinner must be used to dissolve nonpolar paint. You can see a video about soluble and insoluble solutes at this URL: http://www.youtube.com/watch?v=ek6CVVJk4OQ (1:51).



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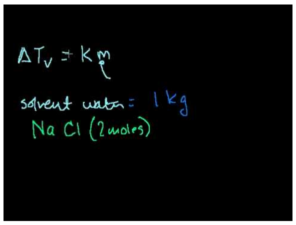
Properties of Solutions

When a solute dissolves in a solvent, it changes the physical properties of the solvent. Two properties that change when a solute is added are the freezing and boiling points. Generally, solutes lower the freezing point and raise the boiling point of solvents. You can see some examples of this in **Figure** below. To see why solutes change the freezing and boiling points of solvents, watch this video: http://www.youtube.com/watch?v=z9LxdqYntlU (14:00).



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In each of these examples, a solute changes the freezing and/or boiling points of a solvent.

Lesson Summary

- A solution forms when a solute dissolves in a solvent. The rate of dissolving is faster with stirring, a higher temperature, or greater surface area. Many solutes are soluble in water because water is polar.
- Solutes change the physical properties of solvents. They lower the freezing point and raise the boiling point of solvents.

Lesson Review Questions

Recall

1. What is a solute? What is a solvent?
2. Describe how an ionic compound such as salt dissolves in water.
3. List three factors that affect the rate at which a solute dissolves.
4. How do solutes affect the properties of solvents?

Apply Concepts

5. Create a lesson that explains to younger students how solutions form. With your teacher's approval, request permission to present your lesson to students in a lower grade.

Think Critically

6. Do you think paint thinner is soluble in water? Why or why not?

Points to Consider

Assume that you will stir salt into a cup of hot water to make a saltwater solution.

- How much salt do you think you could dissolve in the cup of hot water?
- Do you think you could dissolve more of some solutes than others?

8.2 Solubility and Concentration

Lesson Objectives

- Define solubility, and list factors that affect it.
- Define concentration, and explain how to calculate it.

Lesson Vocabulary

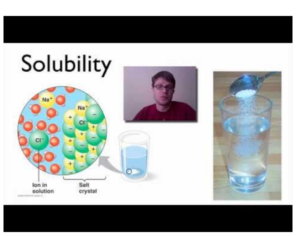
- saturated solution
- solubility
- unsaturated solution

Introduction

Tanya and Jon want to see if baking soda or sugar dissolves faster in water. Tanya adds 500 g of baking soda to 500 mL of room-temperature water. At the same time, Jon adds 500 g of table sugar to 500 mL of room-temperature water. Both students start stirring the mixture they made. In less than a minute, all of the sugar in Jon's mixture has dissolved. Tanya keeps stirring her mixture of baking soda and water, but after 5 minutes, some of the baking soda still hasn't dissolved. Even if Tanya kept stirring her mixture all day, the remaining baking soda would not dissolve. What explains this result? Read on to find out.

Solubility

Solubility is the amount of solute that can dissolve in a given amount of solvent at a given temperature. Some solutes have greater solubility than others in a given solvent. For example, table sugar is much more soluble in water than is baking soda. You can dissolve much more sugar than baking soda in a given amount of water. Compare the solubility of these and other solutes in **Figure** 8.2. For a video about solubility, go to this URL: http://www.youtube.com/watch?v=IKimraU21ws (10:21).



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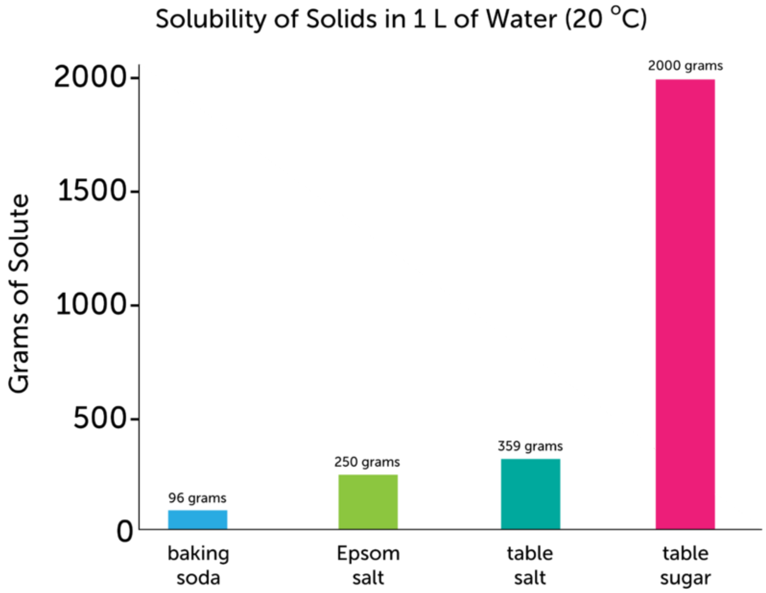


FIGURE 8.2
This graph shows the amount of different solids that can dissolve in 1 L of water at 20 degrees C.

Saturation

There is a limit on the amount of solute that can dissolve in a given solvent. Tanya found this out with her baking soda mixture. But even sugar, which is very soluble, has an upper limit. The maximum amount of table sugar that will dissolve in 1 L of water at 20°C is about 2000 g. If you add more sugar than this, the extra sugar won't dissolve.

A solution that contains as much solute as can dissolve at a given temperature is called a **saturated solution**. A solution that contains less solute than can dissolve at a given temperature is called an **unsaturated solution**. A solution of 2000 grams of sugar in 1 L of 20°C water is saturated. That's all the sugar the solution can hold. Any solution containing less than 2000 g of sugar is unsaturated. It can hold more sugar. To learn more about saturated and unsaturated solutions, watch the video at this URL: http://www.youtube.com/watch?v=IKimraU21ws .

You Try It!

Problem: A solution contains 249 grams of Epsom salt in 1 L of water at 20°C. Is the solution saturated or unsaturated?

Problem: Give an example of an unsaturated solution of table salt in 1 L of 20°C water.

Factors That Affect Solubility

Certain factors can change the solubility of a solute. Temperature is one such factor. How temperature affects solubility depends on the state of the solute, as you can see in **Figure** 8.3.

- If a solute is a solid or liquid, increasing the temperature increases its solubility. For example, more sugar can dissolve in hot tea than in iced tea.
- If a solute is a gas, increasing the temperature decreases its solubility. For example, less carbon dioxide can dissolve in warm ocean water than in cold ocean water.

The solubility of gases is also affected by pressure. Pressure is the amount of force pushing against a given area. Increasing the pressure on a gas increases its solubility. Did you ever open a can of soda and notice how it fizzes out of the can? Soda contains carbon dioxide. Opening the can reduces the pressure on the gas so it is less soluble. As a result, some of the carbon dioxide comes out of solution and rushes into the air.

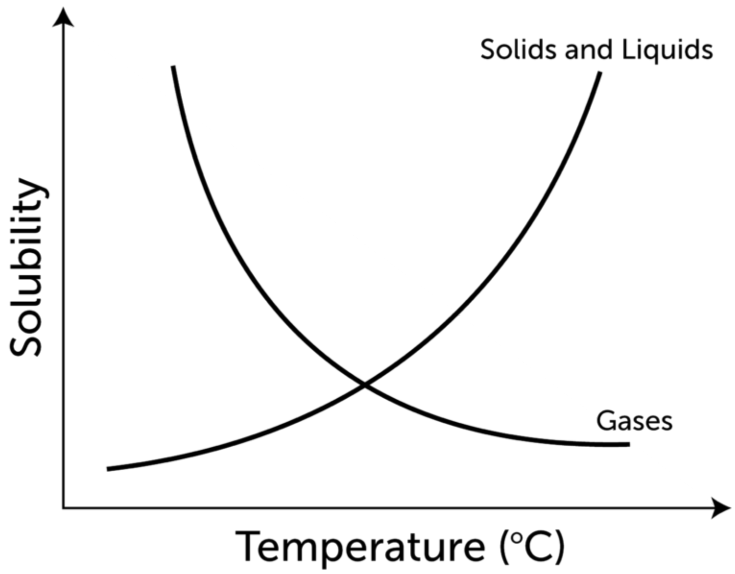


FIGURE 8.3
Temperature affects the solubility of a solute. However, it affects the solubility of gases differently than the solubility of solids and liquids.

Do you wonder why temperature and pressure affect solubility in these ways? If so, watch the video at the URL below. It explains why.

http://www.youtube.com/watch?v=IKimraU21ws

FIGURE 8.4
Soda fizzes when carbon dioxide comes out of solution. Which do you think will fizz more, warm soda or cold soda?

Concentration

The concentration of a solution is the amount of solute in a given amount of solution. A solution with little dissolved solute has a low concentration. It is called a dilute solution. A solution with a lot of dissolved solute has a high concentration. It is called a concentrated solution. Concentration is often expressed as a percent. You can calculate the concentration of a solution using this formula:

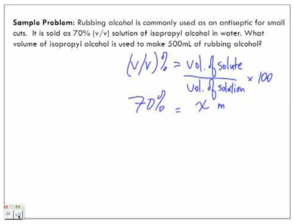
$$\text{Concentration} = \frac{\text{Mass (or Volume) of Solute}}{\text{Mass (or Volume) of Solution}} \times 100\%$$

For example, if a 100 g solution of salt water contains 3 g of salt, then its concentration is:

$$\text{Concentration} = \frac{3\text{ g}}{100\text{ g}} \times 100\% = 3\%$$

For some problems that are more challenging, go to these URLs:

http://www.youtube.com/watch?v=RCbhk3yyM88 (4:03)



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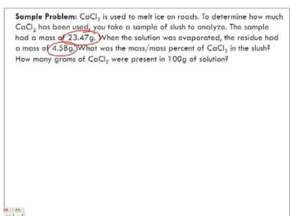
http://www.youtube.com/watch?v=dHxXtkH8ILs (3:39)



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You Try It!

Problem: A 1 L container of juice drink, called brand A, contains 250 mL of juice. The rest of the drink is water. How concentrated is brand A juice drink?

Problem: A 600 mL container of another juice drink, called brand B, contains 200 mL of juice. Which brand of juice drink is more concentrated, brand A or brand B?

Lesson Summary

- Solubility is the amount of solute that can dissolve in a given amount of solvent at a given temperature. A solution that contains as much solute as can dissolve at a given temperature is saturated. A solution that contains less solute than can dissolve at a given temperature is unsaturated. Factors such as temperature affect solubility.
- The concentration of a solution is the amount of solute in a given amount of solution. A dilute solution has a low concentration of solute. A concentrated solution has a high concentration of solute.

Lesson Review Questions

Recall

1. Define solubility.

2. Describe how temperature affects the solubility of gases, liquids, and solids.
3. State the effect of pressure on the solubility of gases.
4. What is the concentration of a solution?

Apply Concepts

5. Regina made a solution with 50 mL of lemon juice and 200 mL of water. How much solution did she make? Which is the solute and which is the solvent? What is the concentration of the solution?

Think Critically

6. A glass of warm soda goes flat more quickly than a glass of cold soda. Explain why.
7. Use data in the graph in **Figure** 8.2 to describe a saturated solution of baking soda and water.

Points to Consider

Some solutions have special properties because they are acids. Orange juice is an example. It contains an acid called citric acid. It makes orange juice taste sour. Some solutions are bases rather than acids.

- Do you know examples of bases?
- How might bases differ from acids?

8.3 Acids and Bases

Lesson Objectives

- Describe acids and how to detect them.
- Describe bases and how to detect them.
- Explain what determines the strength of acids and bases.
- Outline neutralization reactions and the formation of salts.

Lesson Vocabulary

- acid
- acidity
- base
- neutralization reaction
- pH
- salt

Introduction

No doubt you are familiar with some common acids. Besides orange juice, vinegar and lemon juice are both acids. Look at the boy in **Figure** 8.5. You can tell by the expression on his face that lemon juice tastes sour. In fact, all acids taste sour. They share certain other properties as well. You will learn more about their properties in this lesson. For a musical rendition of lesson content, go to this URL: http://www.youtube.com/watch?v=zTLiJE-j1-I .

FIGURE 8.5
Like other acids, lemon juice tastes sour.

Acids

An **acid** is an ionic compound that produces positive hydrogen ions (H^+) when dissolved in water. An example is hydrogen chloride (HCl). When it dissolves in water, its hydrogen ions and negative chloride ions (Cl^-) separate, forming hydrochloric acid. This can be represented by the equation:

$$HCl \xrightarrow{H_2O} H^+ + Cl^-$$

Properties of Acids

You already know that a sour taste is one property of acids. (**Never** taste an unknown substance to see whether it is an acid!) Acids have certain other properties as well. For example, acids can conduct electricity because they consist of charged particles in solution. Acids also react with metals to produce hydrogen gas. For example, when hydrochloric acid (HCl) reacts with the metal magnesium (Mg), it produces magnesium chloride ($MgCl_2$) and hydrogen (H_2). This is a single replacement reaction, represented by the chemical equation:

$$Mg + 2HCl \rightarrow H_2 + MgCl_2$$

You can see an online demonstration of a similar reaction at this URL: http://www.youtube.com/watch?v=oQz5YEsx7Fo .

Detecting Acids

Certain compounds, called indicators, change color when acids come into contact with them. They can be used to detect acids. An example of an indicator is a compound called litmus. It is placed on small strips of paper that may be red or blue. If you place a few drops of acid on a strip of blue litmus paper, the paper will turn red. You can see this in **Figure** 8.6. Litmus isn't the only indicator for detecting acids. Red cabbage juice also works well, as you can see in this entertaining video: http://www.youtube.com/watch?v=vrOUdoS2BtQ .

FIGURE 8.6
Blue litmus paper turns red when placed in an acidic solution.

Uses of Acids

Acids have many important uses, especially in industry. For example, sulfuric acid is used to manufacture a variety of different products, including paper, paint, and detergent. Some other uses of acids are illustrated in **Figure** 8.7.

FIGURE 8.7

Acids are used widely for many purposes.

Bases

A **base** is an ionic compound that produces negative hydroxide ions (OH^-) when dissolved in water. For example, when the compound sodium hydroxide (NaOH) dissolves in water, it produces hydroxide ions and positive sodium ions (Na^+). This can be represented by the equation:

$$NaOH \xrightarrow{H_2O} OH^- + Na^+$$

Properties of Bases

All bases share certain properties, including a bitter taste. (**Never** taste an unknown substance to see whether it is a base!) Did you ever taste unsweetened cocoa powder? It tastes bitter because it is a base. Bases also feel slippery. Think about how slippery soap feels. Soap is also a base. Like acids, bases conduct electricity because they consist of charged particles in solution.

Detecting Bases

Bases change the color of certain compounds, and this property can be used to detect them. A common indicator of bases is red litmus paper. Bases turn red litmus paper blue. You can see an example in **Figure** 8.8. Red cabbage juice can detect bases as well as acids, as you'll see by reviewing this video: http://www.youtube.com/watch?v=vrOUdoS2BtQ (3:14).

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URL: http://www.ck12.org/flx/render/embeddedobject/5011

FIGURE 8.8

Red litmus paper turns blue when placed in a basic solution.

Uses of Bases

Bases are used for a variety of purposes. For example, soaps contain bases such as potassium hydroxide. Other uses of bases are pictured in **Figure** 8.9.

FIGURE 8.9

Bases are used in many products.

Strength of Acids and Bases

The acid in vinegar is weak enough to safely eat on a salad. The acid in a car battery is strong enough to eat through skin. The base in antacid tablets is weak enough to take for an upset stomach. The base in drain cleaner is strong enough to cause serious burns. What causes these differences in strength of acids and bases?

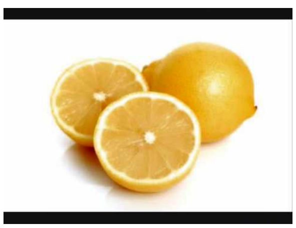
Concentration of Ions

The strength of an acid depends on the concentration of hydrogen ions it produces when dissolved in water. A stronger acid produces a greater concentration of ions than a weaker acid. For example, when hydrogen chloride is added to water, all of it breaks down into H^+ and Cl^- ions. Therefore, it is a strong acid. On the other hand, only about 1 percent of acetic acid breaks down into ions, so it is a weak acid.

The strength of a base depends on the concentration of hydroxide ions it produces when dissolved in water. For example, sodium hydroxide completely breaks down into ions in water, so it is a strong base. However, only a fraction of ammonia breaks down into ions, so it is a weak base.

The pH Scale

The strength of acids and bases is measured on a scale called the pH scale (see **Figure** 8.10). The symbol **pH** represents **acidity**, or the concentration of hydrogen ions (H^+) in a solution. Pure water, which is neutral, has a pH of 7. With a higher concentration of hydrogen ions, a solution is more acidic but has a lower pH. Therefore, acids have a pH less than 7, and the strongest acids have a pH close to zero. Bases have a pH greater than 7, and the strongest bases have a pH close to 14. You can watch a video about the pH scale at this URL: http://www.youtube.com/watch?v=M8tTELZD5Ek (2:23).



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Why pH Matters

Acidity is an important factor for living things. For example, many plants grow best in soil that has a pH between 6 and 7. Fish also need a pH close to 7. Some air pollutants form acids when dissolved in water droplets in the air. This results in acid fog and acid rain, which may have a pH of 4 or even lower (see **Figure** 8.10). **Figure** 8.11 shows the effects of acid fog and acid rain on a forest. Acid rain also lowers the pH of surface waters such as streams and lakes. As a result, the water became too acidic for fish and many other water organisms to survive.

Even normal (not acid) rain is slightly acidic. That's because carbon dioxide in the air dissolves in raindrops, producing a weak acid called carbonic acid. When acidic rainwater soaks into the ground, it can slowly dissolve rocks, particularly those containing calcium carbonate. This is how water forms caves, like the one that opened this chapter.

Reactions of Acids and Bases

As you read above, an acid produces positive hydrogen ions and a base produces negative hydroxide ions. If an acid and base react together, the hydrogen and hydroxide ions combine to form water. This is represented by the equation:

$$H^+ + OH^- \rightarrow H_2O$$

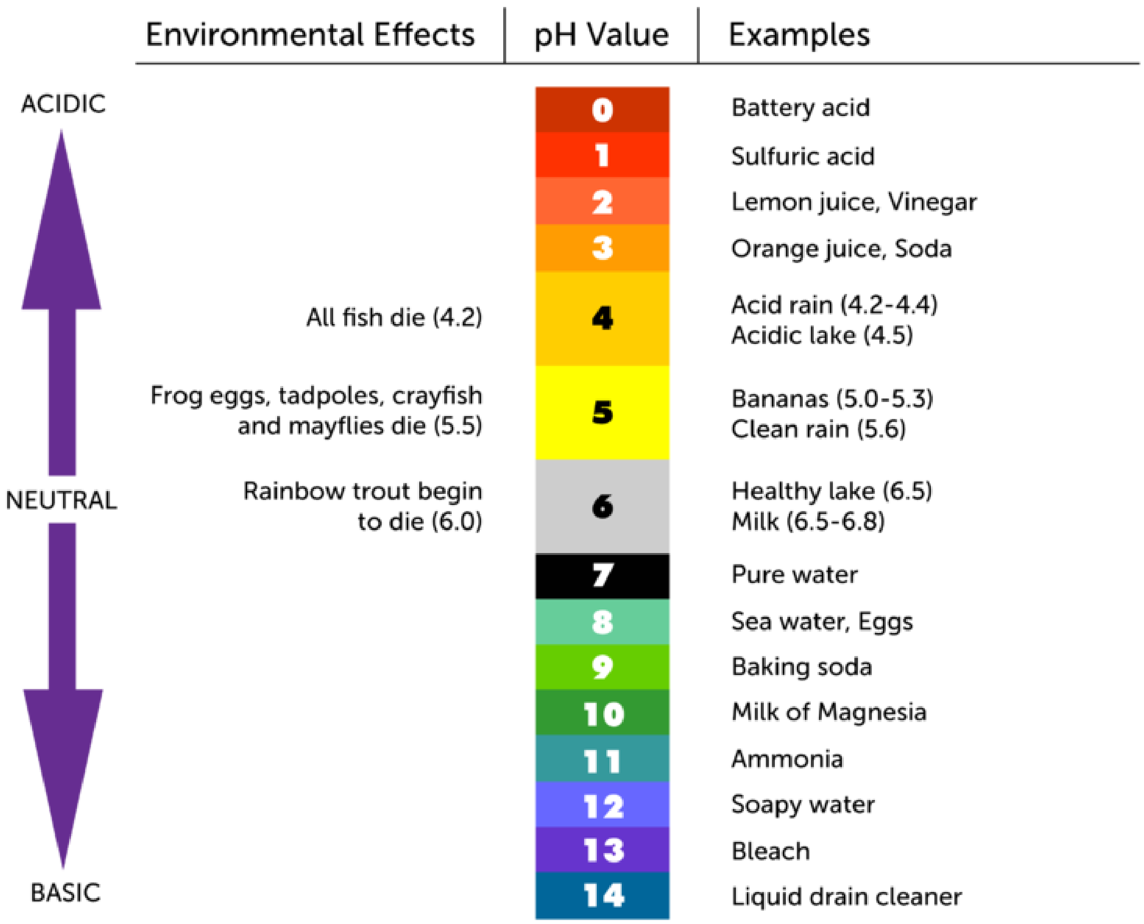

FIGURE 8.10

This pH scale shows the acidity of several common acids and bases. Which substance on this scale is the weakest acid? Which substance is the strongest base?

An acid also produces negative ions, and a base also produces positive ions. For example, the acid hydrogen chloride (HCl), when dissolved in water, produces negative chloride ions (Cl^-) as well as hydrogen ions. The base sodium hydroxide (NaOH) produces positive sodium ions (Na^+) in addition to hydroxide ions. These other ions also combine when the acid and base react. They form sodium chloride (NaCl). This is represented by the equation:

$$Na^+ + Cl^- \rightarrow NaCl$$

Sodium chloride is called table salt, but salt is a more general term. A **salt** is any ionic compound that forms when an acid and base react. It consists of a positive ion from the base and a negative ion from the acid. Like pure water, a salt is neutral in pH. That's why reactions of acids and bases are called **neutralization reactions**. Another example of a neutralization reaction is described in **Figure** 8.12. You can learn more about salts and how they form at this

FIGURE 8.11
Acid fog and acid rain killed the trees in this forest.

URL: http://www.youtube.com/watch?v=zjIVJh4JLNo (13:21).

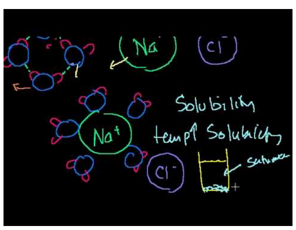

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FIGURE 8.12
What neutral products are produced when antacid tablets react with hydrochloric acid in the stomach?

Lesson Summary

- An acid is an ionic compound that produces positive hydrogen ions when dissolved in water. Acids taste sour and turn blue litmus paper red.
- A base is an ionic compound that produces negative hydroxide ions when dissolved in water. Bases taste bitter and turn red litmus paper blue.
- The strength of acids and bases is determined by the concentration of ions they produce when dissolved in water. The concentration of hydrogen ions in a solution is called acidity. It is measured by pH. A neutral substance has a pH of 7. An acid has a pH lower than 7, and a base has a pH greater than 7.
- The reaction of an acid and a base is called a neutralization reaction. It produces a salt and water, both of which are neutral.

Lesson Review Questions

Recall

1. What is an acid? Give one use of acids.
2. What is a base? Name a common product that contains a base.
3. Outline how litmus paper can be used to detect acids and bases.
4. Define acidity. How is it measured?

Apply Concepts

5. An unknown substance has a pH of 7.2. Is it an acid or a base? Explain your answer.
6. If hydrochloric acid (HCl) reacts with the base lithium hydroxide (LiOH), what are the products of the reaction? Write a chemical equation for the reaction.

Think Critically

7. Battery acid is a stronger acid than lemon juice. Explain why.

Points to Consider

Neutralization reactions, like the other chemical reactions you have read about so far, involve electrons. Electrons are outside the nucleus of an atom. Certain other reactions involve the nucleus of an atom instead. These reactions are called nuclear reactions. You will read about them in the next chapter, "Nuclear Chemistry."

- How do you think nuclear reactions might differ from chemical reactions?
- Elements involved in nuclear reactions are radioactive. How do you think radioactive elements differ from other elements?

8.4 References

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CHAPTER 9 MS Introduction to Ecology

Chapter Outline

The lake in this photo looks as though it might be completely lacking in life. Even its name—the Dead Sea—adds to that impression. Located far below sea level, the Dead Sea is much saltier than the ocean. It's too salty for fish, frogs, or other animals to survive. Yet even here, living things thrive. The bottom of the Dead Sea, for example, is carpeted with mats of microorganisms. How do they manage to live in these unusual conditions? How have they adapted to their extreme environment?

All organisms must adapt to their environment in order to survive. This is true whether they live in the highly salty water of the Dead Sea or in a lush tropical rainforest that is bursting with life. Most environments are not as extreme as the Dead Sea. But they all have conditions that require adaptations. In this chapter, you'll read about a wide variety of environments and the organisms that live in them.

9.1 What Is Ecology?

Lesson Objectives

- Define ecology.
- Distinguish between biotic and abiotic factors in the environment.
- Outline levels of organization in ecology.

Lesson Vocabulary

- abiotic factor
- biosphere
- biotic factor
- ecology

Introduction

The science of how living things interact with each other and their environment is called ecology. Ecology is a major branch of life science, but it overlaps with many other fields. For example, it shares data and theories with geography, biology, climatology, and other sciences. In this lesson, you'll learn some of the basic concepts of ecology.

Organisms and Environmental Factors

Organisms are individual living things. They range from microscopic bacteria to gigantic blue whales (see **Figure** 9.1). Despite their great diversity, all organisms have the same basic needs: energy and matter. Energy and matter must be obtained from the environment.

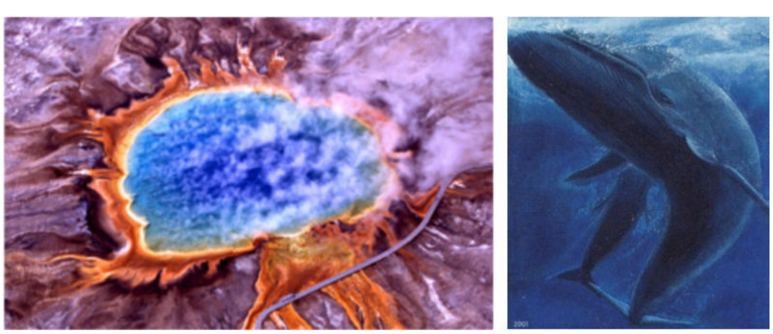


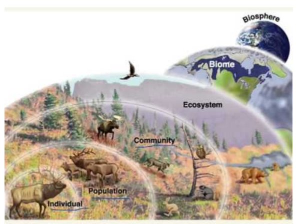
FIGURE 9.1
Organisms show tremendous diversity. Some of the smallest and largest living organisms are pictured here: billions of microorganisms that thrive in this hot spring give it its striking colors (left); blue whales are the largest living organisms (right).

Organisms depend on their environment to meet their needs, so they are greatly influenced by it. There are many factors in the environment that affect organisms. The factors can be classified as either biotic or abiotic.

- Biotic factors are all of the living or once-living aspects of the environment. They include all the organisms that live there as well as the remains of dead organisms.
- Abiotic factors are all of the aspects of the environment that have never been alive. They include factors such as sunlight, minerals in soil, temperature, and moisture.

Levels of Organization in Ecology

Ecologists study organisms and environments at several different levels, from the individual to the biosphere. The levels are depicted in **Figure** 9.2 and described below. For a video introduction to the levels of organization in ecology, click on this link: http://www.youtube.com/watch?v=5FtlqU1DDK0 .



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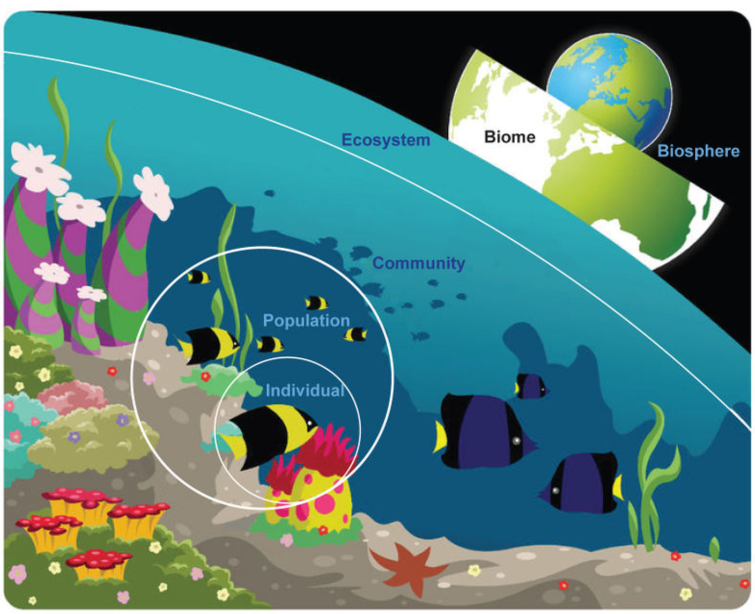


FIGURE 9.2

From individuals to the biosphere, ecology can be studied at several different levels.

- An individual is an organism, or single living thing.
- A population is a group of individuals of the same species that live in the same area. Members of the same population generally interact with each other.
- A community is made up of all the populations of all the species that live in the same area. Populations in a community also generally interact with each other.

- An ecosystem consists of all the biotic and abiotic factors in an area. It includes a community, the abiotic factors in the environment, and all their interactions.
- A biome is a group of similar ecosystems with the same general abiotic factors and primary producers. Biomes may be terrestrial (land-based) or aquatic (water-based).
- The biosphere consists of all the parts of Earth where life can be found. This is the highest level of organization in ecology. It includes all of the other levels below it. The biosphere consists of all the world's biomes, both terrestrial and aquatic.

Lesson Summary

- Ecology is the science of how living things interact with each other and their environment.
- All organisms depend on their environment for energy and matter and are influenced by their environment. Factors in the environment that can affect organisms include biotic factors and abiotic factors.
- Ecologists study organisms and environments at several different levels. From smallest to largest, they include the individual, population, community, ecosystem, biome, and biosphere.

Lesson Review Questions

Recall

1. What is ecology?
2. Define the biosphere.

Apply Concepts

3. Make an illustrated chart to show the different levels of organization in ecology.

Think Critically

4. Explain why organisms depend on their environment.
5. Compare and contrast biotic and abiotic factors in the environment.

Points to Consider

The population is an important level of organization in ecology. It is also the unit of microevolution.

1. What is a population?
2. How can a population grow?

9.2 Populations

Lesson Objectives

- Define population.
- Identify measures of population size, growth, and structure.
- Describe how the human population grew in the past and is predicted to grow in the future.

Lesson Vocabulary

- age-sex structure
- carrying capacity
- demographic transition
- exponential growth
- logistic growth
- population density
- population distribution
- population growth rate
- population pyramid

Introduction

A population is a group of individuals of the same species that live in the same area. The population is the unit of natural selection, adaptation, and microevolution. In ecology, how large a population is and how quickly it is growing are often used as measures of a species' health.

Population Size, Growth, and Structure

Population size is the number of individuals in a population. Population size influences the chances of a species surviving or going extinct. If a species' populations become very small, the species may be at risk of going extinct.

Population Density and Distribution

Another sign of a species' state of health is the density of its populations. Population density is the average number of individuals in a population for a given area. Density is a measure of how crowded or spread out the individuals in a population are on average. For example, a population of 100 deer that live in an area of 10 square kilometers has a population density of 10 deer per square kilometer.

Population density is an average measure. Often, individuals in a population are not spread out evenly. Instead, they may live in clumps or some other pattern. How individuals in a population are distributed, or spread throughout their area, is called population distribution. You can see different patterns of population distribution in **Figure** 9.3. Different patterns characterize different species and types of environments, as you can read in the figure.

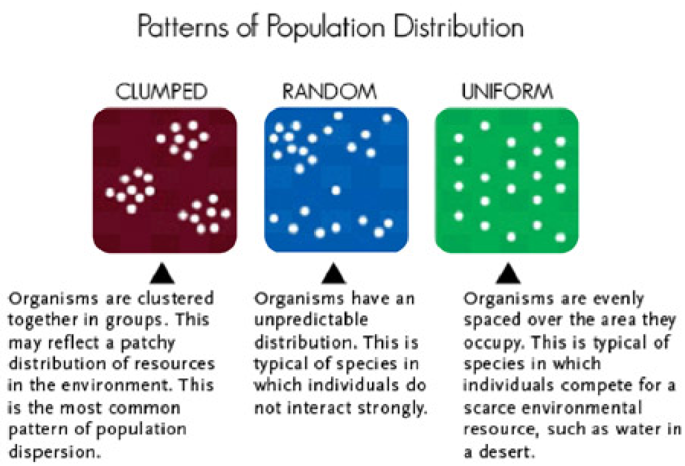


FIGURE 9.3

Patterns of population distribution include clumped, random, and uniform distributions. Each pattern is associated with different types of species or environments.

Population Growth

Whether its populations are growing or shrinking in size may be another indicator of a species' health. Individuals may be added to a population through births and the migration of individuals into the population. Individuals may be lost from a population through deaths and the migration of individuals out of the population.

The population growth rate is how quickly a population changes in size over time. The rate of growth of a population may be positive or negative. A positive growth rate means that the population is increasing in size because more people are being added than lost. A negative growth rate means that the population is decreasing in size because more people are being lost than added.

Populations may show different patterns of growth. The growth pattern depends partly on the conditions under which a population lives. Two common growth patterns are exponential growth and logistic growth. Both are represented in **Figure** 9.4.

- With exponential growth, the population starts out growing slowly. As population size increases, the growth rate also increases. The larger the population becomes, the more quickly it grows. This type of growth generally occurs only when a population is living under ideal conditions. However, it can't continue for very long.
- With logistic growth, the population starts out growing slowly, and then the rate of growth increases—but only to a point. The rate of growth tapers off as the population size approaches its carrying capacity. Carrying capacity is the largest population size that can be supported in an area without harming the environment. This type of growth characterizes many populations.

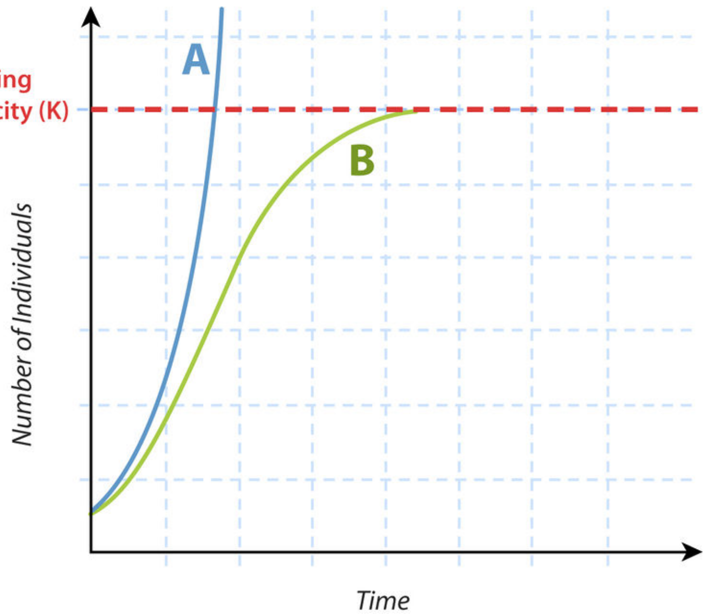
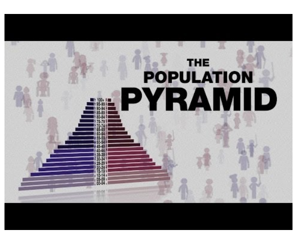


FIGURE 9.4
Curve A represents exponential population growth. Curve B represents logistic population growth.

Population Age and Sex Structure

Another way of describing a population is its age-sex structure. This refers to the numbers of individuals of each sex and age in the population. The age-sex structure of a population may influence the population growth rate. This is because only individuals of certain ages are able to reproduce, and because individuals of certain ages may be more likely to die. For example, if there are many individuals of reproductive age, there are likely to be many births, causing the population to grow rapidly.

The age-sex structure of a population is often represented with a special bar graph called a population pyramid. You can see an example of a population pyramid in **Figure** 9.5. The graph in the figure actually has a pyramid shape because the bars become narrower from younger to older ages. However, this is not always the case. In some populations, for example, there may be more people at older than younger ages, resulting in a top-heavy population pyramid. Learn more about population pyramids and what you can learn from them, watch this TED video: http://www.youtube.com/watch?v=RLmKfXwWQtE .



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The Human Population

Human beings have been called the most successful weed species on Earth. Like garden weeds, populations of human beings grow quickly and disperse rapidly. Human beings have colonized almost every terrestrial part of the planet. Overall, the human population has had a pattern of exponential growth, as you can see in **Figure** 9.6. The early human population grew very slowly. However, as the population grew larger, it started to grow more rapidly.

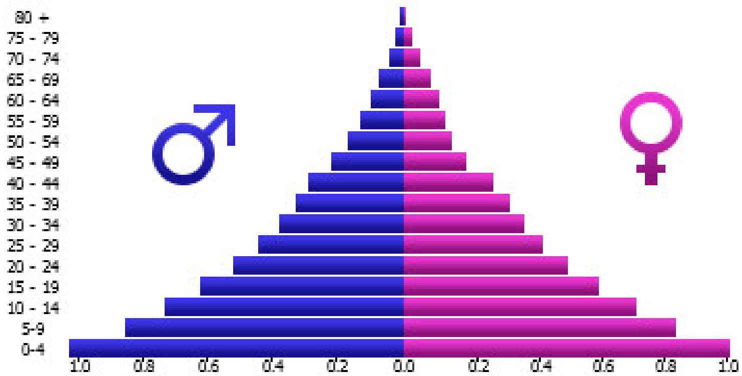

FIGURE 9.5

A population pyramid shows the age-sex structure of a population. This population pyramid represents the human population of the African country of Angola in 2005.

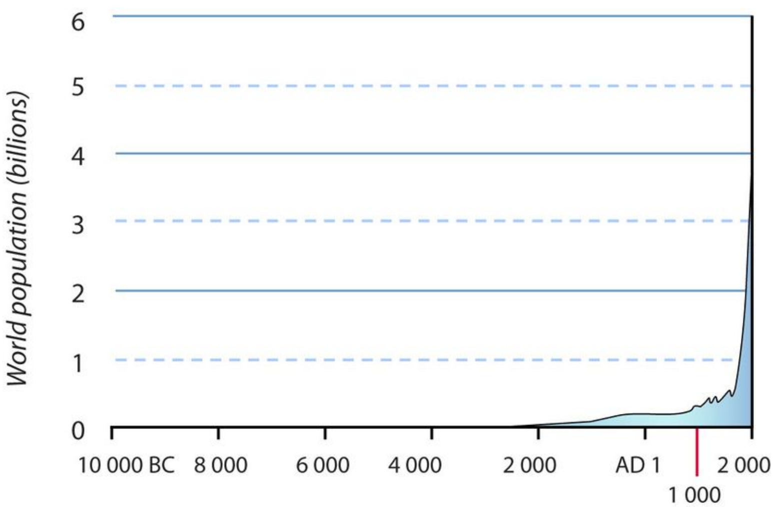

FIGURE 9.6

Growth of the Human Population.

Early Population Growth

The earliest members of the human species evolved around 200,000 years ago in Africa. Early humans lived in small populations of nomadic hunters and gatherers. Human beings remained in Africa until about 40,000 years ago. After that, they spread throughout Europe, Asia, and Australia. By 10,000 years ago, the first human beings colonized the Americas. During this long period of time, the total number of human beings increased very slowly. Birth rates were fairly high but so were death rates, producing low rates of population growth.

Human beings invented agriculture about 10,000 years ago. This provided a bigger, more dependable food supply. It also allowed people to settle down in villages and cities for the first time. Birth rates went up because there was more food and settled life had other advantages. Death rates also rose because of crowded living conditions and diseases that spread from domestic animals. Because the higher birth rates were matched by higher death rates, the human population continued to grow very slowly.

Demographic Transition

Major changes in the human population first began in the 1700s. These changes occurred mainly in Europe, North America, and a few other places that became industrialized. First death rates fell. Then, somewhat later, birth rates also fell. These changes in death and birth rates affected the rate of population growth and are referred to as the demographic transition. The graph in **Figure** 9.7 shows the stages in which the demographic transition occurred. You can learn more about the stages by watching this video: http://education-portal.com/academy/lesson/what-is-demographic-transition-definition-stages.html

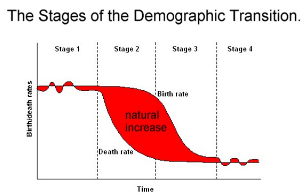

FIGURE 9.7
The demographic transition occurred in the stages shown in this graph.

In Stage 1, both birth and death rates were high so population growth was slow. In Stage 2, death rates fell while birth rates remained high. Why did death rates fall? There were several reasons, including new scientific knowledge of the causes of disease. Water supplies were cleaned up and sewage was disposed of more safely. Better farming techniques and machines increased the food supply and the distribution of food. For all these reasons, death rates fell, especially in children. Birth rates, on the other hand, remained high. This resulted in faster population growth.

Before long, birth rates also started to fall. People started having fewer children because large families became too expensive. For example, with better farming machines, farm families no longer needed as many children to work in the fields. Laws were also passed that required children to go to school. They could no longer work and help support the family. Having many children became too costly. Eventually, birth rates fell to match death rates (Stage 4). As a result, population growth slowed down.

Recent Population Growth

Just as they did in Europe and North America, death rates have fallen throughout the world. No country today remains in Stage 1 of the demographic transition. However, birth rates are still high in many of the poorest countries of the world. These populations seem to be stuck in Stage 2 or 3 of the demographic transition. They have high population growth rates because low death rates are not matched by equally low birth rates. Whether these populations will ever enter Stage 4 and attain very low rates of population growth is uncertain.

Future Population Growth

As of 2014, there were more than 7 billion human beings on planet Earth. That number is increasing rapidly. More than 200,000 people are added to the human population each day! At this rate, the human population will pass 9 billion by 2050.

Many experts think that the human population has reached its carrying capacity. It has already harmed the environment. An even larger human population may cause severe environmental problems. It could also lead to devastating outbreaks of disease, starvation, and war. To solve these problems, two approaches may be needed:

- Slow down human population growth so there are fewer people.
- Distribute Earth's resources more fairly so that everyone has enough.

Hopefully, we will act before it's too late. Otherwise, the planet may be ruined for future generations of human beings and other species.

Lesson Summary

- A population is a group of individuals of the same species that live in the same area.
- Populations can be described in terms of size, density, and distribution. Population growth may be exponential or logistic. The age-sex structure of a population affects the rate of population growth.
- The world's human population has shown exponential growth. It grew very slowly for tens of thousands of years. Then it started growing very rapidly as many populations reached and remained in Stage 2 or 3 of the demographic transition. At the current rate of growth, the human population is predicted to pass 9 billion by 2050.

Lesson Review Questions

Recall

1. Define population.
2. What is a population pyramid?
3. What are some changes that caused the original demographic transition?

Apply Concepts

4. Describe the growth of a population that in a given year has 10 births, 8 deaths, and no migration.
5. If the human population reaches predicted levels by 2050, how do you think this may affect the environment?

Think Critically

6. Compare and contrast the concepts of population density and population distribution.
7. Relate carrying capacity to logistic growth of a population.

Points to Consider

A population doesn't exist alone. It is part of a community.

1. What is a community?
2. How might populations in a community interact?

9.3 Communities

Lesson Objectives

- Define community.
- Explain how predation affects predator and prey populations.
- Describe outcomes of intraspecific and interspecific competition.
- Identify three types of symbiotic relationships.

Lesson Vocabulary

- commensalism
- community
- competition
- host
- keystone species
- mutualism
- parasite
- parasitism
- predation
- predator
- prey
- symbiosis

Introduction

A community is the biotic component of an ecosystem. It consists of the populations of all the species that live in the same area. Populations in communities often interact with each other. Community interactions are important factors in natural selection. They help shape the evolution of the interacting species. Types of community interactions include predation, competition, and symbiosis. You'll read about each type of interaction in this lesson.

Predation

Predation is a relationship in which members of one species consume members of another species. The consuming species is called the predator. The species that is consumed is called the prey. In **Figure** 9.8, the wolves are predators, and the moose is their prey.

FIGURE 9.8
Pack of wolves preying on a moose

Predator and Prey Populations

A predator-prey relationship tends to keep the populations of both species in balance. Look at the graph in **Figure** 9.9. As the prey population increases, there is more food for the predators. So after a slight lag time, the predator population also increases. As the number of predators increases, more prey are captured. This causes the prey population to decrease, followed by the predator population decreasing again.

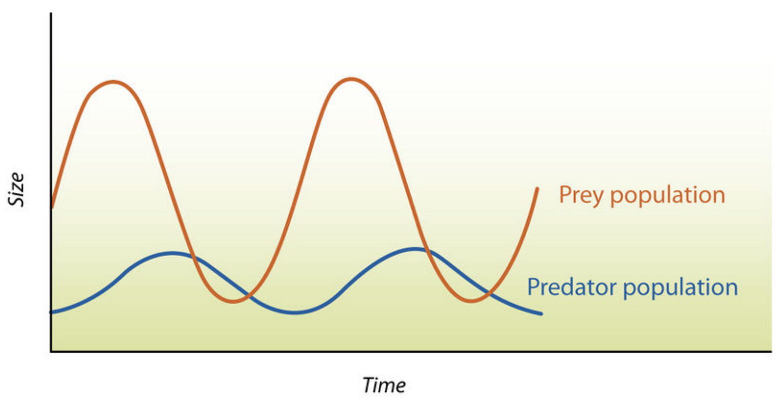

FIGURE 9.9
Predator-Prey populations.

Keystone Species

Some predator species play a special role in their community. They are called keystone species. When the population size of a keystone species changes, the populations of many other species are affected. Prairie dogs, pictured in **Figure** 9.10, are an example of a keystone species. Their numbers affect most of the other species in their community. Prairie dog actions improve the quality of soil and water for plants, upon which most other species in the community depend.

Adaptations to Predation

Both predators and prey have adaptations to predation that evolve through natural selection. Predator adaptations help them capture prey. Prey adaptations help them avoid predators. A common adaptation in both predator and prey species is camouflage. You can see an example in **Figure** 9.11. You can also see some amazing examples in

FIGURE 9.10
Prairie dogs are a keystone species in their community.

this video: http://www.ted.com/talks/david_gallo_shows_underwater_astonishments?language=en

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FIGURE 9.11
There is a well-camouflaged frog in this photo. Do you see it?

Competition

Competition is a relationship between organisms that depend on the same resources. The resources might be food, water, or space. Competition can occur between organisms of the same species or between organisms of different species.

- Competition within a species is called intraspecific competition. It leads to natural selection within the species, so the species becomes better adapted to its environment.

- Competition between different species is called interspecific competition. It might lead to the less well-adapted species going extinct. Or it might lead to one or both species evolving specialized adaptations. For example, competing species might evolve adaptations that allow them to use different food sources. You can see an example in **Figure** 9.12.

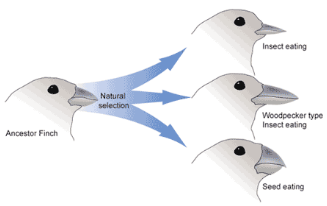


FIGURE 9.12
These species of birds have evolved different types of beaks to exploit different food sources. This allows them to live in the same area without competing for food.

Symbiosis

Symbiosis is a close relationship between two species in which at least one species benefits. For the other species, the relationship may be beneficial, harmful, or neutral. There are three types of symbiosis: mutualism, parasitism, and commensalism.

Mutualism

Mutualism is a symbiotic relationship in which both species benefit. An example of mutualism is pictured in **Figure** 9.13. The clownfish in the photo is hiding among the tentacles of a sea anemone. The tentacles have stingers that can inject poison in the anemone's prey. The clownfish is protected from the stingers by mucus that covers its body.

How do the two species benefit from their close relationship? The anemone provides the clownfish with a safe place to live by keeping away predatory fish. The clownfish also feeds on the remains of the anemone's prey. In return, the clownfish helps the anemone catch food by attracting prey with its bright colors. Its feces also provide nutrients to the anemone.

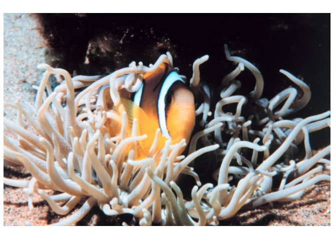


FIGURE 9.13
A clownfish takes refuge among the tentacles of a sea anemone.

Parasitism

Parasitism is a symbiotic relationship in which one species benefits and the other species is harmed. The species that benefits is called the parasite. The species that is harmed is called the host. Many species of animals are parasites, at least during some stage of their life cycle. Most animal species are also hosts to one or more parasites.

A parasite generally lives in or on its host. An example of a parasite that lives in its host is the hookworm. **Figure** 9.14 shows two hookworms living inside a human host's intestines. The hookworms obtain nutrients and shelter from their host, which is harmed by the loss of nutrients and blood.

Some parasites kill their host, but most do not. It's easy to see why. If a parasite kills its host, the parasite may also die. Instead, parasites usually cause relatively minor damage to their host.

FIGURE 9.14
Hookworm parasites inside their human host's intestines

Commensalism

Commensalism is a symbiotic relationship in which one species benefits while the other species is not affected. An example is the relationship between birds called cattle egrets and cattle (see **Figure** 9.15). Cattle egrets feed on insects. They follow cattle herds around to take advantage of the insects stirred up by the feet of the cattle. The egrets get ready access to food from the relationship, whereas the cattle are not affected.

FIGURE 9.15
A cattle egret "hangs out" near cattle to catch insects stirred up by the cattle's feet.

Lesson Summary

- A community is the biotic component of an ecosystem. It consists of the populations of all the species that live in the same area.
- Predation is a relationship in which members of one species, called the predator, consume members of another species, called the prey.
- Competition is a relationship between organisms that depend on the same resources. Competition can occur between members of the same species or between members of different species.
- Symbiosis is a close relationship between two species in which at least one species benefits. Types of symbiosis include mutualism, parasitism, and commensalism.

Lesson Review Questions

Recall

1. Define community.
2. Describe two potential outcomes of interspecific competition.
3. Identify three types of symbiosis.

Apply Concepts

4. After a rainy summer and excessive weed growth, a population of mice has doubled in size because of a greater food supply. The main predators of the mice are owls. Predict how the owl population in the same community is likely to change.

Think Critically

5. Explain how camouflage could benefit both predator and prey species.
6. Why do parasites usually not kill their host?

Points to Consider

A community is the biotic component of an ecosystem.

1. What is an ecosystem?
2. What are some examples of ecosystems?

9.4 Ecosystems

Lesson Objectives

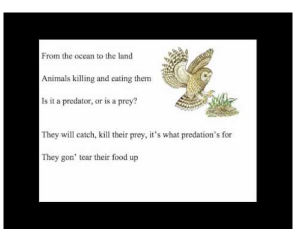
- Define ecosystem.
- Describe the role of energy and matter in ecosystems.
- Define niche and habitat, and explain the competitive exclusion principle.

Lesson Vocabulary

- competitive exclusion principle
- ecosystem
- habitat
- niche

Introduction

The focus of study in ecology is often the ecosystem. Ecosystems are units of nature. Each ecosystem consists of all the biotic and abiotic factors in an area and all the ways in which the factors interact. A forest could be an ecosystem, but so could a dead log on the forest floor. Both the forest and the log contain a community of species that interact with each other and with abiotic factors. For an entertaining introduction to ecosystems, watch this great music video: http://www.youtube.com/watch?v=GUY_-LK_lOc .



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Energy and Matter in Ecosystems

Ecosystems need a constant input of energy to supply the needs of their organisms. Most ecosystems get energy from sunlight. A few ecosystems get energy from chemical compounds.

Unlike energy, matter doesn't need to be constantly added to ecosystems. Instead, matter is recycled through ecosystems. Water and elements such as carbon and nitrogen that living things need are used over and over again.

Key Ecosystem Concepts

Two important concepts associated with the ecosystem are niche and habitat.

Niche

Niche is the role that a particular species plays in its ecosystem. This role includes all the ways that the species interacts with the biotic and abiotic factors in the ecosystem.

A major aspect of any niche is how the species obtains energy and matter. Look at **Figure** 9.16. The grass in the figure obtains energy from sunlight and uses it to convert carbon dioxide and water to sugar by photosynthesis. The deer in the figure gets matter and energy by consuming and digesting the grass. Each species has a different and distinctive niche.

FIGURE 9.16

The grass and deer fill two different niches in an ecosystem.

Habitat

Another important aspect of a species' niche is its habitat. Habitat is the physical environment in which a species lives and to which it has adapted. Features of a habitat depend mainly on abiotic factors, such as temperature and rainfall. These factors influence the traits of the organisms that live there.

Just One Species Please!

A given habitat may contain many different species. However, each species in the same habitat must have a different niche. Two different species cannot occupy the same niche in the same habitat at the same time. This is called the competitive exclusion principle.

What do you think would happen if two species were to occupy the same niche in the same habitat? The two species would compete for everything they needed in the environment. One species might outcompete and replace the other. Or, both species might evolve different specializations so they can fill slightly different niches.

Lesson Summary

- An ecosystem is a unit of nature. It consists of all the biotic and abiotic factors in an area and all the ways in which they interact.
- Ecosystems need a constant input of energy for their organisms, but matter is recycled through ecosystems.

- Niche is the role that a particular species plays in its ecosystem. Habitat is the physical environment in which a species lives and to which it has adapted. According to the competitive exclusion principle, two different species cannot occupy the same niche in the same habitat at the same time.

Lesson Review Questions

Recall

1. What is an ecosystem?
2. Define niche.

Apply Concepts

3. Two different species of birds live in the same habitat and eat the same foods. What can you conclude about the niches of the two species?

Think Critically

4. Relate the competitive exclusion principle to the concepts of niche, habitat, and competition.

Points to Consider

Similar ecosystems are found in different parts of the world. For example, forests and deserts are found on almost all of Earth's continents.

1. What factors do you think determine where a particular terrestrial ecosystem is found?
2. Think about your own ecosystem. Where else in the world might a similar ecosystem be found?

9.5 Biomes

Lesson Objectives

- Define biome.
- Explain how climate affects terrestrial biomes, and give examples of terrestrial biomes.
- Identify freshwater and marine biomes and relate them to sunlight and nutrients.

Lesson Vocabulary

- aphotic zone
- aquatic biome
- biome
- climate
- freshwater biome
- marine biome
- photic zone
- terrestrial biome

Introduction

Look at the two photos in **Figure** 9.17. The left photo shows a forest in South Carolina. The right photo shows Death Valley, a desert in California. Both places are found at about the same latitude, or distance from the equator. However, in many other ways, the two places could hardly be more different. What explains the differences? The South Carolina forest is near an ocean, giving it a wet climate. Death Valley is the rain shadow of mountains, giving it a very dry climate.

FIGURE 9.17
Two locations in the US at about 35 degrees North latitude: South Carolina forest (left) and California desert (right).

The two photos in **Figure** 9.17 represent two different biomes. A biome is a group of similar ecosystems with the same general abiotic factors and primary producers. Producers are organisms that produce food for themselves and other organisms. Biomes may be terrestrial or aquatic.

Terrestrial Biomes

Terrestrial biomes are land-based biomes. They range from arctic tundra to tropical rainforests. **Figure** 9.18 shows the locations of the world's major terrestrial biomes.

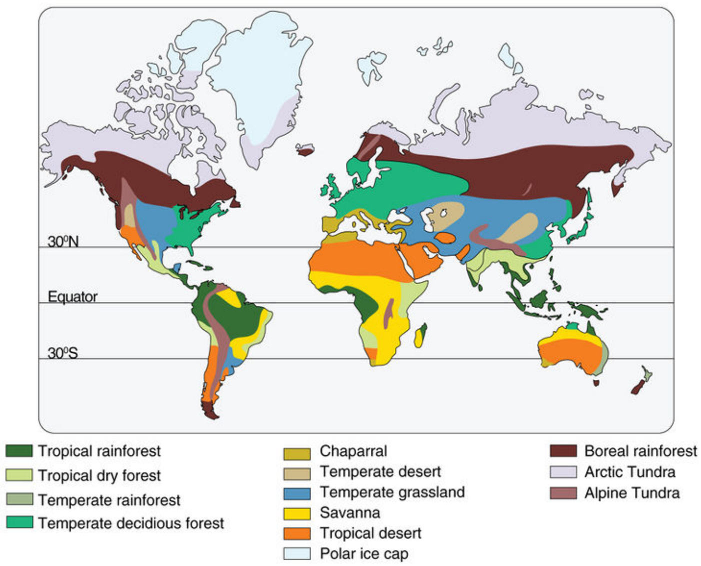

FIGURE 9.18
Major terrestrial biomes

Terrestrial Biomes and Climate

Plants are the primary producers in terrestrial biomes. They make food for themselves and other organisms by photosynthesis. The major plants in a given biome, in turn, help determine the types of animals and other organisms that can live there.

Which plants grow in a given biome depends mainly on climate. Climate is the average weather in a place over a long period of time. The major climatic factors affecting plant growth are temperature and moisture.

Examples of Terrestrial Biomes

You can read about three different terrestrial biomes in **Figure** 9.19: tropical rainforest, temperate grassland, and tundra. You can learn more about these and other terrestrial biomes by watching this video: http://www.youtube.com/watch?v=dTaWsFct32g .

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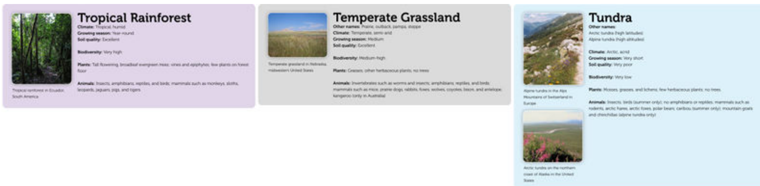

FIGURE 9.19

Terrestrial biomes include tropical rainforest, temperate grassland, and tundra.

Aquatic Biomes

Aquatic biomes are water-based biomes. They include both freshwater biomes, such as rivers and lakes, and marine biomes, which are salt-water biomes in the ocean. The primary producers in most aquatic biomes are phytoplankton. Phytoplankton consist of microscopic bacteria and tiny algae that make food by photosynthesis. Unlike terrestrial biomes, which are determined mainly by temperature and moisture, aquatic biomes are determined mainly by sunlight and dissolved substances in the water. These factors, in turn, depend mainly on depth of water and distance from shore.

Aquatic Biomes and Sunlight

Only the top 200 meters or so of water receive enough sunlight for photosynthesis. This part of the water is called the photic zone. Below 200 meters, there is too little sunlight for photosynthesis to take place. This part of the water is called the aphotic zone. In this zone, food must come from other sources. It may be made by chemosynthesis, in which microorganisms use energy in chemicals instead of sunlight to make food. Or, food may drift down from the water above.

Aquatic Biomes and Dissolved Substances

In addition to sunlight, aquatic producers also need dissolved oxygen and nutrients. Water near the surface generally contains more dissolved oxygen than deeper water. Many nutrients enter the water from the land. Therefore, water nearer shore usually contains more dissolved nutrients than water farther from shore.

Freshwater Zones

A lake is an example of a freshwater biome. Water in a lake generally forms three different zones based on water depth and distance from shore.

- The shallow water near the shore is called the littoral zone. It has diverse community of organisms. There is adequate light for photosynthesis and plenty of dissolved oxygen and nutrients. Producers include algae and aquatic plants (see **Figure** 9.20). Animals in this zone may include insects, crustaceans, fish, and turtles.

- The top layer of water farther from shore is called the limnetic zone. There is enough light for photosynthesis and plenty of dissolved oxygen. However, dissolved nutrients tend not to be as plentiful as they are in the littoral zone. Producers here are mainly phytoplankton. A variety of zooplankton and fish also occupy this zone.
- The deeper water of a lake makes up the profundal zone. There isn't enough light for photosynthesis in this zone, so most organisms here eat dead organisms that drift down from the water above. Organisms in the profundal zone may include clams, snails, and some species of fish.

FIGURE 9.20
Plants and algae are producers in the littoral zone along the shore of this lake in Iceland.

Ocean Zones

Zones in the oceans include the intertidal, pelagic, and benthic zones. The types of organisms found in these ocean zones are also determined by such factors as depth of water and distance from shore, among other factors.

One of the most familiar ocean zones is the intertidal zone. This is the narrow strip along a coastline that is covered by water at high tide and exposed to air at low tide. You can see an example of an intertidal zone in **Figure** 9.21. There are plenty of nutrients and sunlight in the intertidal zone. Producers here include phytoplankton and algae. Other organisms include barnacles, snails, crabs, and mussels. They must have adaptations for the constantly changing conditions in this zone.

FIGURE 9.21
Intertidal zone along the North Sea in the Netherlands

Other ocean zones are farther from shore in the open ocean. All the water in the open ocean is called the pelagic zone. It is further divided by depth:

- The top 200 meters of water is the photic zone. Producers here include seaweeds and phytoplankton. Other organisms are plentiful. They include zooplankton and animals such as fish, whales, and dolphins.

- Below 200 meters is the aphotic zone. There are no primary producers here because there isn't enough sunlight for photosynthesis. However, the water may be rich in nutrients because of dead organisms drifting down from above. Organisms that live here may include bacteria, sponges, sea anemones, worms, sea stars, and fish.
- The bottom of the ocean is called the benthic zone. It includes the sediments on the bottom of the ocean and the water just above it. Organisms living in this zone include clams and crabs. They may be few in number due to relatively scarce nutrients in this zone.
- There are many more organisms around deep-sea vents. Microorganisms use chemicals that pour out of the vents to make food by chemosynthesis. These producers support large numbers of other organisms, including crustaceans and red tubeworms like those pictured in **Figure** 9.22.

FIGURE 9.22
Ocean vent biome

Lesson Summary

- A biome is a group of similar ecosystems with the same general abiotic factors and primary producers.
- Terrestrial biomes are determined mainly by temperature and moisture. Plants are the primary producers. Examples of terrestrial biomes include tropical rainforests, temperate grasslands, and tundra.
- Aquatic biomes are determined mainly by depth of water and distance from shore. They include freshwater and marine biomes.

Lesson Review Questions

Recall

1. What is a biome?
2. Identify three terrestrial biomes.
3. Describe the intertidal zone.

Apply Concepts

4. Randomly choose a location on the map in **Figure** 9.18. Identify its biome and then research that biome to find out what plants and animals you might find there.

Think Critically

5. Explain the relationship between climate and terrestrial biomes.
6. Compare and contrast the photic and aphotic zones of a body of water.

Points to Consider

In all biomes, ecosystems need a constant input of energy. Matter, on the other hand, is constantly recycled in ecosystems.

1. Where do most ecosystems get energy?
2. What are some examples of cycles of matter?

9.6 References

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CHAPTER 10 MS Ecosystem Dynamics

Chapter Outline

Sunlight strikes the leaves of this plant. The leaves are like tiny factories. They use the energy in sunlight to manufacture food. Light from the sun is the driving force behind photosynthesis and most of the planet's ecosystems.

10.1 Flow of Energy

Lesson Objectives

- Explain how living things are classified based on the way they obtain energy.
- Show how food chains and food webs model the flow of energy through ecosystems.
- Identify trophic levels, and state how they are related to energy and biomass.

Lesson Vocabulary

- biomass
- chemoautotroph
- chemosynthesis
- consumer
- decomposer
- detritivore
- food chain
- food web
- photoautotroph
- producer
- saprotroph
- scavenger
- trophic level

Introduction

Energy is the ability to change or move matter. All living things need energy. They need energy for everything they do, whether it is to move long distances or simply to carry out basic biochemical processes inside cells. Energy enters most ecosystems in the form of sunlight. In a few ecosystems, energy enters in the form of chemical compounds. All ecosystems need a constant input of energy in one of these two forms.

Types of Organisms and Energy

Living things can be classified based on how they obtain energy. Some use the energy in sunlight or chemical compounds directly to make food. Some get energy indirectly by consuming other organisms, either living or dead.

Producers

Producers are living things that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. Producers are vital to all ecosystems because all organisms need organic compounds for energy.

Producers are also called autotrophs. There are two basic types of autotrophs: photoautotrophs and chemoautotrophs.

- Photoautotrophs use energy in sunlight to make organic compounds by photosynthesis. They include plants, algae, and some bacteria (see **Figure** 10.1).
- Chemoautotrophs use energy in chemical compounds to make organic compounds. This process is called chemosynthesis. Chemoautotrophs include certain bacteria and archaea.

FIGURE 10.1
The green streaks in this brilliant blue Guatemalan lake are billions of photosynthetic bacteria.

Consumers

Consumers are organisms that depend on other living things for food. They take in organic compounds by eating or absorbing other living things. Consumers include all animals and fungi. They also include some bacteria and protists.

Consumers are also called heterotrophs. There are several different types of heterotrophs depending on exactly what they consume. They may be herbivores, carnivores, or omnivores.

- Herbivores are heterotrophs that consume producers such as plants or algae. Examples include rabbits and snails.
- Carnivores are heterotrophs that consume animals. Examples include lions and frogs.
- Omnivores are heterotrophs that consume both plants and animals. They include crows and human beings. The grizzly bears pictured in **Figure** 10.2 are also omnivores.

Decomposers

Decomposers are heterotrophs that break down the wastes of other organisms or the remains of dead organisms. When they do, they release simple inorganic molecules back into the environment. Producers can then use the

FIGURE 10.2
Grizzly bears eat both plant and animal foods, including grasses, berries, fish, and clams.

inorganic molecules to make new organic compounds. For this reason, decomposers are essential to every ecosystem. Imagine what would happen if there were no decomposers. Organic wastes and dead organisms would pile up everywhere, and their nutrients would no longer be recycled.

Decomposers are classified by the type of organic matter they break down. They may be scavengers, detritivores, or saprotrophs.

- Scavengers are decomposers that consume the soft tissues of dead animals. Examples of scavengers include hyenas and cockroaches.
- Detritivores are decomposers that consume dead leaves, animal feces, and other organic debris that collects on the ground or at the bottom of a body of water. Examples of detritivores include earthworms and catfish. You can see another example in **Figure** 10.3.
- Saprotrophs are decomposers that feed on any remaining organic matter that is left after other decomposers do their work. Examples of saprotrophs include fungi and protozoa.

FIGURE 10.3
These dung beetles are detritivores. They are feasting on a pile of horse dung (feces).

Modeling the Flow of Energy

Energy flows through ecosystems from producers, to consumers, to decomposers. Food chains and food webs are diagrams that model this flow of energy. They represent feeding relationships by showing who eats whom.

Food Chains

A food chain is a diagram that represents a single pathway through which energy flows through an ecosystem. Food chains are generally simpler than what really happens in nature. That's because most organisms consume and are consumed by more than one species. You can see examples of terrestrial and aquatic food chains in **Figure** 10.4. See if you can construct a food chain of each type by playing the animation at this link: http://www.ecokids.ca/pub/eco_info/topics/frogs/chain_reaction/play_chainreaction.cfm

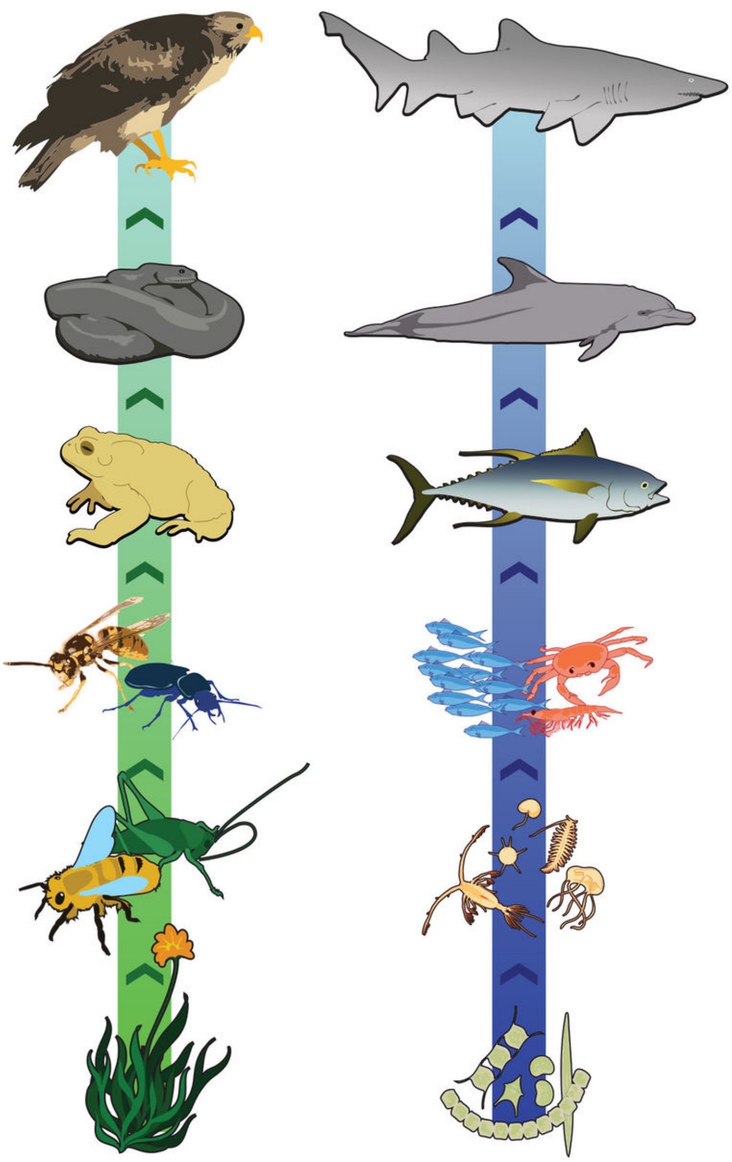


FIGURE 10.4
Terrestrial (left) and aquatic (right) food chains

Food Webs

A food web is a diagram that represents many pathways through which energy flows through an ecosystem. It includes a number of intersecting food chains. Food webs are generally more similar to what really happens in nature. They show that most organisms consume and are consumed by multiple species. You can see an example of a food web in **Figure** 10.5.

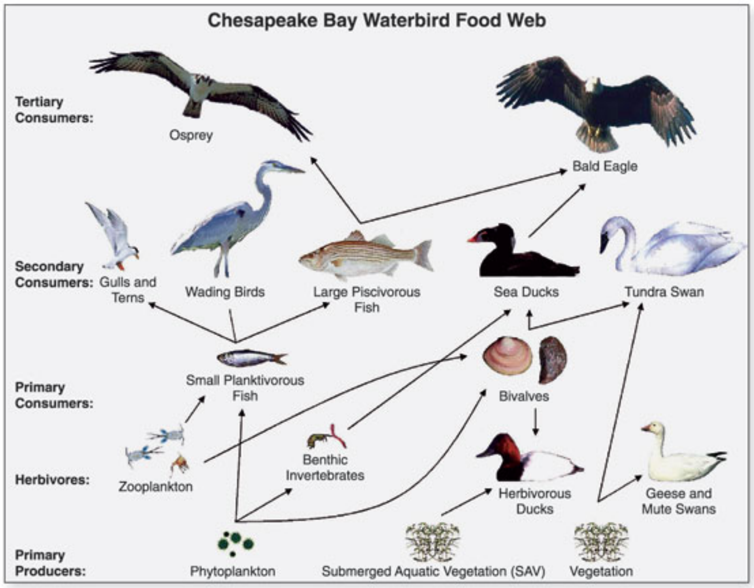


FIGURE 10.5
Food web showing trophic levels

Trophic Levels

Each food chain or food web has organisms at different trophic levels. A trophic level is a feeding position in a food chain or web. The trophic levels are identified in the food web in **Figure** 10.5. All food chains and webs have at least two or three trophic levels, but they rarely have more than four trophic levels. The trophic levels are:

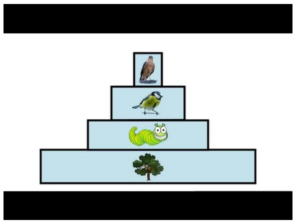
1. Trophic level 1 = producers that make their own food
2. Trophic level 2 = primary consumers that eat producers
3. Trophic level 3 = secondary consumers that eat primary consumers
4. Trophic level 4 = tertiary consumers that eat secondary consumers

Many consumers feed at more than one trophic level. For example, the bivalves in **Figure** 10.5 eat both producers and primary consumers. Therefore, they feed at trophic levels 2 and 3.

Trophic Levels and Energy

Energy is passed up a food chain or web from lower to higher trophic levels. However, only about 10 percent of the energy at one level is passed up the next level. This is represented by the ecological pyramid in **Figure** 10.6. The other 90 percent of energy at each trophic level is used for metabolic processes or given off to the environment as heat. This loss of energy explains why there are rarely more than four trophic levels in a food chain or web. There isn't enough energy left to support additional levels. It also explains why ecosystems need a constant input of energy.

You can learn more about ecological pyramids in this video: http://www.youtube.com/watch?v=wGfOoRrICto .



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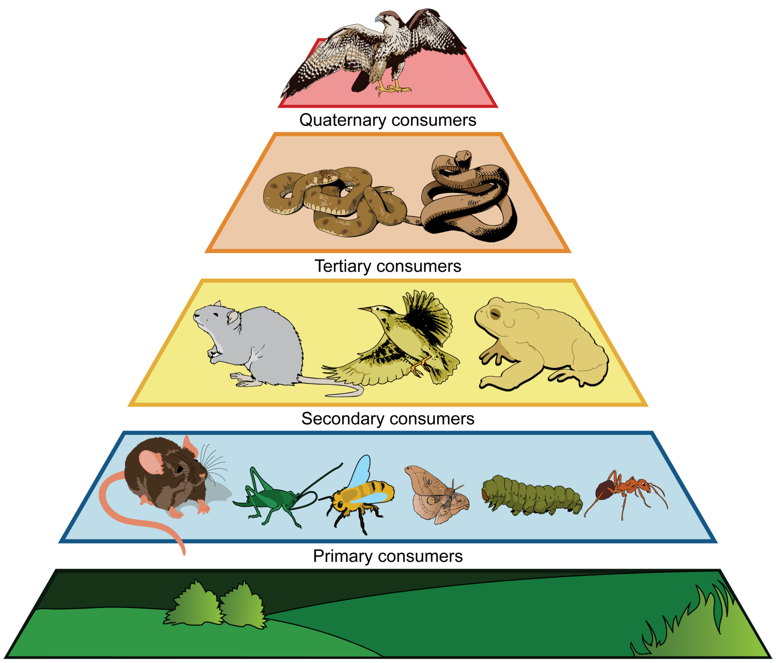

FIGURE 10.6

This ecological pyramid shows how energy and biomass decrease from lower to higher trophic levels.

Trophic Levels and Biomass

Biomass is the total mass of organisms at a trophic level. With less energy at higher trophic levels, there are usually fewer organisms as well. This is also represented in the pyramid in **Figure** 10.6. Organisms tend to be larger in size at higher trophic levels. However, their smaller numbers result in less biomass.

Lesson Summary

- All ecosystems need a constant input of energy in the form of sunlight or chemical compounds. Living things can be classified based on how they obtain energy as producers, consumers, or decomposers.
- Food chains and food webs are diagrams that model the flow of energy through ecosystems. They show who eats whom.
- A trophic level is a feeding position in a food chain or food web. Most food chains and webs have a maximum of four trophic levels. There is less energy and biomass at higher trophic levels.

Lesson Review Questions

Recall

1. Identify three major categories of living things based on how they obtain energy.
2. What is a food chain? Why are food chains simpler than actual feeding relationships in nature?
3. Define trophic level. How does an organism at trophic level 2 obtain energy?

4. At which trophic levels are you consuming when you eat a cheeseburger and French fries?

Think Critically

5. Compare and contrast three types of decomposers.
6. Explain why food chains and webs rarely have more than four trophic levels.

Points to Consider

Energy must constantly be added to an ecosystem for use by organisms. Matter, on the other hand, is continuously recycled through ecosystems.

1. Give an example of a cycle of matter.
2. What role do living things play in this cycle?

10.2 Cycles of Matter

Lesson Objectives

- Define biogeochemical cycle.
- Describe the processes of the water cycle.
- Summarize the carbon cycle.
- Outline the nitrogen cycle.

Lesson Vocabulary

- biogeochemical cycle
- carbon cycle
- condensation
- evaporation
- groundwater
- nitrogen cycle
- precipitation
- runoff
- sublimation
- water cycle

Introduction

Where does the water come from that is needed by your cells? What is the source of the carbon and nitrogen that are needed to make your organic molecules? These forms of matter are recycled in an ecosystem. Unlike energy, matter is not lost as it passes through an ecosystem. It just keeps cycling.

Biogeochemical Cycles

The chemical elements and water that are needed by living things keep recycling on Earth. They pass back and forth through biotic and abiotic components of ecosystems. That's why their cycles are called biogeochemical cycles. For example, a chemical element or water might move from organisms (bio) to the atmosphere or ocean (geo) and back to organisms again.

Elements or water may be held for various periods of time in different parts of a biogeochemical cycle.

- An exchange pool is part of a cycle that holds a substance for a short period of time. For example, the atmosphere is an exchange pool for water. It usually holds water (as water vapor) for just a few days.

- A reservoir is part of a cycle that holds a substance for a long period of time. For example, the ocean is a reservoir for water. It may hold water for thousands of years.

The rest of this lesson describes three biogeochemical cycles: water cycle, carbon cycle, and nitrogen cycle.

Water Cycle

Water is an extremely important aspect of every ecosystem. Life can't exist without water. Most organisms contain a large amount of water, and many live in water. Therefore, the water cycle is essential to life on Earth.

Water on Earth is billions of years old. However, individual water molecules keep moving through the water cycle. The water cycle is a global cycle. It takes place on, above, and below Earth's surface, as shown in **Figure** 10.7. During the water cycle, water occurs in three different states: gas (water vapor), liquid (water), and solid (ice). Many processes are involved as water changes state to move through the cycle. Watch this video for an excellent visual introduction to the water cycle: http://www.youtube.com/watch?v=al-do-HGuIk .

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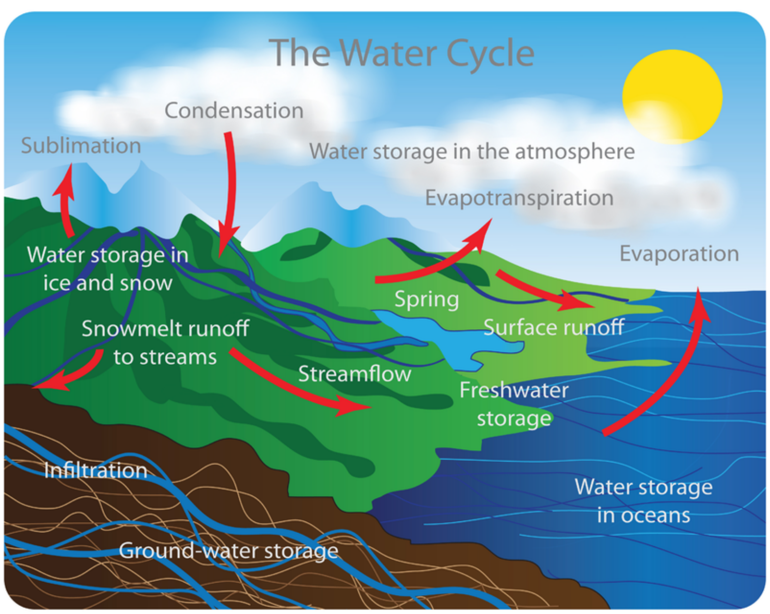

FIGURE 10.7

The water cycle has no beginning or end. It just keeps repeating.

Evaporation, Sublimation, and Transpiration

Water changes to a gas by three different processes called evaporation, sublimation, and transpiration.

- Evaporation takes place when water on Earth's surface changes to water vapor. The sun heats the water and gives water molecules enough energy to escape into the atmosphere. Most evaporation occurs from the surface of the ocean.
- Sublimation takes place when snow and ice on Earth's surface change directly to water vapor without first melting to form liquid water. This also happens because of heat from the sun.
- Transpiration takes place when plants release water vapor through pores in their leaves called stomata.

Condensation and Precipitation

Rising air currents carry water vapor into the atmosphere. As the water vapor rises in the atmosphere, it cools and condenses. Condensation is the process in which water vapor changes to tiny droplets of liquid water. The water droplets may form clouds. If the droplets get big enough, they fall as precipitation.

Precipitation is any form of water that falls from the atmosphere. It includes rain, snow, sleet, hail, and freezing rain. Most precipitation falls into the ocean. Eventually, this water evaporates again and repeats the water cycle. Some frozen precipitation becomes part of ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or even longer.

Condensation may also form fog or dew. Some living things, like the lizard in **Figure** 10.8, depend directly on these sources of liquid water.

FIGURE 10.8

The thorny devil lizard lives in such a dry environment in Australia that it has a unique specialization for obtaining water. The scales on its body collect dew and channel it to the corners of the mouth, so the lizard can drink it.

Runoff and Groundwater

Precipitation that falls on land may flow over the surface of the ground. This water is called runoff. It may eventually flow into a body of water.

Some precipitation that falls on land soaks into the ground. This water becomes groundwater. Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater is taken up by plant roots. Some may flow deeper underground to an aquifer. An aquifer is an underground layer of rock that stores water. Water may be stored in an aquifer for thousands of years.

Carbon Cycle

The element carbon is the basis of all life on Earth. Biochemical compounds consist of chains of carbon atoms and just a few other elements. Like water, carbon is constantly recycled through the biotic and abiotic factors of ecosystems.

The carbon cycle includes carbon in sedimentary rocks and fossil fuels under the ground, the ocean, the atmosphere, and living things. The diagram in **Figure** 10.9 represents the carbon cycle. It shows some of the ways that carbon moves between the different parts of the cycle. You can see an animated carbon cycle at this link: http://commons.wikimedia.org/wiki/Category:Carbon_cycle#mediaviewer/File:Carbon_Cycle-animated_forest.gif

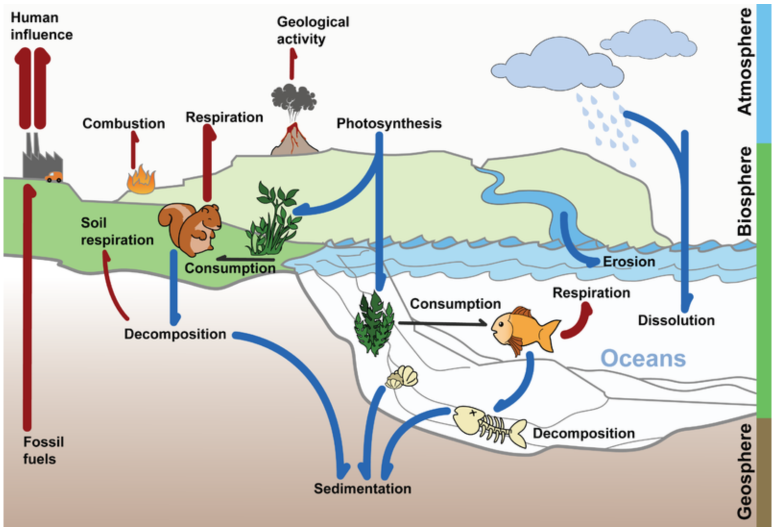

FIGURE 10.9
The Carbon Cycle.

Carbon Reservoirs

Major reservoirs of carbon include sedimentary rocks, fossil fuels, and the ocean. Sediments from dead organisms may form carbon-containing sedimentary rocks. Alternatively, the sediments may form carbon-rich fossil fuels, which include oil, natural gas, and coal. Carbon can be stored in these reservoirs for millions of years. However, if fossil fuels are extracted and burned, the stored carbon enters the atmosphere as carbon dioxide. Natural processes, such as volcanic eruptions, can also release underground carbon from rocks into the atmosphere.

Water erosion by runoff, rivers, and streams dissolves carbon in rocks and carries it to the ocean. Ocean water near the surface dissolves carbon dioxide from the atmosphere. Dissolved carbon may be stored in the deep ocean for thousands of years.

Carbon Exchange Pools

Major exchange pools of carbon include organisms and the atmosphere. Carbon cycles more quickly between these components of the carbon cycle.

- Photosynthesis by plants and other producers removes carbon dioxide from the atmosphere to make organic compounds for living things.
- Cellular respiration by living things releases carbon into the atmosphere or ocean as carbon dioxide.
- Decomposition of dead organisms and organic wastes releases carbon back to the atmosphere, soil, or ocean.

Nitrogen Cycle

Nitrogen is another common element found in living things. It is needed to form both proteins and nucleic acids such as DNA. Nitrogen gas makes up 78 percent of Earth's atmosphere. In the nitrogen cycle, nitrogen flows back and forth between the atmosphere and living things. You can see how it happens in **Figure** 10.10. Several different types of bacteria play major roles in the cycle.

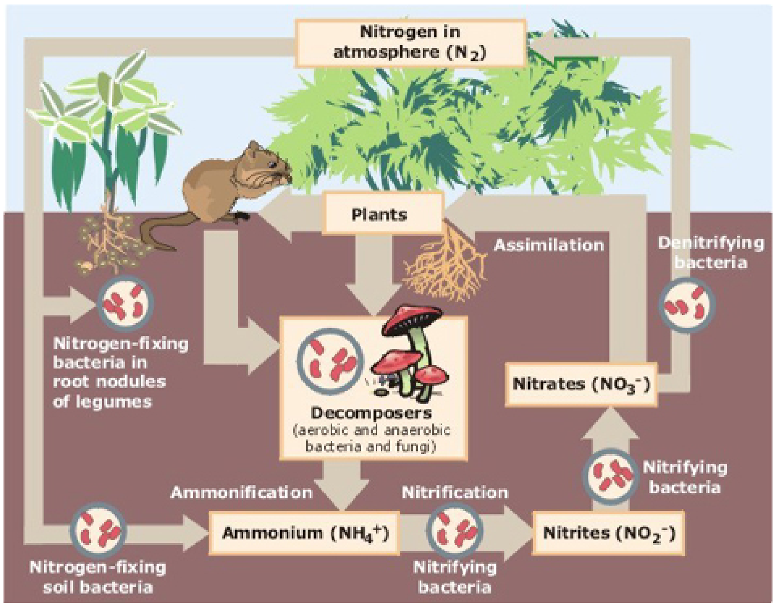

FIGURE 10.10
The nitrogen cycle

Animals get nitrogen by eating plants or other organisms that eat plants. Where do plants get nitrogen? They can't use nitrogen gas in the air. The only form of nitrogen that plants can use is in chemical compounds called nitrates. Plants absorb nitrates through their roots. This is called assimilation. Most of the nitrates are produced by bacteria that live in soil or in the roots of plants called legumes.

- Nitrogen-fixing bacteria change nitrogen gas from the atmosphere to nitrates in soil.
- When organisms die and decompose, their nitrogen is returned to the soil as ammonium ions. Nitrifying bacteria change some of the ammonium ions into nitrates.
- The other ammonium ions are changed into nitrogen gas by denitrifying bacteria.

Lesson Summary

- Water and chemical elements that organisms need keep recycling through biogeochemical cycles. These cycles include biotic and abiotic components of ecosystems.
- The water cycle includes the ocean, atmosphere, ground, and living things. During the water cycle, water keeps changing state by processes such as evaporation, transpiration, condensation, and precipitation.
- The carbon cycle includes photosynthesis, in which plants change carbon dioxide to organic compounds. It also includes cellular respiration, in which living things "burn" organic compounds and release carbon dioxide. Rocks, fossil fuels, and the ocean are also part of the carbon cycle.
- Bacteria play important roles in the nitrogen cycle. They change nitrogen gas and products of decomposition

into nitrates, which plants can assimilate. Animals obtain nitrogen by eating plants or other organisms. Still other bacteria return nitrogen gas to the atmosphere.

Lesson Review Questions

Recall

1. What is a biogeochemical cycle?
2. Identify three ways in which water vapor enters the atmosphere in the water cycle.
3. Describe three ways that carbon can enter the ocean in the carbon cycle.
4. What roles do bacteria play in the nitrogen cycle?

Apply Concepts

5. A farmer may plant a field with a legume crop to improve the soil. How does this work?

Think Critically

6. Compare and contrast exchange pools and reservoirs in biogeochemical cycles. Give an example of each from the water and carbon cycles.
7. Explain the role of decomposers in the nitrogen cycle.

Points to Consider

Ecosystem dynamics include more than the flow of energy and recycling of matter. Ecosystems are also dynamic because they change through time.

1. What are some ways ecosystems might change through time?
2. Do you think there are any ecosystems that do not change through time?

10.3 Ecosystem Change

Lesson Objectives

- Define ecological succession.
- Explain how primary succession occurs.
- Explain why secondary succession occurs more rapidly than primary succession.
- Discuss the concept of climax community.

Lesson Vocabulary

- climax community
- ecological succession
- pioneer species
- primary succession
- secondary succession

Introduction

Imagine walking in the forest in **Figure** 10.11. The towering trees have been growing here for hundreds of years. It may seem as though the forest has been there forever. But no ecosystem is truly static. The numbers and types of species in most ecosystems change to some degree through time. This is called ecological succession. Important cases of ecological succession are primary succession and secondary succession.

FIGURE 10.11
An old redwood forest seems unchanging, but even here change happens.

Primary Succession

Primary succession occurs in an area that has never before been colonized by living things. Generally, the area is nothing but bare rock.

Where It Happens

This type of environment could come about when:

- a landslide uncovers bare rock
- a glacier retreats and leaves behind bare rock
- lava flows from a volcano and hardens into bare rock (see **Figure** 10.12)

How It Happens

The first few species to colonize a disturbed area are called pioneer species. In primary succession, pioneer species must be organisms that can live on bare rock. They usually include bacteria and lichens (see **Figure** 10.12). Along with wind and water, the pioneer species help weather the rock and form soil. Once soil begins to form, plants can move in. The first plants are usually grasses and other small plants that can grow in thin, poor soil. As more plants grow and die, organic matter is added to the soil. This improves the soil and helps it hold water. The improved soil allows shrubs and trees to move into the area.

FIGURE 10.12
Lichen growing on bare lava rocks

Secondary Succession

Secondary succession occurs in a formerly inhabited area that was disturbed.

Where It Happens

Secondary succession could result from a fire, flood, or human action such as farming. For example, a forest fire might kill all the trees and other plants in a forest, leaving behind only charred wood and soil.

How It Happens

Secondary succession is faster than primary succession. The soil is already in place. After a forest fire, for example, the pioneer species are plants such as grasses and fireweed. You can see a forest in this stage of recovery in **Figure** 10.13. As organic matter from the pioneer species improves the soil, trees and other forest plants will move into the area. You can see the amazing real-world story of secondary succession on Mount St. Helens by watching this short video: http://www.youtube.com/watch?v=4RsMyVavT2Q .

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FIGURE 10.13

Just a few months after a forest fire, fireweed and other pioneer plants are already growing among the charred tree trunks.

Climax Community

Does a changing ecosystem ever stop changing? Does its community of organisms ever reach some final, stable state? Scientists used to think that ecological succession always ended at a stable state, called a climax community. Now their thinking has changed. Theoretically, a climax community is possible. But continued change is probably more likely for real-world ecosystems. Most ecosystems are disturbed too often to ever develop a climax community.

Lesson Summary

- Ecological succession is the process in which the numbers and types of species in an ecosystem change over time.
- Primary succession occurs in an area that has never before been colonized. Pioneer species include bacteria and lichens that can grow on bare rock and help make soil.
- Secondary succession occurs in a formerly inhabited area that was disturbed. Soil is already in place, so pioneer species include small plants such as grasses.
- Most ecosystems are disturbed too often to attain a final, stable climax community.

Lesson Review Questions

Recall

1. What is ecological succession?
2. Define climax community, and state why climax communities are unlikely.

Apply Concepts

3. Assume that a flood washed out all of the plants in a large area along the bank of a river. It left behind nothing but soil. How will ecological succession occur in this area?

Think Critically

1. Compare and contrast primary and secondary succession.

Points to Consider

Many ecosystems have changed because of human actions. The human species is responsible for a range of environmental problems.

1. What environmental problems have human actions caused?
2. How have these environmental problems affected living things?

10.4 References

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CHAPTER 11

MS Environmental Problems

Chapter Outline

It was a sunny afternoon when this picture was taken, but you'd never know it. Noxious smoke from a steel plant filled the air and obscured the sun. The picture was taken in Houston, Texas, in 1972. Since then, laws have been passed in the U.S. to reduce air pollution. However, air pollution is still a major environmental problem.

11.1 Air Pollution

Lesson Objectives

- Define air pollution
- Identify causes and effects of outdoor air pollution.
- Describe sources and ways of controlling indoor air pollution.

Lesson Vocabulary

- acid rain
- air pollution
- global climate change
- greenhouse effect

Introduction

The air we breathe plays an important role in maintaining all life on Earth. For example, the atmosphere is a major part of the water cycle. It refills rivers and lakes with fresh water from precipitation. In addition, the atmosphere provides organisms with the gases needed for life. It contains oxygen needed for cellular respiration and carbon dioxide needed for photosynthesis. It also contains nitrogen needed for proteins and nucleic acids.

Earth's atmosphere is vast. However, it has been seriously polluted. Air pollution consists of chemical substances and particles released into the atmosphere, mainly by human actions. Before reading more about the causes of air pollution, watch this video to see some of its devastating effects: http://www.youtube.com/watch?v=UcWpkWBX04E .

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Outdoor Air Pollution

The major cause of outdoor air pollution is the burning of fossil fuels. Fossil fuels are burned in power plants, factories, motor vehicles, and home heating systems. Ranching and using chemicals such as fertilizers also cause outdoor air pollution. Erosion of soil in farm fields, mining activities, and construction sites adds dust particles to the air as well. Some specific outdoor air pollutants are described in **Table** 11.1.

TABLE 11.1: Pollutants in outdoor air

Air Pollutant	Source	Problem
Sulfur oxides	coal burning	acid rain
Nitrogen oxides	motor vehicle exhaust	acid rain
Carbon monoxide	motor vehicle exhaust	poisoning
Carbon dioxide	all fossil fuel burning	global climate change
Particles (dust, smoke)	wood and coal burning	respiratory problems
Mercury	coal burning	nerve poisoning
Smog	coal burning	respiratory problems
Ground-level ozone	motor vehicle exhaust	respiratory problems

Heath Effects of Outdoor Air Pollution

Outdoor air pollution causes serious human health problems. For example, pollutants in the air are major contributors to respiratory and cardiovascular diseases. Air pollution may trigger asthma attacks and heart attacks in people with underlying health problems. In fact, more people die each year from air pollution than automobile accidents.

Acid Rain

Air pollution may also cause acid rain. This is rain that is more acidic (has a lower pH) than normal rain. Acids form in the atmosphere when nitrogen and sulfur oxides mix with water in air. Nitrogen and sulfur oxides come mainly from motor vehicle exhaust and coal burning.

If acid rain falls into lakes, it lowers the pH of the water and may kill aquatic organisms. If it falls on the ground, it may damage soil and soil organisms. If it falls on plants, it may make them sick or even kill them. Acid rain also damages stone buildings, bridges, and statues, like the one in **Figure** 11.1.

FIGURE 11.1
This stone statue has been dissolved by acid rain.

Global Climate Change

Another major problem caused by air pollution is global climate change. Gases such as carbon dioxide from the burning of fossil fuels increase the greenhouse effect and raise Earth's temperature.

The greenhouse effect is a natural feature of Earth's atmosphere. It occurs when certain gases in the atmosphere, including carbon dioxide, radiate the sun's heat back down to Earth's surface. **Figure** 11.2 shows how this happens. Without greenhouse gases in the atmosphere, the heat would escape into space. The natural greenhouse effect of Earth's atmosphere keeps the planet's temperature within a range that can support life.

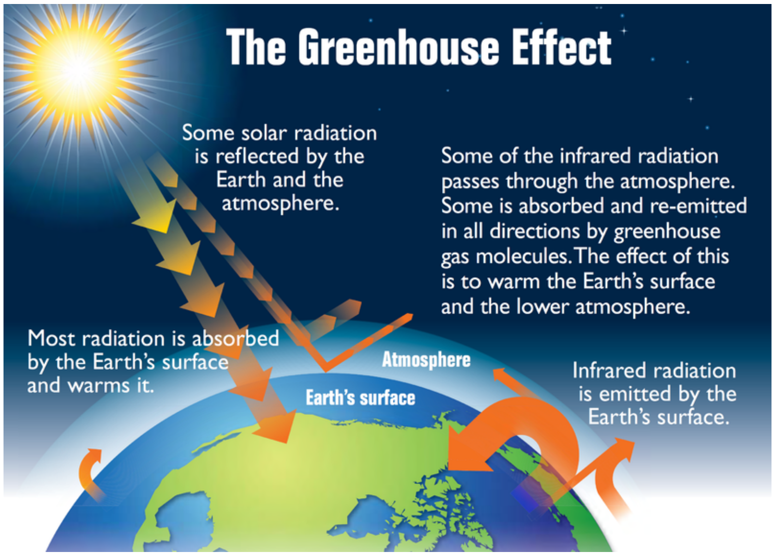

FIGURE 11.2
Earth's atmosphere creates a natural greenhouse effect that moderates Earth's temperature.

The rise in greenhouse gases due to human actions is too much of a good thing. It increases the greenhouse effect and causes Earth's average temperature to rise. Rising global temperatures, in turn, are melting polar ice caps and glaciers. **Figure** 11.3 shows how much smaller the Arctic ice cap was in 2012 than it was in 1984. With more liquid water on Earth's surface, sea levels are rising.

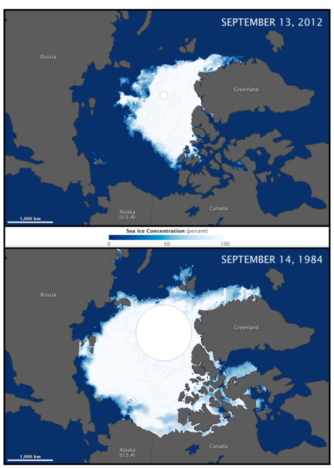

FIGURE 11.3
Shrinking of the Arctic ice cap due to global warming contributes to rising sea levels.

Adding more heat energy to Earth's atmosphere also causes more extreme weather and changes in precipitation patterns. Global warming is already causing food and water shortages and species extinctions. These problems will only grow worse unless steps are taken to curb greenhouse gases and global climate change.

Indoor Air Pollution

You may be able to avoid some of the health effects of outdoor air pollution by staying indoors on high-pollution days. However, some indoor air is just as polluted as outdoor air.

Sources of Indoor Air Pollution

One source of indoor air pollution is radon gas. Radon is a radioactive gas that may seep into buildings from rocks underground. Exposure to radon gas may cause lung cancer. Another potential poison in indoor air is carbon monoxide. It may be released by faulty or poorly vented furnaces or other fuel-burning appliances. Indoor furniture, carpets, and paints may release toxic compounds into the air as well. Other possible sources of indoor air pollution include dust, mold, and pet dander.

Controlling Indoor Air Pollution

It's easier to control the quality of indoor air than outdoor air. Steps home owners can take to improve indoor air quality include:

- keeping the home clean so it is as free as possible from dust, mold, and pet dander.
- choosing indoor furniture, flooring, and paints that are low in toxic compounds such as VOCs (volatile organic compounds).
- making sure that fuel-burning appliances are working correctly and venting properly.
- installing carbon monoxide alarms like the one in **Figure** 11.4 at every level of the home.

FIGURE 11.4
Carbon monoxide alarm

Lesson Summary

- Air pollution consists of chemical substances and particles released into the atmosphere, mainly by human actions. Both outdoor and indoor air may be polluted, but indoor air pollution is easier to control.
- The main cause of outdoor air pollution is the burning of fossil fuels. Outdoor air pollution causes human health problems, acid rain, and global climate change.
- There are many possible sources of indoor air pollution, including radon gas, fuel-burning appliances, and mold. Home owners can take several steps to improve the quality of indoor air.

Lesson Review Questions

Recall

1. Identify causes of outdoor air pollution.
2. What is acid rain? What causes it, and what are its effects?
3. Describe the natural greenhouse effect.

Apply Concepts

4. Create a public service announcement about indoor air pollution. Focus on practical tips for improving the quality of indoor air.

Think Critically

5. Explain how human actions contribute to the greenhouse effect and global climate change.

Points to Consider

Acid rain from air pollution can pollute bodies of water.

1. What are some other causes of water pollution?
2. How does water pollution affect living things?

11.2 Water Pollution

Lesson Objectives

- Define water pollution.
- Explain how fertilizer in runoff leads to algal blooms and dead zones.
- Give examples of point-source pollution, and define thermal pollution.
- Describe how the ocean is being polluted with trash and why ocean water is becoming more acidic.

Lesson Vocabulary

- algal bloom
- dead zone
- nonpoint-source pollution
- ocean acidification
- point-source pollution
- thermal pollution
- waterborne disease
- water pollution
- wetland

Introduction

All living things need water. For most human uses, water must be fresh. Of all the water on Earth, only 1 percent is fresh, liquid water. Most of the rest of Earth's water is either salt water in the ocean or ice in glaciers and ice caps.

Although water is constantly recycled through the water cycle, Earth's water is in danger. Water pollution is an increasing problem. It occurs when chemicals, sewage, trash, or heat enter water resources. Water pollution is threatening the limited supply of water that human beings and other living things depend on. Already, more than 1 billion people worldwide do not have enough clean, fresh water. With the rapidly growing human population and global climate change, the water shortage is likely to get worse.

Algal Blooms and Dead Zones

Water pollution has many causes. One of the biggest causes is fertilizer in runoff. Runoff dissolves fertilizer as it flows over farm fields, lawns, and golf courses. It carries the dissolved fertilizer into bodies of water. More dissolved fertilizer may enter a body of water at the mouth of a river, but there is generally no single point where this type of pollution enters the water. That's why this type of water pollution is called nonpoint-source pollution.

Algal Blooms

When fertilizer ends up in bodies of water, the added nutrients cause excessive growth of algae. This is called an algal bloom. You can see one in **Figure** 11.5. The algae out-compete other water organisms. They may make the water unfit for human consumption or recreation.

FIGURE 11.5
Algal bloom

Dead Zones

Eventually, the algae in an algal bloom die and decompose. Their decomposition uses up oxygen in the water so that the water becomes hypoxic ("without oxygen"). This has occurred in many bodies of fresh water and large areas of the ocean, creating dead zones. Dead zones are areas where the hypoxic water can't support life. A very large dead zone exists in the Gulf of Mexico (see **Figure** 11.6). Nutrients carried into the Gulf by the Mississippi River caused this dead zone.

Cutting down on the use of chemical fertilizers is one way to prevent dead zones in bodies of water. Preserving wetlands is also important. Wetlands are habitats such as swamps, marshes, and bogs where the ground is soggy or covered with water much of the year. Wetlands slow down and filter runoff before it reaches bodies of water. Wetlands also provide breeding grounds for many different species of organisms.

FIGURE 11.6
Hypoxic dead zone in the Gulf of Mexico

Point-Source Pollution

Unlike runoff, which enters bodies of water everywhere, some sources of pollution enter the water at a single point. This type of water pollution is called point-source pollution.

Sewage and Other Waste

An example of point-source pollution is the release of pollution into a body of water through a pipe from a factory or sewage treatment plant. Waste water from a factory might contain dangerous chemicals such as strong acids, mercury, or lead. Water from a sewage treatment plant might contain untreated or partially treated sewage. Such pollution can make water dangerous for drinking or other uses. You can learn more about the problem of sewage contaminating the water in U.S. coastal communities by watching this video: http://www.youtube.com/watch?v=rreBKDko6OY .

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In poor nations, many people have no choice but to drink water from polluted sources. Drinking sewage-contaminated water causes waterborne diseases, due to pathogens such as protozoa, viruses, or bacteria. Most waterborne diseases cause diarrhea.

Thermal Pollution

If heated water is released into a body of water, it may cause thermal pollution. Thermal pollution is a reduction in the quality of water because of an increase in water temperature. A common cause of thermal pollution is the use of water as a coolant by power plants and factories. This water is heated and then returned to the natural environment at a higher temperature.

Warm water can't hold as much dissolved oxygen as cool water, so an increase in the temperature of water decreases the amount of oxygen it contains. Fish and other organisms adapted to a particular temperature range and oxygen concentration may be killed by the change in water temperature.

Ocean Pollution

The ocean is huge but even this body of water is becoming seriously polluted. Climate change also affects the quality of ocean water for living things.

Plastic Waste

One way that the ocean is becoming polluted is with trash, mainly plastics. The waste comes from shipping accidents, landfill erosion, and the dumping of trash. Plastics may take hundreds or even thousands of years to break down. In the meantime, the waste can be very dangerous to aquatic organisms. Some organisms may swallow plastic bags, for example, and others may be strangled by plastic six-pack rings. You can see some of the trash that routinely washes up on coastlines in **Figure** 11.7. There are five massive garbage patches floating on the Pacific Ocean. Watch this video to learn more about them: http://www.youtube.com/watch?v=1qT-rOXB6NI .

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FIGURE 11.7

Plastic debris in the ocean washes up on shore in the Hawaiian Islands

Ocean Acidification

Ocean water normally dissolves some of the carbon dioxide in the atmosphere. The burning of fossil fuels has increased the amount of carbon dioxide in the atmosphere. As a result, ocean water is also dissolving more carbon dioxide. When carbon dioxide dissolves in water, it forms a weak acid. With higher levels of dissolved carbon dioxide in ocean water, the water becomes more acidic. This process is called ocean acidification.

Ocean acidification can kill some aquatic organisms, including corals and shellfish. It may make it more difficult for other aquatic organisms to reproduce. Both effects of acidification interfere with marine food webs, threatening the survival of many aquatic organisms.

Lesson Summary

- Water pollution occurs when chemicals, sewage, trash, or heat enter water resources. Water pollution is threatening the limited supply of clean, fresh water that human beings and other living things depend on.
- Fertilizer in runoff leads to algal blooms and dead zones in bodies of water. This type of pollution is called nonpoint-source pollution. Point-source pollution includes waste water from factories and sewage treatment plants. Hot water discharge causes thermal pollution.
- The ocean is becoming increasingly polluted with trash. Ocean acidification is also occurring because ocean water dissolves some of the excess carbon dioxide in the atmosphere. The more acidic water harms aquatic organisms.

Lesson Review Questions

Recall

1. What is a dead zone? How does it develop?
2. What are wetlands? How do they reduce water pollution?
3. Define thermal pollution, and state when it occurs.

Apply Concepts

4. After a month of heavy rain, a formerly clear pond on a golf course is covered with slimy green algae. What do you think happened?

Think Critically

5. Compare and contrast point-source and nonpoint-source water pollution. Which type of pollution do you think would be easier to control?
6. Explain the process of ocean acidification. Why does it threaten the survival of many aquatic organisms?

Points to Consider

Water is one of our most important natural resources.

1. What is a natural resource? Besides water, what are some other examples of natural resources?
2. What is the difference between renewable and nonrenewable natural resources?

11.3 Natural Resources

Lesson Objectives

- Define natural resource.
- Distinguish between renewable and nonrenewable natural resources.
- Identify pros and cons of different types of energy resources.
- Explain how to conserve natural resources by reducing, reusing, and recycling.

Lesson Vocabulary

- biomass energy
- fossil fuel
- natural resource
- nonrenewable resource
- recycling
- renewable resource
- soil
- solar energy
- sustainable use
- wind energy

Introduction

A natural resource is something supplied by nature that helps support life. When you think of natural resources, you may think of fossil fuels, like the coal in the coal field pictured in **Figure** 11.8. However, sunlight, wind, soil, and living things are also important natural resources.

Renewable and Nonrenewable Resources

From a human point of view, natural resources can be classified as either renewable or nonrenewable.

Renewable Resources

Renewable resources are natural resources that are remade by natural processes as quickly as people use them. Examples of renewable resources include sunlight and wind. They are in no danger of being used up. Metals and some other minerals are considered renewable as well because they are not destroyed when they are used. Instead, they can be recycled and used over and over again.

FIGURE 11.8
This photo shows a huge coal field in the Philippines as it appears from space. Coal is a fossil fuel and a nonrenewable natural resource.

Living things are also renewable resources. They can reproduce to replace themselves. However, living things can be over-used or misused to the point of extinction. For example, over-fishing has caused some of the best fishing spots in the ocean to be nearly depleted, threatening entire fish species with extinction. To be truly renewable, living things must be used wisely. They must be used in a way that meets the needs of the present generation but also preserves them for future generations. Using resources in this way is called sustainable use.

Nonrenewable Resources

Nonrenewable resources are natural resources that can't be remade or else take too long to remake to keep up with human use. Examples of nonrenewable resources are coal, oil, and natural gas, all of which are fossil fuels. Fossil fuels form from the remains of plants and animals over hundreds of millions of years. We are using them up far faster than they can be replaced. At current rates of use, oil and natural gas will be used up in just a few decades, and coal will be used up in a couple of centuries.

Uranium is another nonrenewable resource. It is used to produce nuclear power. Uranium is a naturally occurring chemical element that can't be remade. It will run out sooner or later if nuclear energy continues to be used.

Soil is a very important natural resource. Plants need soil to grow, and plants are the basis of terrestrial ecosystems. Theoretically, soil can be remade. However, it takes millions of years for soil to form, so from a human point of view, it is a nonrenewable resource. Soil can be misused and eroded (see **Figure** 11.9). It must be used wisely to preserve it for the future. This means taking steps to avoid soil erosion and contamination of soil by toxins such as oil spills.

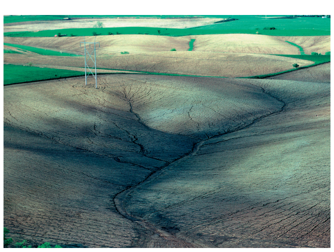

FIGURE 11.9
Bare soil is easily washed away by heavy rains or winds, but it takes millions of years to replace. Ruts in soil washed away by runoff are evident in this photo.

Energy Resources

Some of the resources we depend on the most are energy resources. Whether it's powering our lights and computers, heating our homes, or providing energy for cars and other vehicles, it's hard to imagine what our lives would be like without a constant supply of energy.

Fossil Fuels and Nuclear Energy

Fossil fuels and nuclear energy are nonrenewable energy resources. People worldwide depend far more on these energy sources than any others. **Figure** 11.10 shows the worldwide consumption of energy sources by type in 2010. Nonrenewable energy sources accounted for 83 percent of the total energy used. Fossil fuels and the uranium needed for nuclear power will soon be used up if we continue to consume them at these rates.

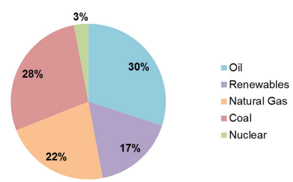

FIGURE 11.10
Worldwide energy use in 2010

Using fossil fuels and nuclear energy creates other problems as well. The burning of fossil fuels releases carbon dioxide into the atmosphere. This is one of the major greenhouse gases causing global climate change. Nuclear power creates another set of problems, including the disposal of radioactive waste.

Alternative Energy Resources

Switching to renewable energy sources solves many of the problems associated with nonrenewable energy. While it may be expensive to develop renewable energy sources, they are clearly the way of the future. **Figure** 11.11 represents three different renewable energy sources: solar, wind, and biomass energy. The three types are described below. You can watch Bill Nye's introduction to renewable energy resources in this video: http://www.youtube.com/watch?v=grI3BDSGEC4 .

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- Solar energy is energy provided by sunlight. Solar cells can turn sunlight into electricity. The energy in sunlight is virtually limitless and free and creates no pollution to use.
- Wind energy is energy provided by the blowing wind. Wind turbines, like those in **Figure** 11.11, can turn wind energy into electricity. The wind blows because of differences in heating of Earth's atmosphere by the sun. There will never be a shortage of wind.

FIGURE 11.11
Sunlight, wind, and living things can all be used as energy resources.

- Biomass energy is energy provided by burning or decomposing organic matter. For example, when garbage decomposes in a landfill, it releases methane gas. This gas can be captured and burned to produce electricity. Crops such as corn can also be converted into a liquid fuel and added to gasoline. Although biomass is renewable, burning it produces carbon dioxide, similar to fossil fuels.

Conserving Natural Resources

Especially when it comes to nonrenewable resources, conserving natural resources is important. Using less of them means that they will last longer. It also means they will impact the environment less. Everyone can help make a difference. There are three basic ways that all of us can conserve natural resources. They are referred to as the three R's: reduce, reuse, and recycle.

Reduce

Reducing the amount of natural resources you use is the best way to conserve resources. It takes energy to make new items, and even reusing or recycling items takes energy. You can reduce the amount of natural resources you use by not using the resources in the first place. Often, this involves just being less wasteful. Follow these tips to reduce your use of natural resources:

- Walk, bike, or use public transit instead of driving. If you must drive, a fuel-efficient vehicle will reduce energy use. Plan ahead to avoid making extra trips.
- Don't buy more than you need. For example, don't buy more fresh food than you can use without it going to waste. You will not only reduce your use of food. You will also reduce your use of energy resources. It takes a lot of energy to grow, process, and ship many of the foods we buy.
- When you shop, keep packaging in mind. "Precycle" by buying items with the least amount of wasted packaging.
- Use energy-efficient appliances and LED light bulbs. Also, turn off appliances and lights when you aren't using them. Both steps will reduce the amount of energy resources you use.
- Keep the thermostat set low in the winter and high in the summer (see **Figure** 11.12). Instead of turning up the heat in cold weather, put on an extra layer of clothes to save energy resources. Open windows and use fans in hot weather rather than turning on the air conditioning.

FIGURE 11.12
If you use air conditioning in hot weather, set the thermostat above normal room temperature to save energy resources.

Reuse

Reusing means to use an item again rather than throwing it away and replacing it. Items can be reused for the same purpose or for a different purpose. Generally, it takes less energy to reuse an item than to recycle it, so choose this option over recycling when you can. Here are some specific tips for reusing natural resources:

- Consider mending or repairing worn or broken items rather than throwing them out and replacing them.
- Shop with reuse in mind. You can find great buys at flea markets and resale shops. You may be able to get free items online at free-cycle sites. You'll save money as well as natural resources. You can also sell (or give away) your own reusable items.
- Reuse cloth shopping bags. Instead of getting new plastic or paper bags for your purchases each time you shop, take your own reusable bag to the store each time.
- Even little steps can add up and help save natural resources. For example, unwrap gifts carefully and you'll be able to reuse the gift wrap on a package for someone else. You can also reuse writing paper that has only been used on one side. It's great for notes and shopping lists.

Recycle

If an item can no longer be used or reused, try to recycle it. Recycling means taking a used item, breaking it down, and reusing the components. It generally takes less energy to recycle materials than obtain new ones. Recycling also keeps waste out of landfills. Some of the items that can be recycled include: glass, paper, cardboard, plastic, aluminum, iron, steel, batteries, electronics, tires, and concrete. You can learn how some of these materials are recycled by watching this video: http://www.youtube.com/watch?v=7nZXyjrBraY .

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/140784

Even kitchen scraps and garden wastes can be recycled. They can be tossed into a compost bin, like the one in **Figure** 11.13. The recycled compost gradually breaks down to form rich humus that can be added to lawns and gardens to improve the soil.

Encourage your family to recycle if they don't already. Even if you don't have curbside recycling where you live, there are likely to be recycling drop boxes or centers available for recycling many items. If you have recycling bins at school, be sure to use them. If not, raise the issue with your teacher or principal. You can also write a letter to the editor of your local newspaper encouraging everyone in your community to recycle.

FIGURE 11.13
Kitchen and garden wastes can be recycled by composting them.

Lesson Summary

- A natural resource is something supplied by nature that helps support life.
- From a human point of view, natural resources can be classified as either renewable or nonrenewable. Renewable resources, such as sunlight and living things, can be remade quickly by natural processes. Nonrenewable resources, such as fossil fuels and soil, cannot be remade or else take millions of years to remake.
- Nonrenewable energy resources (fossil fuels and nuclear energy) provide most of the energy used today. They may run out, and their use creates environmental problems. Renewable energy resources (such as solar, wind, and biomass energy) will always be available and are generally better for the environment.
- There are three basic ways to conserve natural resources: reduce, reuse, and recycle.

Lesson Review Questions

Recall

1. What is a natural resource?
2. List two cons of using fossil fuels for energy.
3. Describe three renewable energy resources.

Apply Concepts

4. Identify ways you could conserve natural resources in your own life.

Think Critically

5. New soil is always being formed, yet soil is considered to be a nonrenewable resource. Explain why.
6. Compare and contrast renewable and nonrenewable natural resources.

Points to Consider

Biodiversity is another important natural resource.

1. What is biodiversity?
2. Why is biodiversity considered to be a natural resource?

11.4 Biodiversity and Extinction

Lesson Objectives

- Define biodiversity.
- List benefits of biodiversity to people and ecosystems.
- Describe the sixth mass extinction, and identify its chief causes.
- Identify ways individuals can protect biodiversity.

Lesson Vocabulary

- biodiversity
- exotic species
- habitat loss
- sixth mass extinction

Introduction

It's obvious that living things are important natural resources needed by human beings. After all, other species provide us with all of the food we eat. We couldn't survive without them. But that's far from the only reason that other species are important for human survival. Biodiversity is an important natural resource in and of itself.

Biodiversity

Biodiversity refers to the variety of life and its processes. It includes the variation in living organisms, the genetic differences among them, and the range of communities and ecosystems in which they live. Scientists have identified about 1.9 million species alive today, but they are discovering new species all the time.

How many species actually exist in the world? No one knows for sure because only a small percentage of them have already been discovered. Estimates range from 5 to 30 million total species currently in existence. Many of them live on coral reefs and in tropical rainforests (see **Figure** 11.14). These two ecosystems have some of the greatest biodiversity on the planet.

Importance of Biodiversity

Biodiversity is important to human beings for many reasons. For one thing, biodiversity has direct economic benefits. Here are a few of the economic benefits of biodiversity:

FIGURE 11.14
This coral reef (top) and tropical rainforest (bottom) have a tremendous variety of different species.

- Besides food, diverse living things provide us with many different products. Some examples include dyes, rubber, fibers, paper, adhesives, and timber.
- Living things are an invaluable source of medical drugs. More than half of the most important prescription drugs come from wild species. However, only a fraction of species have yet been studied for their medical potential.
- Certain species may warn us of toxins in the environment. Amphibians are particularly sensitive to toxins because of their permeable skin. Their current high rates of extinction serve as an early warning of environmental damage and danger to us all.
- Wild organisms maintain a valuable pool of genetic variation. This is important because most domestic species have been bred to be genetically uniform. This puts domestic crops and animals at great risk of dying out due to disease.
- Some living things provide inspiration for technology. For example, water strider insects like the one in **Figure** 11.15 have helped engineers develop tiny robots that can walk on water. The robots could be used to monitor water quality, among other useful purposes.

FIGURE 11.15
Water strider insect

Ecosystem Services

Biodiversity is important for healthy ecosystems. It generally increases ecosystem productivity and stability. It helps ensure that at least some species will survive environmental change. Biodiversity also provides many other ecosystem services. For example:

- Plants and algae maintain Earth's atmosphere. They add oxygen to the air and remove carbon dioxide when they undertake photosynthesis.
- Plants help protect the soil. Their roots grip the soil and keep it from washing or blowing away. When plants die, their organic matter improves the soil as it decomposes.

- Microorganisms purify water in rivers and lakes. They also decompose organic matter and return nutrients to the soil. Certain bacteria fix nitrogen and make it available to plants.
- Predator species such as birds and spiders control insect pests. They reduce the need for chemical pesticides, which are expensive and may be harmful to human beings and other organisms.
- Animals, like the bee in **Figure** below, pollinate flowering plants. Many crop plants depend on pollination by wild animals.

FIGURE 11.16

A bee pollinates a flowering plant.

Extinction

Extinction is the complete dying out of a species. Once a species goes extinct, it can never return. More than 99 percent of all the species that ever lived on Earth have gone extinct. Five mass extinctions have occurred in Earth's history. They were caused by major geologic and climatic events. The fifth mass extinction wiped out the dinosaurs 65 million years ago.

The Sixth Mass Extinction

Evidence shows that a sixth mass extinction is happening right now. Species are currently going extinct at the fastest rate since the dinosaurs died out. Dozens of species are going extinct every day. If this rate continues, as many as half of all remaining species could go extinct by 2050.

Why are so many species going extinct today? Unlike previous mass extinctions, the sixth mass extinction is due mainly to human actions.

Habitat Loss

The single biggest cause of the sixth mass extinction is habitat loss. A habitat is the area where a species lives and to which it has become adapted. When a habitat is disturbed or destroyed, it threatens all the species that live there with extinction.

More than half of Earth's land area has been disturbed or destroyed by farming, mining, forestry, or the development of cities, suburbs, and golf courses. Habitats that are rapidly being destroyed include tropical rainforests. They are being cut and burned, mainly to clear the land for farming. Half of Earth's mature tropical forests have already been destroyed. At current rates of destruction, they will all be gone by 2090. In the U.S., half of the wetlands and almost all of the tall-grass prairies (see **Figure** 11.17) have already been destroyed for farming.

Other Causes of Extinction

There are several other causes of the sixth mass extinction. Most of them contribute to habitat destruction.

FIGURE 11.17
Bison graze on grasses in a tall-grass prairie nature preserve in Oklahoma.

- The burning of fossil fuels has increased the greenhouse effect and caused global climate change. Increasing temperatures are changing basic climate factors of habitats, and rising sea levels are covering them with water. These changes threaten many species.
- Pollution of air, water, and soil makes habitats toxic to many organisms. A well-known example is the near extinction of the peregrine falcon in the mid-1900s due to the pesticide DDT.
- Humans have over-harvested trees, fish, and other wild species. This threatens not only their survival but the survival of all the other species that depend on them.
- Humans have introduced exotic species into new habitats. These are species that are not native to the habitat where they are introduced. They may lack predators in the new habitat so they can out-compete native species and drive them extinct. Exotic species may also carry new diseases, prey on native species, and disrupt local food webs. You can read about an example of an exotic species in **Figure** 11.18.

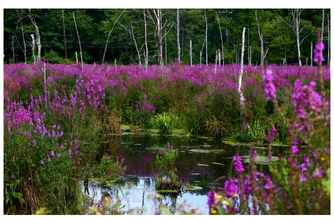

FIGURE 11.18
Purple loosestrife is a European wildflower that was introduced to North America in the early 1800s. It soon spread to take over wetland habitats throughout the U.S. and Canada. Purple loosestrife replaces native wetland plants and threatens native wildlife by eliminating natural foods and cover. It also blocks irrigation systems.

Protecting Biodiversity

Government policies and laws are needed to protect biodiversity. Such actions have been shown to work in the past. For example, peregrine falcons made an incredible recovery after laws were passed banning the use of DDT.

Individuals can also play a role in protecting biodiversity. What can you do? Here are a few suggestions:

- Start a compost pile to recycle organic wastes. Use the compost to enrich yard and garden soil. It will reduce the need for chemical fertilizers and added water.
- Make your backyard welcoming to native wildlife. Plant native plants that will provide food and shelter for native animals such as birds and amphibians. Add a water source, such as a fountain or bird bath.
- Avoid the introduction of exotic species to local habitats.
- Avoid the use of herbicides and pesticides. In addition to killing garden weeds and pests, they may harm native organisms, such as wildflowers, honey bees, and song birds.
- Conserve natural resources, including energy resources. Always reduce, reuse, or recycle.
- Learn more about biodiversity and how to protect it. Then pass on what you learn to others.

Lesson Summary

- Biodiversity refers to the variety of life and its processes. Biodiversity has direct economic benefits. It also increases ecosystem productivity and stability and provides vital ecosystem services.
- Extinction is the complete dying out of a species. Five mass extinctions have occurred in Earth's history, caused by major geologic and climatic events. A sixth mass extinction is happening right now. The single biggest cause of the current mass extinction is habitat loss due to human actions.
- Government policies and laws are needed to protect biodiversity, but individuals can also play a role.

Lesson Review Questions

Recall

1. What is biodiversity?
2. Identify some of the direct benefits of biodiversity to human beings.
3. Describe two ecosystem services provided by biodiversity.

Apply Concepts

4. Describe one specific change you could make in your life to help protect biodiversity.

Think Critically

5. Explain causes and effects of habitat loss.

Points to Consider

The human species has been incredibly successful. In a relatively short period of time, it has colonized almost all of Earth's terrestrial habitats. Unfortunately, human beings have also impacted Earth, its climate, and its environment. Human actions threaten Earth's valuable biodiversity.

1. What do you think Earth's future may hold?
2. Do you think people will take steps to save Earth for future generations before it's too late?

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Chapter 12 MS Plate Tectonics

Chapter Outline

Earth is a restless planet. Heat in the Earth's interior causes giant plates of crust to move around on the surface. The crashing and smashing of these plates leads to nearly all of the geological activity we see. Plate collisions bring us volcanoes and earthquakes, mountain ranges, and many resources. Seafloor forms as plates move apart. Some of Earth's most beautiful landscapes come from plate tectonics. The Grand Tetons in Wyoming rose up as the Farallon Plate sunk beneath the North American Plate during the Laramide orogeny.

12.1 Inside Earth

Lesson Objectives

- Compare and describe each of Earth's layers.
- Compare some of the ways geologists learn about Earth's interior.
- Define oceanic and continental crust and the lithosphere.
- Describe how heat moves, particularly how convection takes place in the mantle.
- Compare the two parts of the core and describe why they are different from each other.

Vocabulary

- asthenosphere
- convection cell
- continental crust
- core
- crust
- lithosphere
- mantle
- meteorite
- oceanic crust
- plate tectonics
- seismic waves

Introduction

From outside to inside, Earth is divided into crust, mantle, and core. Each has a different chemical makeup. Earth can also be divided into layers with different properties. The two most important are lithosphere and asthenosphere.

How Do We Know About Earth's Interior?

If someone told you to figure out what is inside Earth, what would you do? How could you figure out what is inside our planet? How do scientists figure it out?

Seismic Waves

Geologists study earthquake waves to "see" Earth's interior. Waves of energy radiate out from an earthquake's focus. These are called **seismic waves** (**Figure** 12.1). Seismic waves change speed as they move through different materials. This causes them to bend. Some seismic waves do not travel through liquids or gases. Scientists use all of this information to understand what makes up the Earth's interior.

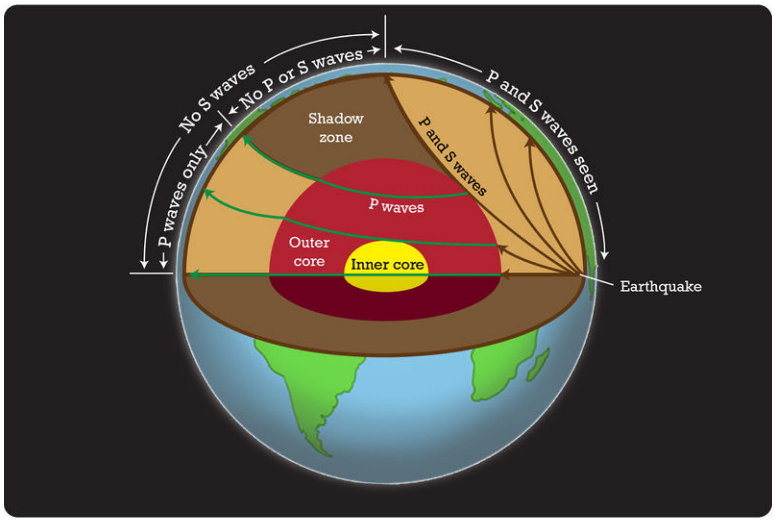

FIGURE 12.1
The properties of seismic waves allow scientists to understand the composition of Earth's interior.

Meteorites

Scientists study **meteorites** to learn about Earth's interior. Meteorites formed in the early solar system. These objects represent early solar system materials. Some meteorites are made of iron and nickel. They are thought to be very similar to Earth's core (**Figure** 12.2). An iron meteorite is the closest thing to a sample of the core that scientists can hold in their hands!

FIGURE 12.2
The Willamette Meteorite is a metallic meteorite that was found in Oregon.

Crust

Crust, mantle, and core differ from each other in chemical composition. It's understandable that scientists know the most about the crust, and less about deeper layers (**Figure** 12.3). Earth's **crust** is a thin, brittle outer shell. The crust is made of rock. This layer is thinner under the oceans and much thicker in mountain ranges.

Oceanic Crust

There are two kinds of crust. **Oceanic crust** is made of basalt lavas that flow onto the seafloor. It is relatively thin, between 5 to 12 kilometers thick (3 - 8 miles). The rocks of the oceanic crust are denser (3.0 g/cm^3) than the rocks that make up the continents. Thick layers of mud cover much of the ocean floor.

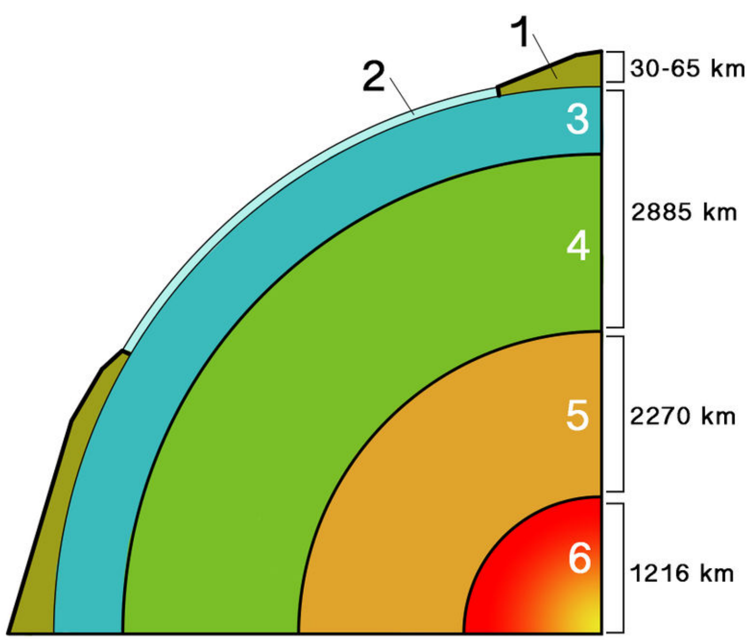

FIGURE 12.3
A cross-section of Earth showing the following layers: (1) continental crust, (2) oceanic crust, (3) upper mantle, (4) lower mantle, (5) outer core, (6) inner core.

Continental Crust

Continental crust is much thicker than oceanic crust. It is 35 kilometers (22 miles) thick on average, but it varies a lot. Continental crust is made up of many different rocks. All three major rock types —igneous, metamorphic, and sedimentary —are found in the crust. On average, continental crust is much less dense (2.7 g/cm3) than oceanic crust. Since it is less dense, it rises higher above the mantle than oceanic crust.

Mantle

Beneath the crust is the **mantle**. The mantle is made of hot, solid rock. Through the process of conduction, heat flows from warmer objects to cooler objects (**Figure** 12.4). The lower mantle is heated directly by conduction from the core.

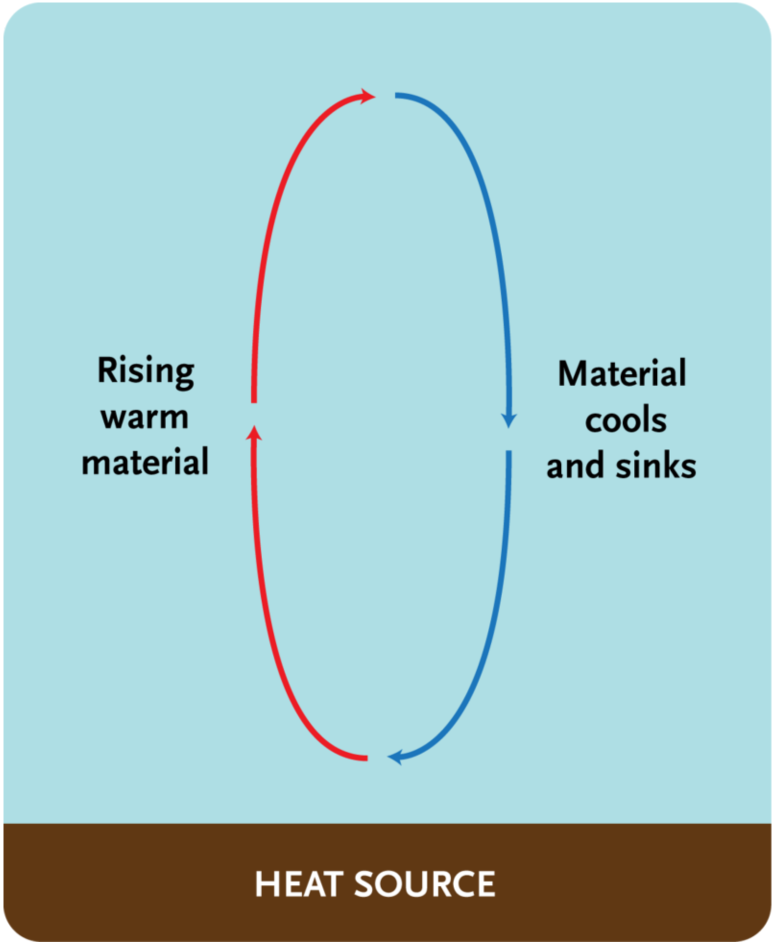

FIGURE 12.4
In the process of conduction, heat flows from warmer objects to cooler objects.

Hot lower mantle material rises upwards (**Figure** 12.5). As it rises, it cools. At the top of the mantle it moves horizontally. Over time it becomes cool and dense enough that it sinks. Back at the bottom of the mantle, it travels horizontally. Eventually the material gets to the location where warm mantle material is rising. The rising and sinking of warm and cooler material is convection. The motion described creates a convection cell.

Core

The dense, iron **core** forms the center of the Earth. Scientists know that the core is metal from studying metallic meteorites and the Earth's density. Seismic waves show that the outer core is liquid, while the inner core is solid. Movement within Earth's outer liquid iron core creates Earth's magnetic field. These convection currents form in the outer core because the base of the outer core is heated by the even hotter inner core.

Lithosphere and Asthenosphere

Lithosphere and asthenosphere are layers based on physical properties. The outermost layer is the **lithosphere**. The lithosphere is the crust and the uppermost mantle. In terms of physical properties, this layer is rigid, solid, and brittle. It is easily cracked or broken.

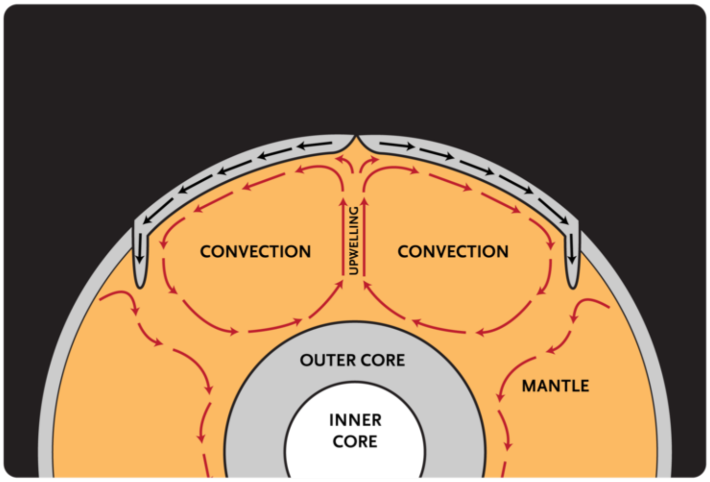

FIGURE 12.5
The rising and sinking of mantle material of different temperatures and densities creates a convection cell.

Below the lithosphere is the **asthenosphere**. The asthenosphere is also in the upper mantle. This layer is solid, but it can flow and bend. A solid that can flow is like silly putty.

Lesson Summary

- The Earth is made of three layers with different composition: the crust, mantle, and core.
- The lithosphere is made of the rigid, brittle, solid crust and uppermost mantle.
- Beneath the lithosphere, the asthenosphere is solid rock that can flow.
- The hot core warms the base of the mantle, which creates convection currents in the mantle.

Lesson Review Questions

Recall

1. List two ways that scientists learn about what makes up the Earth's interior.

2. What type of rock makes up the oceanic crust?

3. What types of rock make up the continental crust?

Apply Concepts

4. Describe the properties of the lithosphere and asthenosphere. What parts of the Earth do these layers include?

5. When you put your hand near a pan above a pan filled with boiling water, does your hand warm up because of convection or conduction? If you touch the pan, does your hand warm up because of convection or conduction?

Think Critically

6. List two reasons that scientists know that the outer core is liquid.

7. Suppose that Earth's interior contains a large amount of lead. Lead is very dense: 11.34 g/cm^3. Would the lead be more likely to be found in the crust, mantle, or core?

Points to Consider

- The oceanic crust is thinner and denser than continental crust. All crust sits atop the mantle. What might our planet be like if this were not true.
- If sediments fall onto the seafloor over time, what can sediment thickness tell scientists about the age of the seafloor in different regions?
- How might convection cells in the mantle affect the movement of plates of lithosphere on the planet's surface?

12.2 Continental Drift

Lesson Objectives

- Be able to explain the continental drift hypothesis.
- Describe the evidence Wegener used to support his continental drift idea.
- Describe how the north magnetic pole appeared to move, and how that is evidence for continental drift.

Vocabulary

- continental drift
- magnetic field

Introduction

To develop plate tectonics, first scientists had to accept that continents could move. Today they do. But it took a long time for scientists to accept that this could happen (**Figure** 12.6). This idea is called continental drift.

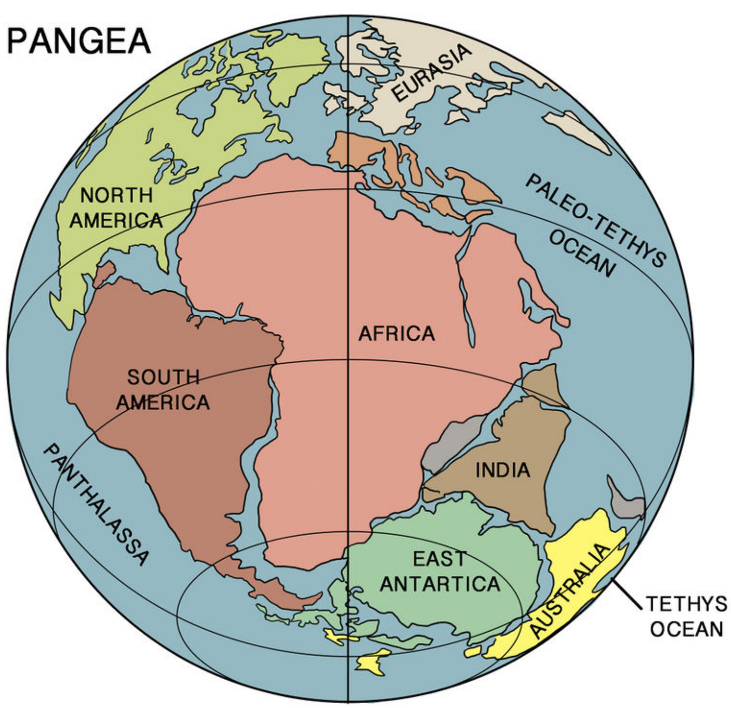

FIGURE 12.6
The supercontinent Pangaea contained all of the modern day continents.

The Continental Drift Idea

Alfred Wegener was an early 20th century German meteorologist. Wegener believed that the continents were once all joined together. He named the supercontinent Pangaea, meaning “all earth.“ Wegener suggested that Pangaea broke up long ago. Since then, the continents have been moving to their current positions. He called his hypothesis **continental drift**.

Evidence for Continental Drift

Wegener and his supporters collected a great deal of evidence for the continental drift hypothesis. Wegener found that this evidence was best explained if the continents had at one time been joined together.

Rocks and Geologic Structures

Wegener found rocks of the same type and age on both sides of the Atlantic Ocean. He thought that the rocks formed side by side. These rocks then drifted apart on separate continents.

Wegener also matched up mountain ranges across the Atlantic Ocean. The Appalachian Mountains were just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway. Wegener concluded that they formed as a single mountain range. This mountain range broke apart as the continents split up. The mountain range separated as the continents drifted.

Fossil Plants and Animals

Wegener also found evidence for continental drift from fossils (**Figure** 12.7). The same type of plant and animal fossils are found on continents that are now widely separated. These organisms would not have been able to travel across the oceans.

Fossils of the seed fern Glossopteris are found across all of the southern continents. These seeds are too heavy to be carried across the ocean by wind. Mesosaurus fossils are found in South America and South Africa. Mesosaurus could swim, but only in fresh water. Cynognathus and Lystrosaurus were reptiles that lived on land. Both of these animals were unable to swim at all. Their fossils have been found across South America, Africa, India and Antarctica.

Wegener thought that all of these organisms lived side by side. The lands later moved apart so that the fossils are separated.

Glaciation

Wegener also looked at evidence from ancient glaciers. Glaciers are found in very cold climates near the poles. The evidence left by some ancient glaciers is very close to the equator. Wegener knew that this was impossible! However, if the continents had moved, the glaciers would have been centered close to the South Pole.

Climate

Coral reefs are found only in warm water. Coal swamps are also found in tropical and subtropical environments. Wegener discovered ancient coal seams and coral reef fossils in areas that are much too cold today. Wegener thought that the continents have moved since the time of Pangaea.

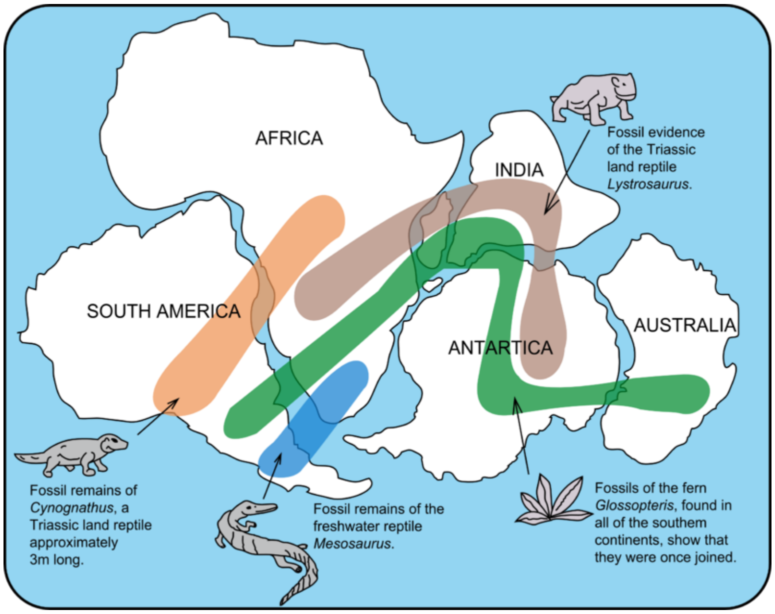

FIGURE 12.7
Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart. Wegener suggested that when the organisms were alive, the lands were joined and the organisms were living side-by-side.

Magnetic Evidence

Some important evidence for continental drift came after Wegener's death. This is the magnetic evidence. Earth's magnetic field surrounds the planet from pole to pole. If you have ever been hiking or camping, you may have used a compass to help you find your way. A compass points to the magnetic North Pole. The compass needle aligns with Earth's **magnetic field** (**Figure** 12.8).

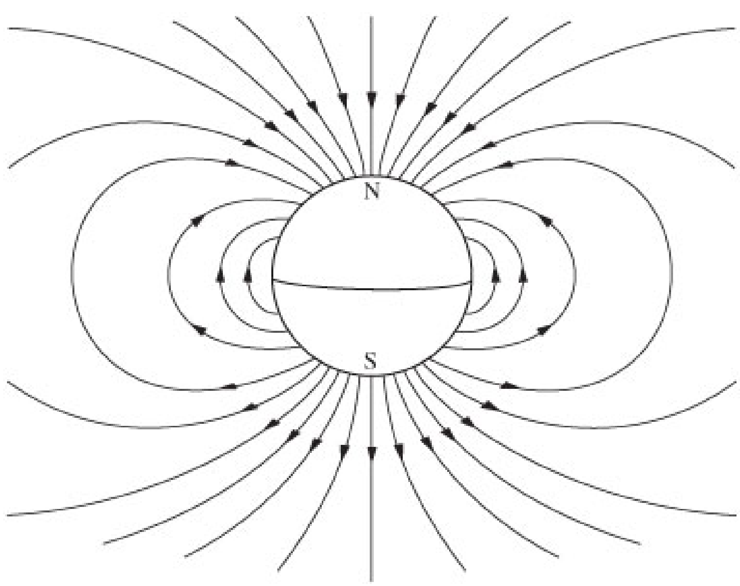

FIGURE 12.8
Earth's magnetic field is like a magnet with its north pole near the geographic north pole and the south pole near the geographic south pole.

Some rocks contain little compasses too! As lava cools, tiny iron-rich crystals line up with Earth's magnetic field.

Anywhere lavas have cooled, these magnetite crystals point to the magnetic poles. The little magnets point to where the north pole was when the lava cooled. Scientists can use this to figure out where the continents were at that time. This evidence clearly shows that the continents have moved.

During Wegener's life, scientists did not know how the continents could move. Wegener's idea was nearly forgotten. But as more evidence mounted, new ideas came about.

Lesson Summary

- Alfred Wegener gathered evidence that the continents had moved around on Earth's surface.
- The evidence for continental drift included the fit of the continents; the distribution of ancient fossils, rocks, and mountain ranges; and the locations of ancient climate zones.
- Although the evidence was extremely strong, scientists did not yet know how continents could move, so most rejected the idea.

Lesson Review Questions

Recall

1. How do the continents resemble puzzle pieces?

2. List the evidence Wegener had for continental drift.

Apply Concepts

3. What other regions fit together besides South America and Africa?

Think Critically

4. Make a case before a scientific jury to convince them that continental drift is real. Line up all your evidence. Does the lack of a mechanism for continents to move destroy your case?

5. What ideas can you come up with for what could drive continental motions?

Points to Consider

- Why is continental drift referred to as a hypothesis and not a theory?
- Why is Wegener's continental drift idea accepted today?
- Explain how each of these phenomena can be used as evidence for continental drift:
- The fit of the continents
- The distribution of fossils
- The distribution of similar rock types
- Rocks from ancient climate zones

12.3 Seafloor Spreading

Lesson Objectives

- List the main features of the seafloor: mid-ocean ridges, deep sea trenches, and abyssal plains.
- Describe what seafloor magnetism tells scientists about the seafloor.
- Describe the process of seafloor spreading.

Vocabulary

- echo sounder
- seafloor spreading
- trenches

Introduction

Ocean research during World War II gave scientists the tools to find out how the continents move. The evidence all pointed to seafloor spreading.

Seafloor Bathymetry

Before World War II, people thought the seafloor was completely flat and featureless. There was no reason to think otherwise.

Echo Sounders

But during the war, battleships and submarines carried echo sounders. Their goal was to locate enemy submarines (**Figure** 12.9). **Echo sounders** produce sound waves that travel outward in all directions. The sound waves bounce off the nearest object, and then return to the ship. Scientists know the speed of sound in seawater. They then can calculate the distance to the object that the sound wave hit. Most of these sound waves did not hit submarines. They instead were used to map the ocean floor.

Features of the Seafloor

Scientists were surprised to find huge mountains and deep trenches when they mapped the seafloor. The mid-ocean ridges form majestic mountain ranges through the deep oceans (**Figure** 12.10).

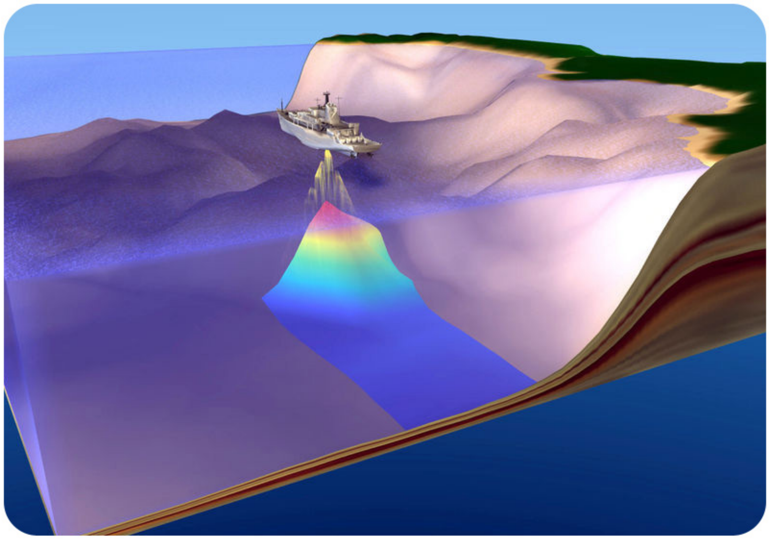

FIGURE 12.9
A ship sends out sound waves to create a picture of the seafloor below it. The echo sounder pictured has many beams and as a result it creates a three dimensional map of the seafloor beneath the ship. Early echo sounders had only a single beam and created a line of depth measurements.

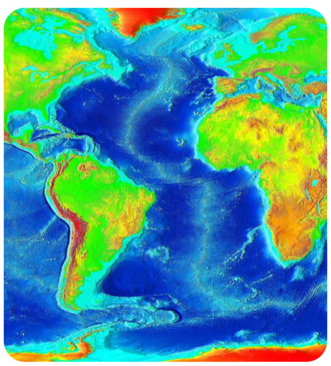

FIGURE 12.10
A modern map of the eastern Pacific and Atlantic Oceans. Darker blue indicates deeper seas. A mid-ocean ridge can be seen running through the center of the Atlantic Ocean. Deep sea trenches are found along the west coast of Central and South America and in the mid-Atlantic, east of the southern tip of South America. Isolated mountains and flat, featureless regions can also be spotted.

Deep sea trenches are found near chains of active volcanoes. These volcanoes can be at the edges of continents or in the oceans. **Trenches** are the deepest places on Earth. The deepest trench is the Mariana Trench in the southwestern Pacific Ocean. This trench plunges about 11 kilometers (35,840 feet) beneath sea level. The ocean floor does have lots of flat areas. These abyssal plains are like the scientists had predicted.

Seafloor Magnetism

Warships also carried magnetometers. They were also used to search for submarines. The magnetometers also revealed a lot about the magnetic properties of the seafloor.

Polar Reversals

Indeed, scientists discovered something astonishing. Many times in Earth's history, the magnetic poles have switched positions. North becomes south and south becomes north! When the north and south poles are aligned as they are now, geologists say it is normal polarity. When they are in the opposite position, they say that it is reversed polarity.

Magnetic Stripes

Scientists were also surprised to discover a pattern of stripes of normal and reversed polarity. These stripes surround the mid-ocean ridges. There is one long stripe with normal magnetism at the top of the ridge. Next to that stripe are two long stripes with reversed magnetism. One is on either side of the normal stripe. Next come two normal stripes and then two reversed stripes, and so on across the ocean floor. The magnetic stripes end abruptly at the edges of continents. Sometimes the stripes end at a deep sea trench (**Figure** 12.11).

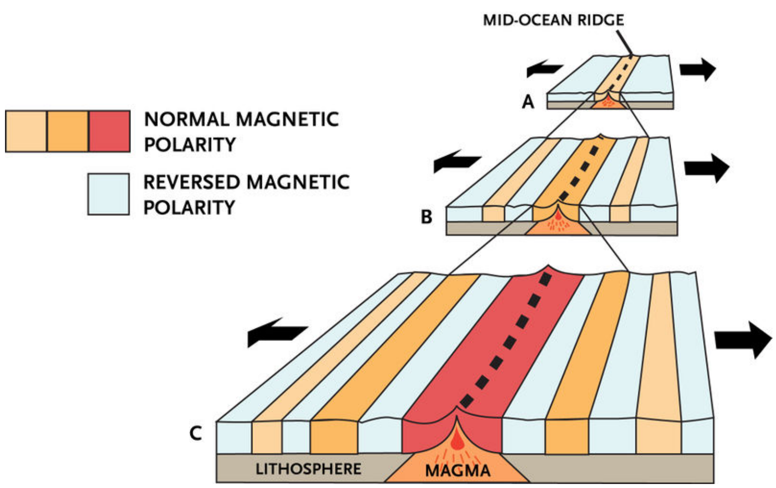

FIGURE 12.11
Scientists found that magnetic polarity in the seafloor was normal at mid-ocean ridges but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

Seafloor Ages

The scientists used geologic dating techniques on seafloor rocks. They found that the youngest rocks on the seafloor were at the mid-ocean ridges. The rocks get older with distance from the ridge crest. The scientists were surprised to find that the oldest seafloor is less than 180 million years old. This may seem old, but the oldest continental crust is around 4 billion years old.

Scientists also discovered that the mid-ocean ridge crest is nearly sediment free. The crust is also very thin there. With distance from the ridge crest, the sediments and crust get thicker. This also supports the idea that the youngest rocks are on the ridge axis and that the rocks get older with distance away from the ridge (**Figure** 12.12). Something causes the seafloor to be created at the ridge crest. The seafloor is also destroyed in a relatively short time.

The Seafloor Spreading Hypothesis

The **seafloor spreading** hypothesis brought all of these observations together in the early 1960s. Hot mantle material rises up at mid-ocean ridges. The hot magma erupts as lava. The lava cools to form new seafloor. Later, more lava erupts at the ridge. The new lava pushes the seafloor that is at the ridge horizontally away from ridge axis. The seafloor moves!

In some places, the oceanic crust comes up to a continent. The moving crust pushes that continent away from the ridge axis as well. If the moving oceanic crust reaches a deep sea trench, the crust sinks into the mantle. The creation and destruction of oceanic crust is the reason that continents move. Seafloor spreading is the mechanism that Wegener was looking for!

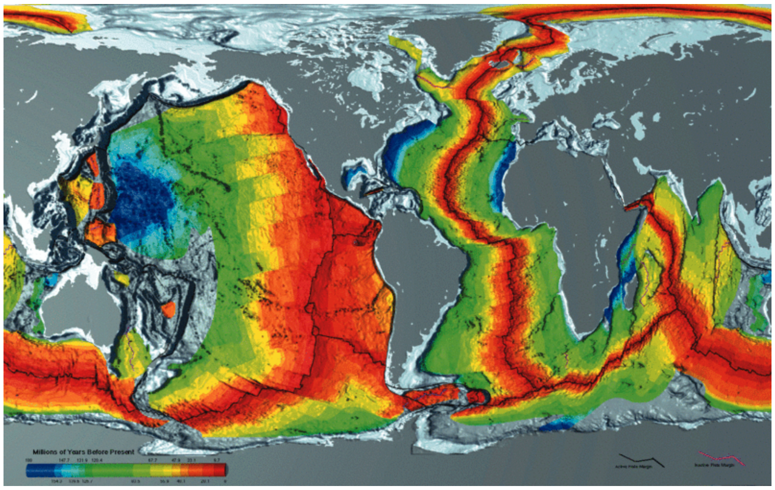

FIGURE 12.12
Seafloor is youngest near the mid-ocean ridges and gets progressively older with distance from the ridge. Orange areas show the youngest seafloor. The oldest seafloor is near the edges of continents or deep sea trenches.

Lesson Summary

- Using technologies developed during World War II, scientists were able to gather data that allowed them to recognize that seafloor spreading is the mechanism for Wegener's drifting continents.
- Maps of the ocean floor showed high mountain ranges and deep trenches.
- Changes in Earth's magnetic field give clues as to how seafloor forms and the importance of mid-ocean ridges in the creation of oceanic crust.
- Seafloor spreading processes create new oceanic crust at mid-ocean ridges and destroy older crust at deep sea trenches.

Lesson Review Questions

Recall

1. Describe a mid-ocean ridge. What geological processes are happening there?

2. Describe deep sea trenches and abyssal plains and their relative ages.

Apply Concepts

3. Using what you've learned about echo sounders, how do bats and dolphins use sound waves to create pictures of their worlds?

Think Critically

4. Why is the oceanic crust so young? Why is the continental crust so old?

5. Describe how continents move across the ocean basins.

6. Where would plate tectonics theory be if World War II hasn't happened?

Points to Consider

- How were the technologies that were developed during World War II used by scientists for the development of the seafloor spreading hypothesis?
- In what two ways did magnetic data lead scientists to understand more about plate tectonics?
- How does seafloor spreading provide a mechanism for continental drift?
- Describe the features of the North Pacific Ocean basin described in terms of seafloor spreading.

12.4 Theory of Plate Tectonics

Lesson Objectives

- Describe what a plate is and how scientists can recognize its edges.
- Explain how the plates move by convection in the mantle.
- Describe the three types of plate boundaries and the features of each type of boundary.
- Describe how plate tectonics processes lead to changes in Earth's surface features.

Vocabulary

- continental rifting
- convergent plate boundary
- divergent plate boundary
- intraplate activity
- island arc
- plate
- plate boundary
- subduction
- subduction zone
- transform fault
- transform plate boundary

Introduction

The theory of plate tectonics explains most of the features of Earth's surface. Plate tectonics helps us to understand where and why mountains form. Using the theory, we know where new ocean floor will be created and where it will be destroyed. We know why earthquakes and volcanic eruptions happen where they do. We even can search for mineral resources using information about past plate motions. Plate tectonics is the key that unlocks many of the mysteries of our amazing planet.

Earth's Tectonic Plates

The Cold War helped scientists to learn more about our planet. They set up seismograph networks during the 1950s and early 1960s. The purpose was to see if other nations were testing atomic bombs. Of course, at the same time, the seismographs were recording earthquakes.

Earthquake Locations

The scientists realized that the earthquakes were most common in certain areas. In the oceans, they were found along mid-ocean ridges and deep sea trenches. Earthquakes and volcanoes were common all around the Pacific Ocean. They named this region the Pacific Ring of Fire (**Figure** 12.13). Earthquakes are also common in the world's highest mountains, the Himalaya Mountains of Asia. The Mediterranean Sea also has many earthquakes.

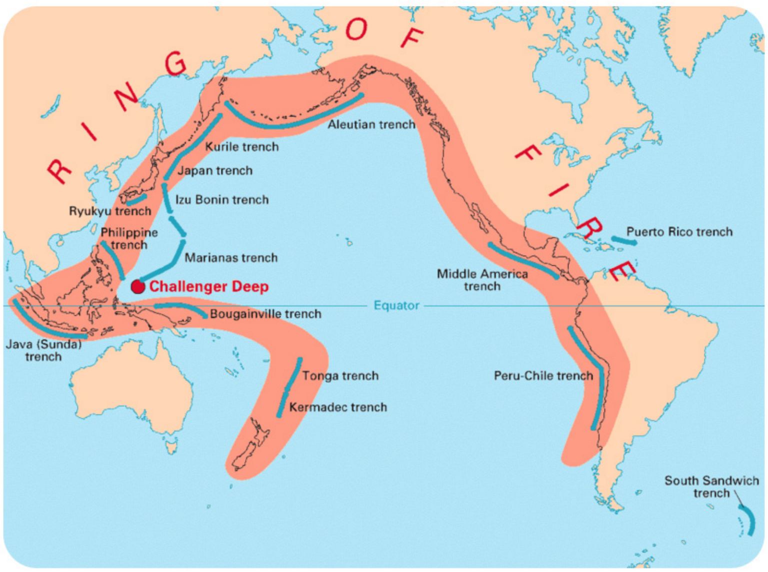

FIGURE 12.13
The Ring of Fire that circles the Pacific Ocean is where the most earthquakes and volcanic eruptions take place.

Earthquakes and Plate Boundaries

Earthquakes are used to identify plate boundaries (**Figure** 12.14). When earthquake locations are put on a map, they outline the **plates**. The movements of the plates are called plate tectonics.

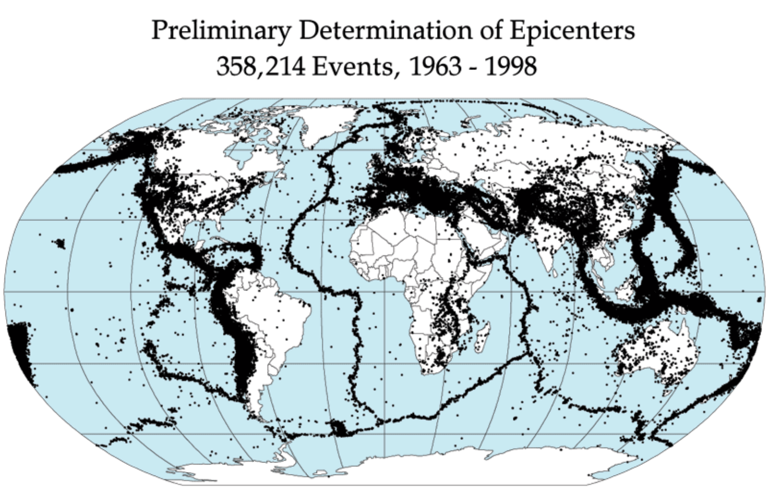

FIGURE 12.14
A map of earthquake epicenters shows that earthquakes are found primarily in lines that run up the edges of some continents, through the centers of some oceans, and in patches in some land areas.

The lithosphere is divided into a dozen major and several minor plates. Each plate is named for the continent or ocean basin it contains. Some plates are made of all oceanic lithosphere. A few are all continental lithosphere. But most plates are made of a combination of both.

Scientists have determined the direction that each plate is moving (**Figure** 12.15). Plates move around the Earth's surface at a rate of a few centimeters a year. This is about the same rate fingernails grow.

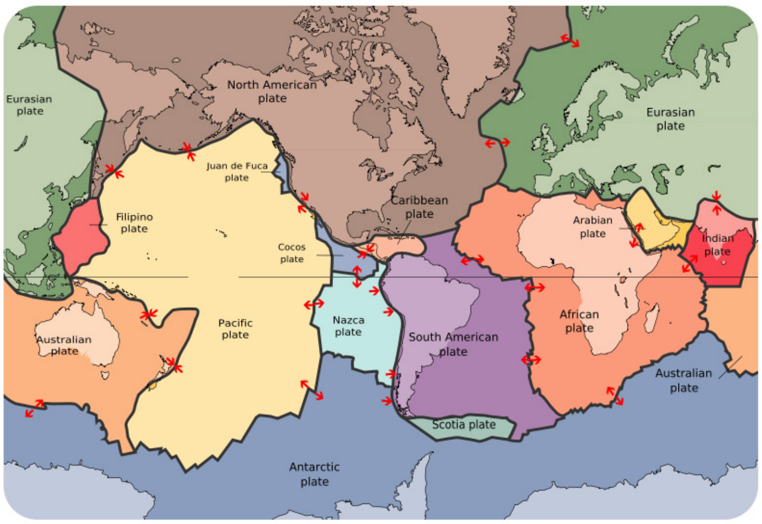

FIGURE 12.15
Earth's plates are shown in different colors. Arrows show the direction the plate is moving.

How Plates Move

Convection within the Earth's mantle causes the plates to move. Mantle material is heated above the core. The hot mantle rises up towards the surface (**Figure** 12.16). As the mantle rises it cools. At the surface the material moves horizontally away from a mid-ocean ridge crest. The material continues to cool. It sinks back down into the mantle at a deep sea trench. The material sinks back down to the core. It moves horizontally again, completing a convection cell.

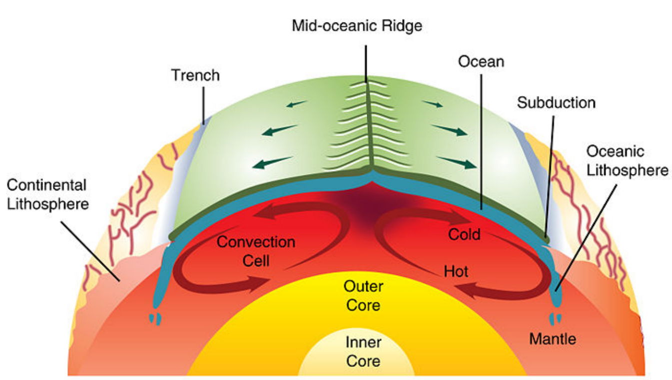

FIGURE 12.16
Plates move for two reasons. Upwelling mantle at the mid-ocean ridge pushes plates outward. Cold lithosphere sinking into the mantle at a subduction zone pulls the rest of the plate down with it.

Plate Boundaries

Plate boundaries are where two plates meet. Most geologic activity takes place at plate boundaries. This activity includes volcanoes, earthquakes, and mountain building. The activity occurs as plates interact. How can plates interact? Plates can move away from each other. They can move toward each other. Finally, they can slide past each other.

These are the three types of plate boundaries:

- **Divergent plate boundaries**: the two plates move away from each other.
- **Convergent plate boundaries**: the two plates move towards each other.
- **Transform plate boundaries**: the two plates slip past each other.

The features that form at a plate boundary are determined by the direction of plate motion and by the type of crust at the boundary.

Divergent Plate Boundaries

Plates move apart at divergent plate boundaries. This can occur in the oceans or on land.

Mid-ocean Ridges

Plates move apart at mid-ocean ridges. Lava rises upward, erupts, and cools. Later, more lava erupts and pushes the original seafloor outward. This is seafloor spreading. Seafloor spreading forms new oceanic crust. The rising magma causes earthquakes. Most mid-ocean ridges are located deep below the sea. The island of Iceland sits right on the Mid-Atlantic ridge (**Figure** 12.17).

FIGURE 12.17
The rift valley in Iceland that is part of the Mid-Atlantic Ridge is seen in this photo.

Continental Rifting

A divergent plate boundary can also occur within a continent. This is called **continental rifting** (**Figure** 12.18). Magma rises beneath the continent. The crust thins, breaks, and then splits apart. This first produces a rift valley. The East African Rift is a rift valley. Eastern Africa is splitting away from the African continent. Eventually, as the continental crust breaks apart, oceanic crust will form. This is how the Atlantic Ocean formed when Pangaea broke up.

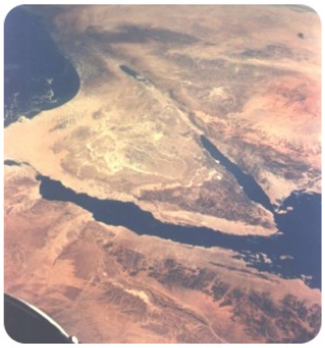

FIGURE 12.18

The Arabian, Indian, and African plates are rifting apart, forming the Great Rift Valley in Africa. The Dead Sea fills the rift with seawater.

Convergent Plate Boundaries

A convergent plate boundary forms where two plates collide. That collision can happen between a continent and oceanic crust, between two oceanic plates, or between two continents. Oceanic crust is always destroyed in these collisions.

Ocean-Continent Convergence

Oceanic crust may collide with a continent. The oceanic plate is denser, so it undergoes **subduction**. This means that the oceanic plate sinks beneath the continent. This occurs at an ocean trench (**Figure** 12.19). **Subduction zones** are where subduction takes place.

As you would expect, where plates collide there are lots of intense earthquakes and volcanic eruptions. The subducting oceanic plate melts as it reenters the mantle. The magma rises and erupts. This creates a volcanic mountain range near the coast of the continent. This range is called a **volcanic arc**. The Andes Mountains, along the western edge of South America, are a volcanic arc (**Figure** 12.20).

Ocean-Ocean Convergence

Two oceanic plates may collide. In this case, the older plate is denser. This plate subducts beneath the younger plate. As the subducting plate is pushed deeper into the mantle, it melts. The magma this creates rises and erupts. This forms a line of volcanoes, known as an **island arc** (**Figure** 12.21). Japan, Indonesia, the Philippine Islands, and the Aleutian Islands of Alaska are examples of island arcs (**Figure** 12.22).

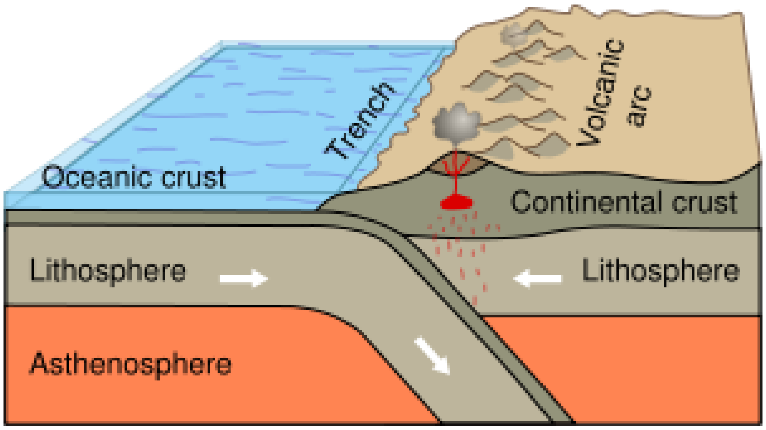

FIGURE 12.19
Subduction of an oceanic plate beneath a continental plate forms a line of volcanoes known as a continental arc and causes earthquakes.

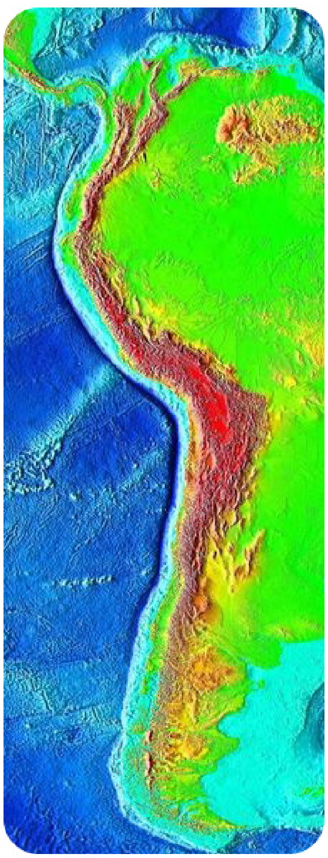

FIGURE 12.20
A relief map of South America shows the trench west of the continent. The Andes Mountains line the western edge of South America.

Continent-Continent Convergence

Continental lithosphere is low in density and very thick. Continental lithosphere cannot subduct. So when two continental plates collide, they just smash together, just like if you put your hands on two sides of a sheet of paper and bring your hands together. The material has nowhere to go but up (**Figure** 12.23)! Earthquakes and metamorphic rocks result from the tremendous forces of the collision. But the crust is too thick for magma to get through, so there are no volcanoes.

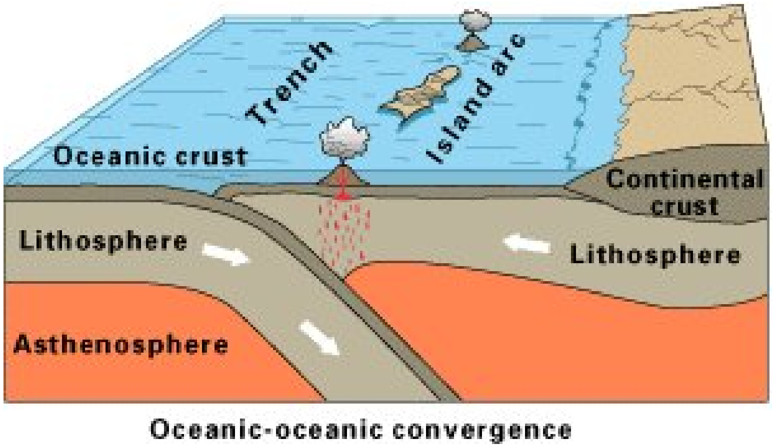

FIGURE 12.21
A convergent plate boundary subduction zone between two plates of oceanic lithosphere. Melting of the subducting plate causes volcanic activity and earthquakes.

FIGURE 12.22
The Aleutian Islands that border southern Alaska are an island arc. In this winter image from space, the volcanoes are covered with snow.

Mountain Building

Continent-continent convergence creates some of the world's largest mountains ranges. The Himalayas (**Figure** 12.24) are the world's tallest mountains. They are forming as two continents collide. The Appalachian Mountains are the remnants of a larger mountain range. This range formed from continent-continent collisions in the time of Pangaea.

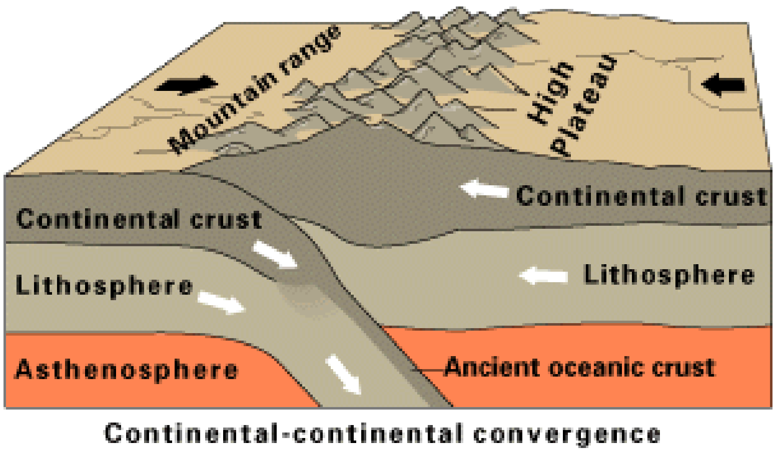

FIGURE 12.23
When two plates of continental crust collide, the material pushes upward, forming a high mountain range. The remnants of subducted oceanic crust remain beneath the continental convergence zone.

FIGURE 12.24
The Karakoram Range is part of the Himalaya Mountains. K2, pictured here, is the second highest mountain the world at over 28,000 feet. The number and height of mountains is impressive.

Transform Plate Boundaries

Two plates may slide past each other in opposite directions. This is called a transform plate boundary. These plate boundaries experience massive earthquakes. The world's best known transform fault is the San Andreas Fault in California (**Figure** 12.25). At this fault, the Pacific and North American plates grind past each other. Transform plate boundaries are most common as offsets along mid-ocean ridges.

Transform plate boundaries are different from the other two types. At divergent plate boundaries, new oceanic crust is formed. At convergent boundaries, old oceanic crust is destroyed. But at transform plate boundaries, crust is not created or destroyed.

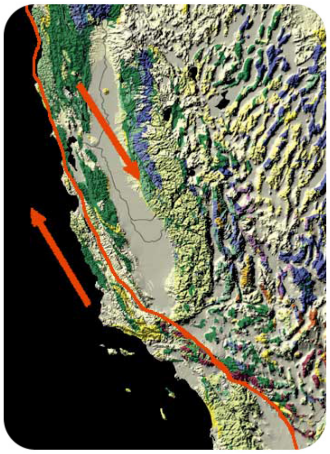

FIGURE 12.25
The red line is the San Andreas Fault. On the left is the Pacific Plate, which is moving northeast. On the right is the North American Plate, which is moving southwest. The movement of the plates is relative to each other.

Earth's Changing Surface

Knowing where plate boundaries are helps explain the locations of landforms and types of geologic activity. The activity can be current or old.

Active Plate Margins

Western North America has volcanoes and earthquakes. Mountains line the region. California, with its volcanoes and earthquakes, is an important part of the Pacific Ring of Fire. This is the boundary between the North American and Pacific Plates.

Passive Plate Margins

Mountain ranges also line the eastern edge of North America. But there are no active volcanoes or earthquakes. Where did those mountains come from? These mountains formed at a convergent plate boundary when Pangaea came together. About 200 million years ago these mountains were similar to the Himalayas today (**Figure** 12.26)! There were also earthquakes.

The Supercontinent Cycle

Scientists think that Pangaea was not the first supercontinent. There were others before it. The continents are now moving together. This is because of subduction around the Pacific Ocean. Eventually, the Pacific will disappear and a new supercontinent will form. This won't be for hundreds of millions of years. The creation and breakup of a supercontinent takes place about every 500 million years.

Intraplate Activity

Most geological activity takes place at plate boundaries. But some activity does not. Much of this **intraplate activity** is found at hot spots. Hotspot volcanoes form as plumes of hot magma rise from deep in the mantle.

FIGURE 12.26
The White Mountains in New Hampshire are part of the Appalachian province. The mountains are only around 6,000 feet high.

Hotspots in the Oceans

A chain of volcanoes forms as an oceanic plate moves over a hot spot. This is how it happens. A volcano forms over the hotspot. Since the plate is moving, the volcano moves off of the hotspot. When the hotspot erupts again, a new volcano forms over it. This volcano is in line with the first. Over time, there is a line of volcanoes. The youngest is directly above the hot spot. The oldest is the furthest away (**Figure** 12.27).

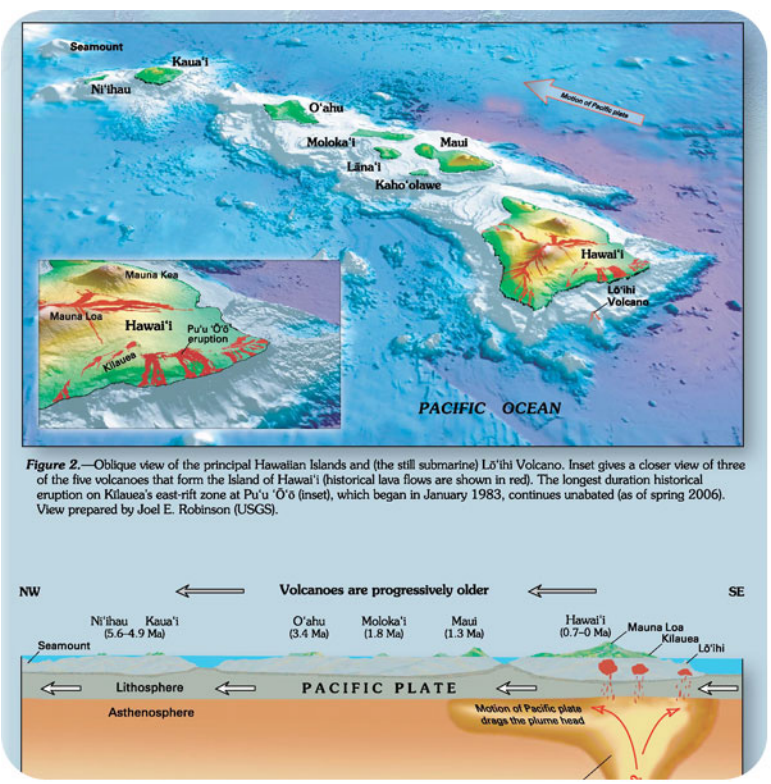

FIGURE 12.27
This view of the Hawaiian islands shows the youngest islands in the southeast and the oldest in the northwest. Kilauea volcano, which makes up the southeastern side of the Big Island of Hawaii, is located above the Hawaiian hotspot.

The Hawaii-Emperor chain of volcanoes formed over the Hawaiian Hotspot. The Hawaiian Islands formed most recently. Kilauea volcano is currently erupting. It is over the hotspot. The Emperor Seamounts are so old they no longer reach above sea level. The oldest of the Emperor Seamounts is about to subduct into the Aleutian trench off of Alaska. Geologists use hotspot chains to tell the direction and the speed a plate is moving.

Hotspots Beneath Continents

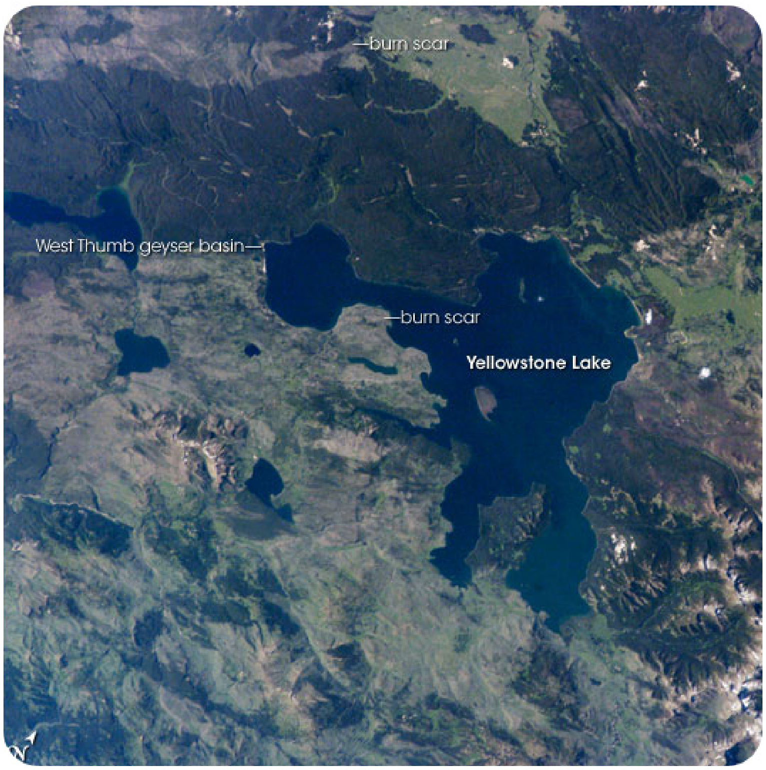

FIGURE 12.28
Yellowstone Lake lies at the center of a giant caldera. This hole in the ground was created by enormous eruptions at the Yellowstone hotspot. The hotspot lies beneath Yellowstone National Park.

Hot spots are also found under the continental crust. Since it is more difficult for magma to make it through the thick crust, they are much less common. One exception is the Yellowstone hotspot (**Figure** 12.28). This hotspot is very active. In the past, the hotspot produced enormous volcanic eruptions. Now its activity is best seen in the region's famous geysers.

Lesson Summary

- Convection in the mantle drives the movement of the plates of lithosphere over the Earth's surface. New oceanic crust forms at the ridge and pushes the older seafloor away from the ridge horizontally.
- Plates interact at three different types of plate boundaries: divergent, convergent and transform fault boundaries, where most of the Earth's geologic activity takes place.
- These processes acting over long periods of time are responsible for the geographic features we see.

Lesson Review Questions

Recall

1. Name the three types of plate boundaries? Which has volcanoes? Which has earthquakes? Which has mountain building?

Apply Concepts

2. Describe convection. How does this work to create plate boundaries?

Think Critically

3. Make some generalizations about which types of plate boundaries have volcanoes and which have earthquakes. Could you look at a plate boundary and determine what geological activity there would be?

4. Why is continental crust thicker than oceanic crust? Why is oceanic crust relatively thin?

Points to Consider

- On the map in **Figure** 12.15, the arrows show the directions that the plates are going. The Atlantic has a mid-ocean ridge, where seafloor spreading is taking place. The Pacific Ocean has many deep sea trenches, where subduction is taking place. What is the future of the Atlantic plate? What is the future of the Pacific plate?
- Using your hands and words, explain to someone how plate tectonics works. Be sure you describe how continents drift and how seafloor spreading provides a mechanism for continental movement.
- Now that you know about plate tectonics, where do you think would be a safe place to live if you wanted to avoid volcanic eruptions and earthquakes?

12.5 References

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CHAPTER 13 MS Earth's Minerals

Chapter Outline

Scientists have discovered more than 4,000 minerals in Earth's crust. Some minerals are found in very large amounts. Most minerals are found in small amounts. Some are very rare. Some are common. Many minerals are useful. Modern society depends on minerals and rocks that are mined. Mining is difficult work, but is necessary for us to have the goods we use.

13.1 Minerals

Lesson Objectives

- Describe the properties that all minerals share.
- Describe some different crystal structures of minerals.
- Identify the groups in which minerals are classified.

Vocabulary

- atom
- chemical compound
- crystal
- compound
- electron
- element
- ion
- matter
- mineral
- molecule
- neutron
- nucleus
- proton
- silicate

Introduction

You use objects that are made from minerals every day, even if you do not realize it. You are actually eating a mineral when you eat food that contains salt. You are drinking from a mineral when you drink from a glass. You might wear silver jewelry. The shiny metal silver, the white grains of salt, and the clear glass may not seem to have much in common, but they are all made from minerals (**Figure** 13.1). Silver is a mineral. Table salt is the mineral halite. Glass is produced from the mineral quartz.

Just looking at that list you see that minerals are very different from each other. If minerals are so different, what do all minerals have in common?

What is Matter?

To understand minerals, we must first understand matter. **Matter** is the substance that physical objects are made of.

FIGURE 13.1
Silver is used to make sterling silver jewelry. Table salt is the mineral halite. Glass is produced from the mineral quartz.

Atoms and Elements

The basic unit of matter is an **atom**. At the center of an atom is its **nucleus**. **Protons** are positively charged particles in the nucleus. Also in the nucleus are **neutrons** with no electrical charge. Orbiting the nucleus are tiny electrons. **Electrons** are negatively charged. An atom with the same number of protons and electrons is electrically neutral. If the atom has more or less electrons to protons it is called an **ion**. An ion will have positive charge if it has more protons than electrons. It will have negative charge if it has more electrons than protons.

An atom is the smallest unit of a chemical **element**. That is, an atom has all the properties of that element. All atoms of the same element have the same number of protons.

Molecules and Compounds

A **molecule** is the smallest unit of a **chemical compound**. A compound is a substance made of two or more elements. The elements in a chemical compound are always present in a certain ratio.

Water is probably one of the simplest compounds that you know. A water molecule is made of two hydrogen atoms and one oxygen atom (**Figure** 13.2). All water molecules have the same ratio: two hydrogen atoms to one oxygen atom.

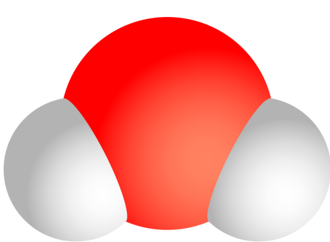

FIGURE 13.2
A water molecule has two hydrogen atoms (shown in gray) bonded to one oxygen molecule (shown in red).

What are Minerals?

A **mineral** is a solid material that forms by a natural process. A mineral can be made of an element or a compound. It has a specific chemical composition that is different from other minerals. One mineral's physical properties differ from others'. These properties include crystal structure, hardness, density and color. Each is made of different elements. Each has different physical properties. For example, silver is a soft, shiny metal. Salt is a white, cube-shaped crystal. Diamond is an extremely hard, translucent crystal.

Natural Processes

Minerals are made by natural processes. The processes that make minerals happen in or on the Earth. For example, when hot lava cools, mineral crystals form. Minerals also precipitate from water. Some minerals grow when rocks are exposed to high pressures and temperatures.

Could something like a mineral be made by a process that was not natural? People make gemstones in a laboratory. Synthetic diamond is a common one. But that stone is not a mineral. It was not formed by a natural process.

Inorganic Substances

A mineral is an inorganic substance. It was not made by living organisms. Organic substances contain carbon. Some organic substances are proteins, carbohydrates, and oils. Everything else is inorganic. In a few cases, living organisms make inorganic materials. The calcium carbonate shells made by marine animals are inorganic.

Definite Composition

All minerals have a definite chemical makeup. A few minerals are made of only one kind of element. Silver is a mineral made only of silver atoms. Diamond and graphite are both made only of the element carbon.

Minerals that are not pure elements are made of chemical compounds. For example, the mineral quartz is made of the compound silicon dioxide, or SiO_2. This compound has one atom of the element silicon for every two atoms of the element oxygen.

Each mineral has its own unique chemical formula. For example, the mineral hematite has two iron atoms for every three oxygen atoms. The mineral magnetite has three iron atoms for every four oxygen atoms. Many minerals have very complex chemical formulas that include several elements. However, even in more complicated compounds, the elements occur in definite ratios.

Solid Crystals

Minerals must be solid. For example, ice and water have the same chemical composition. Ice is a solid, so it is a mineral. Water is a liquid, so it is not a mineral.

Some solids are not crystals. Glass, or the rock obsidian, are solid but not crystals. In a **crystal**, the atoms are arranged in a pattern. This pattern is regular and it repeats. **Figure** 13.3 shows how the atoms are arranged in halite (table salt). Halite contains atoms of sodium and chlorine in a pattern. Notice that the pattern goes in all three dimensions.

The pattern of atoms in all halite is the same. Think about all of the grains of salt that are in a salt shaker. The atoms are arranged in the same way in every piece of salt.

Sometimes two different minerals have the same chemical composition. But they are different minerals because they have different crystal structures. Diamonds are beautiful gemstones because they are very pretty and very hard.

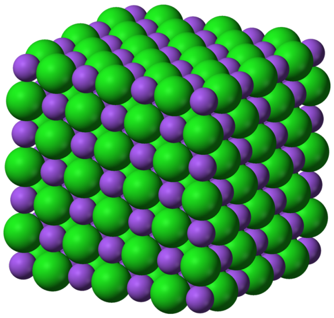

FIGURE 13.3
Sodium ions (purple balls) bond with chloride ions (green balls) to form halite crystals.

Graphite is the "lead" in pencils. It's not hard at all! Amazingly, both are made just of carbon. Compare the diamond with the pencil lead in **Figure** 13.4. Why are they so different? The carbon atoms in graphite bond to form layers. The bonds between each layer are weak. The carbon sheets can just slip past each other. The carbon atoms in diamonds bond together in all three directions. This strong network makes diamonds very hard.

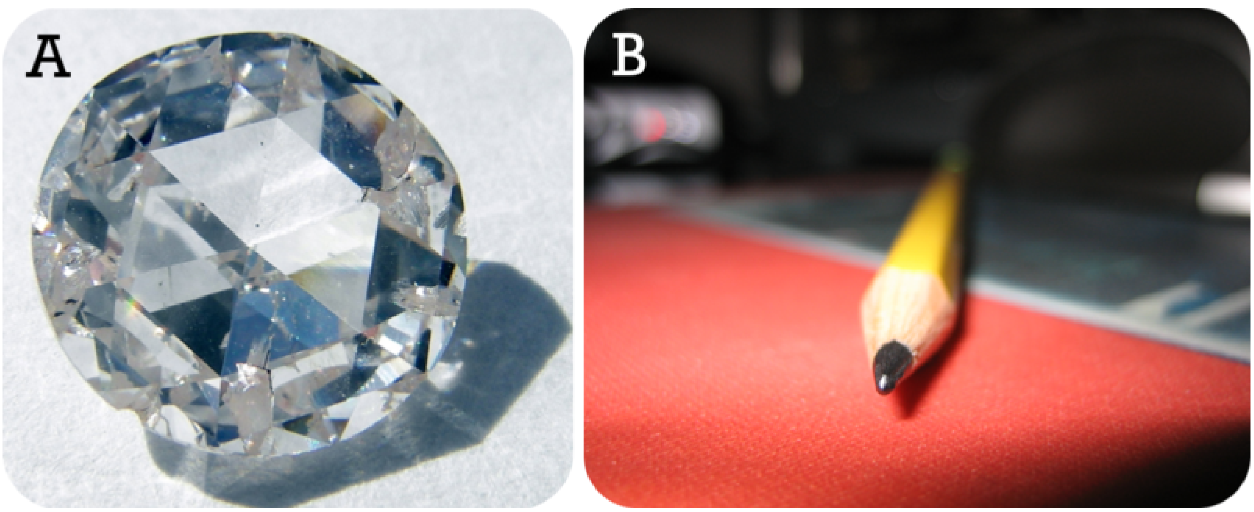

FIGURE 13.4
Diamonds (A) and graphite (B) are both made of only carbon, but they're not much alike.

Physical Properties

The patterns of atoms that make a mineral affect its physical properties. A mineral's crystal shape is determined by the way the atoms are arranged. For example, you can see how atoms are arranged in halite in **Figure** 13.3. You can see how salt crystals look under a microscope in **Figure** 13.5. Salt crystals are all cubes whether they're small or large.

Other physical properties help scientists identify different minerals. They include:

- Color: the color of the mineral.
- Streak: the color of the mineral's powder.

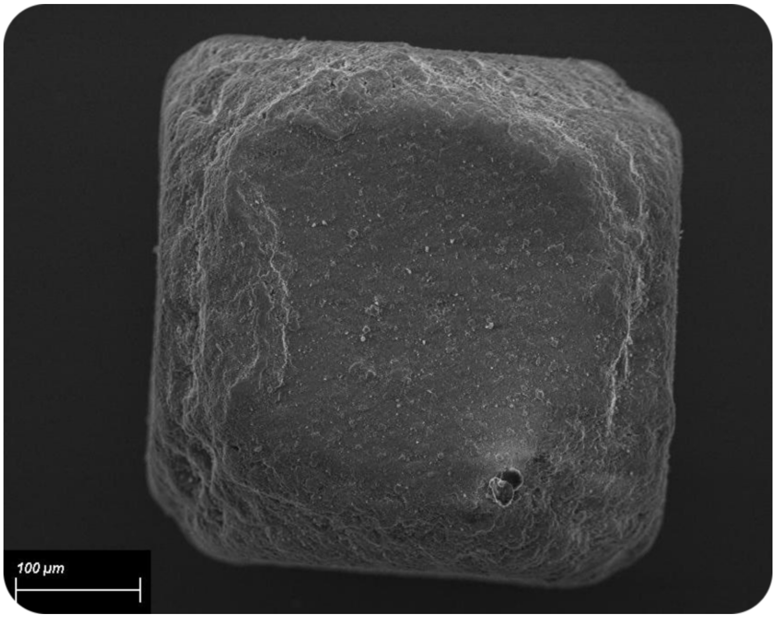

FIGURE 13.5
Under a microscope, salt crystals are cubes.

- Luster: the way light reflects off the mineral's surface.
- Specific gravity: how heavy the mineral is relative to the same volume of water.
- Cleavage: the mineral's tendency to break along flat surfaces.
- Fracture: the pattern in which a mineral breaks.
- Hardness: what minerals it can scratch and what minerals can scratch it.

Groups of Minerals

Imagine you are in charge of organizing more than 100 minerals for a museum exhibit. People can learn a lot more if they see the minerals together in groups. How would you group the minerals together in your exhibit?

Mineralogists are scientists who study minerals. They divide minerals into groups based on chemical composition. Even though there are over 4,000 minerals, most minerals fit into one of eight mineral groups. Minerals with similar crystal structures are grouped together.

Silicate Minerals

About 1,000 silicate minerals are known. This makes silicates the largest mineral group. Silicate minerals make up over 90 percent of Earth's crust!

Silicates contain silicon atoms and oxygen atoms. One silicon atom is bonded to four oxygen atoms. These atoms form a pyramid (**Figure** 13.6). The silicate pyramid is the building block of silicate minerals. Most silicates contain other elements. These elements include calcium, iron, and magnesium.

Silicate minerals are divided into six smaller groups. In each group, the silicate pyramids join together differently. The pyramids can stand alone. They can form into connected circles called rings. Some pyramids link into single and double chains. Others form large, flat sheets. Some join in three dimensions.

Feldspar and quartz are the two most common silicates. In beryl, the silicate pyramids join together as rings. Biotite is mica. It can be broken apart into thin, flexible sheets. Compare the beryl and the biotite shown in **Figure** 13.7.

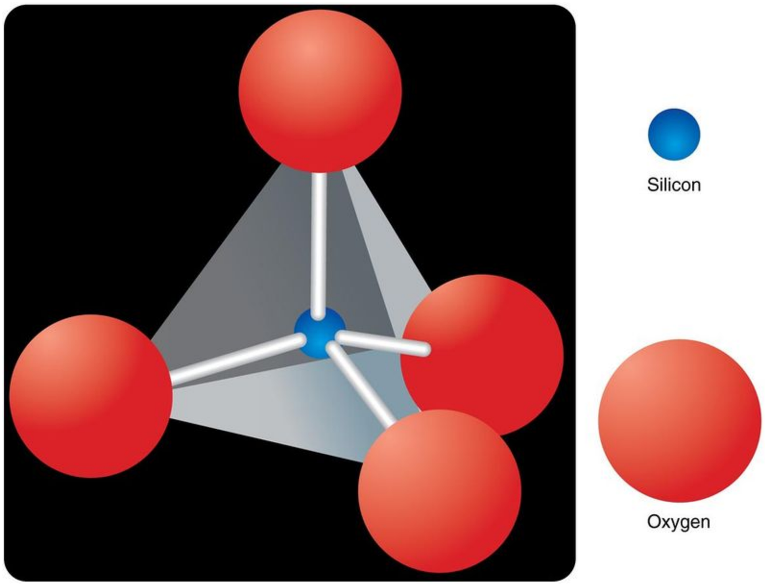

FIGURE 13.6
One silicon atom bonds to four oxygen atoms to form a pyramid

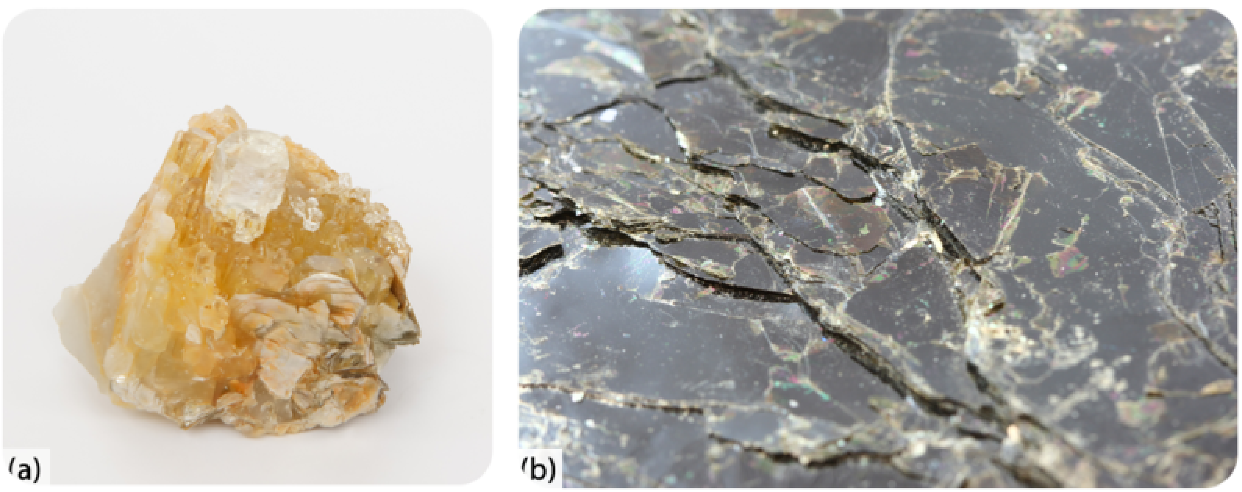

FIGURE 13.7
Beryl (a) and biotite (b) are both silicate minerals.

Native Elements

Native elements contain only atoms of one type of element. They are not combined with other elements. There are very few examples of these types of minerals. Some native elements are rare and valuable. Gold, silver, sulfur, and diamond are examples.

Carbonates

What do you guess **carbonate** minerals contain? If you guessed carbon, you would be right! All carbonates contain one carbon atom bonded to three oxygen atoms. Carbonates may include other elements. A few are calcium, iron, and copper.

Carbonate minerals are often found where seas once covered the land. Some carbonate minerals are very common. Calcite contains calcium, carbon, and oxygen. Have you ever been in a limestone cave or seen a marble tile? Calcite is in both limestone and marble. Azurite and malachite are also carbonate minerals, but they contain copper instead of calcium. They are not as common as calcite. They are used in jewelry. You can see in **Figure** 13.8 that they are very colorful.

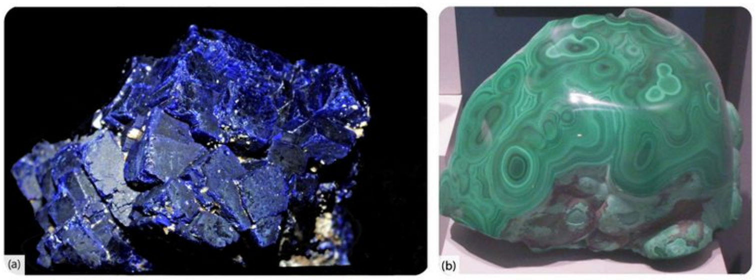

FIGURE 13.8
The deep blue mineral is azurite and the green is malachite. Both of these carbonate minerals are used for jewelry.

Halides

Halide minerals are salts. They form when salt water evaporates. This mineral class includes more than just table salt. Halide minerals may contain the elements fluorine, chlorine, bromine, or iodine. Some will combine with metal elements. Common table salt is a halide mineral that contains the elements chlorine and sodium. Fluorite is a type of halide that contains fluorine and calcium. Fluorite can be found in many colors. If you shine an ultraviolet light on fluorite, it will glow!

Oxides

Earth's crust contains a lot of oxygen. The oxygen combines with many other elements to create oxide minerals. Oxides contain one or two metal elements combined with oxygen. Oxides are different from silicates because they do not contain silicon. Many important metals are found as oxides. For example, hematite and magnetite are both oxides that contain iron. Hematite (Fe_2O_3) has a ratio of two iron atoms to three oxygen atoms. Magnetite (Fe_3O_4) has a ratio of three iron atoms to four oxygen atoms. Notice that the word "magnetite" contains the word "magnet". Magnetite is a magnetic mineral.

Phosphates

Phosphate minerals have a structure similar to silicates. In silicates, an atom of silicon is bonded to oxygen. In phosphates, an atom of phosphorus, arsenic, or vanadium is bonded to oxygen. There are many types of phosphate mineral, but still phosphate minerals are rare. The composition of phosphates is complex. For example, turquoise contains copper, aluminum, and phosphorus. The stone is rare and is used to make jewelry.

Sulfates

Sulfate minerals contain sulfur atoms bonded to oxygen atoms. Like halides, they can form in places where salt water evaporates. Many minerals belong in the sulfate group, but there are only a few common sulfate minerals. Gypsum is a common sulfate mineral that contains calcium, sulfate, and water. Gypsum is found in various forms. For example, it can be pink and look like it has flower petals. However, it can also grow into very large white crystals. Gypsum crystals that are 11 meters long have been found. That is about as long as a school bus! Gypsum also forms at the Mammoth Hot Springs in Yellowstone National Park, shown in **Figure** 13.9.

FIGURE 13.9
Gypsum is the white mineral that is common around hot springs. This is Mammoth Hot Springs in Yellowstone National Park.

Sulfides

Sulfides contain metal elements combined with sulfur. Sulfides are different from sulfates. They do not contain oxygen. Pyrite is a common sulfide mineral. It contains iron combined with sulfur. Pyrite is also known as "fool's gold." Gold miners have mistaken pyrite for gold because pyrite has a greenish gold color.

Lesson Summary

- A mineral is a naturally occurring inorganic solid. It has a definite composition and crystal structure.
- The atoms in minerals are arranged in regular, repeating patterns.
- These patterns are responsible for a mineral's physical properties.
- Minerals are divided into groups. The groups are based on their chemical composition.
- Silicates are the most common minerals.

Lesson Review Questions

Recall

1. What is matter?

2. What are atoms and what are they made of?

3. What is a molecule? What substances do molecules make?

4. Go through the eight mineral groups. List the elements that are contained by all minerals in each group.

Apply Concepts

5. Quartz is made of one silicon atom and two oxygen atoms. If you find a mineral and find that it is made of one silicon atom and one oxygen atom is it quartz?

6. Why is water ice considered a mineral?

7. A shady looking character offers you a valuable mineral made of carbon. You know that diamonds are made of carbon so you give him $100 for one. Have you gotten yourself a good deal? Why or why not?

Think Critically

8. Why are diamonds "a girls best friend?" What other uses might diamonds have?

9. Coal is made of ancient plant parts that were squeezed together and heated. Is coal a mineral? Explain.

Points to Consider

- What is one way you could tell the difference between two different minerals?
- Why would someone want to make minerals when they are found in nature?
- Why are minerals so colorful? Can color be used to identify minerals?

13.2 Identification of Minerals

Lesson Objectives

- Explain how minerals are identified.
- Describe how color, luster, and streak are used to identify minerals.
- Summarize specific gravity.
- Explain how the hardness of a mineral is measured.
- Describe the properties of cleavage and fracture.
- Identify additional properties that can be used to identify some minerals.

Vocabulary

- cleavage
- density
- fracture
- hardness
- luster
- streak

Introduction

How could you describe your shirt when you are talking to your best friend on the phone? You might describe the color, the way the fabric feels, and the length of the sleeves. These are all physical properties of your shirt. If you did a good job describing your shirt, your friend would recognize the shirt when you wear it. Minerals also have physical properties that are used to identify them.

How are Minerals Identified?

Imagine you were given a mineral sample similar to the one shown in **Figure** 13.10. How would you try to identify your mineral? You can observe some properties by looking at the mineral. For example, you can see that its color is beige. The mineral has a rose-like structure. But you can't see all mineral properties. You need to do simple tests to determine some properties. One common one is how hard the mineral is. You can use a mineral's properties to identify it. The mineral's physical properties are determined by its chemical composition and crystal structure.

FIGURE 13.10
You can use properties of a mineral to identify it. The color and rose-like structure of this mineral mean that it is gypsum.

Color, Streak, and Luster

Diamonds have many valuable properties. Diamonds are extremely hard and are used for industrial purposes. The most valuable diamonds are large, well-shaped and sparkly. Turquoise is another mineral that is used in jewelry because of its striking greenish-blue color. Many minerals have interesting appearances. Specific terms are used to describe the appearance of minerals.

Color

Color is probably the easiest property to observe. Unfortunately, you can rarely identify a mineral only by its color. Sometimes, different minerals are the same color. For example, you might find a mineral that is a gold color, and so think it is gold. But it might actually be pyrite, or "fool's gold," which is made of iron and sulfide. It contains no gold atoms.

A certain mineral may form in different colors. **Figure** 13.11 shows four samples of quartz, including one that is colorless and one that is purple. The purple color comes from a tiny amount of iron. The iron in quartz is a chemical impurity. Iron is not normally found in quartz. Many minerals are colored by chemical impurities. Other factors can also affect a mineral's color. Weathering changes the surface of a mineral. Because color alone is unreliable, geologists rarely identify a mineral just on its color. To identify most minerals, they use several properties.

Streak

Streak is the color of the powder of a mineral. To do a streak test, you scrape the mineral across an unglazed porcelain plate. The plate is harder than many minerals, causing the minerals to leave a streak of powder on the plate. The color of the streak often differs from the color of the larger mineral sample, as **Figure** 13.12 shows.

Streak is more reliable than color to identify minerals. The color of a mineral may vary. Streak does not vary. Also, different minerals may be the same color, but they may have a different color streak. For example, samples of hematite and galena can both be dark gray. They can be told apart because hematite has a red streak and galena has a gray streak.

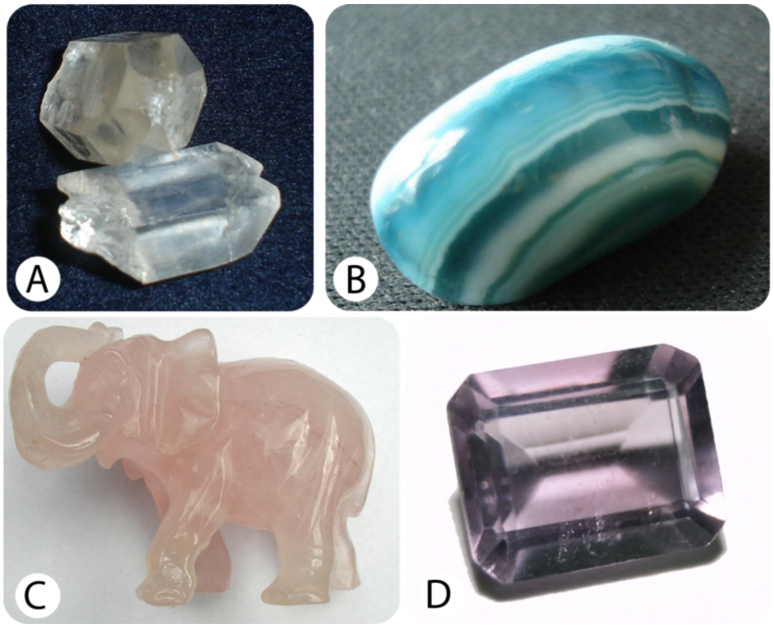

FIGURE 13.11
Quartz comes in many different colors including: (A) transparent quartz, (B) blue agate, (C) rose quartz, and (D) purple amethyst.

FIGURE 13.12
Rub a mineral across an unglazed porcelain plate to see its streak. The hematite shown here has a red streak.

Luster

Luster describes the way light reflects off of the surface of the mineral. You might describe diamonds as sparkly or pyrite as shiny. But mineralogists have special terms to describe luster. They first divide minerals into metallic and non-metallic luster. Minerals that are opaque and shiny, like pyrite, are said to have a "metallic" luster. Minerals with a "non-metallic" luster do not look like metals. There are many types of non-metallic luster. Six are described in **Table** 13.1.

TABLE 13.1: Minerals with Non-Metallic Luster

Non-Metallic Luster	Appearance
Adamantine	Sparkly
Earthy	Dull, clay-like
Pearly	Pearl-like
Resinous	Like resins, such as tree sap
Silky	Soft-looking with long fibers
Vitreous	Glassy

Can you match the minerals in **Figure** 13.13 with the correct luster from **Table** 13.1 without looking at the caption?

Density

You are going to visit a friend. You fill one backpack with books so you can study later. You stuff your pillow into another backpack that is the same size. Which backpack will be easier to carry? Even though the backpacks are the same size, the bag that contains your books is going to be much heavier. It has a greater density than the backpack with your pillow.

Density describes how much matter is in a certain amount of space. Substances that have more matter packed into a given space have higher densities. The water in a drinking glass has the same density as the water in a bathtub or swimming pool. All substances have characteristic densities, which does not depend on how much of a substance you have.

Mass is a measure of the amount of matter in an object. The amount of space an object takes up is described by its volume. The density of an object depends on its mass and its volume. Density can be calculated using the following equation:

$$\text{Density} = \text{Mass}/\text{Volume}$$

Samples that are the same size, but have different densities, will have different masses. Gold has a density of about 19 g/cm^3. Pyrite has a density of only about 5 g/cm^3. Quartz is even less dense than pyrite, and has a density of 2.7 g/cm^3. If you picked up a piece of pyrite and a piece of quartz that were the same size, the pyrite would seem almost twice as heavy as the quartz.

Hardness

Hardness is a mineral's ability to resist being scratched. Minerals that are not easily scratched are hard. You test the hardness of a mineral by scratching its surface with a mineral of a known hardness. Mineralogists use the Mohs Hardness Scale, shown in **Table** 13.2, as a reference for mineral hardness. The scale lists common minerals in order of their relative hardness. You can use the minerals in the scale to test the hardness of an unknown mineral.

Mohs Hardness Scale

As you can see, diamond is a 10 on the Mohs Hardness Scale. Diamond is the hardest mineral; no other mineral can scratch a diamond. Quartz is a 7. It can be scratched by topaz, corundum, and diamond. Quartz will scratch minerals

FIGURE 13.13
(A) Diamonds have an adamantine luster. These minerals are transparent and highly reflective. (B) Kaolinite is a clay with a dull or earthy luster. (C) Opal's luster is greasy. (D) Chalcopyrite, like its cousin pyrite, has metallic luster. (E) Stilbite (orange) has a resinous luster. (F) The white ulexite has silky luster. (G) Sphalerite has a submetallic luster. (H) This Mayan artifact is carved from jade. Jade is a mineral with a waxy luster.

that have a lower number on the scale. Fluorite is one. Suppose you had a piece of pure gold. You find that calcite scratches the gold. Gypsum does not. Gypsum has a hardness of 2 and calcite is a 3. That means the hardness of gold is between gypsum and calcite. So the hardness of gold is about 2.5 on the scale. A hardness of 2.5 means that gold is a relatively soft mineral. It is only about as hard as your fingernail.

TABLE 13.2: Mohs Scale

Hardness	Mineral
1	Talc

TABLE 13.2: (continued)

Hardness	Mineral
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Cleavage and Fracture

Different types of minerals break apart in their own way. Remember that all minerals are crystals. This means that the atoms in a mineral are arranged in a repeating pattern. This pattern determines how a mineral will break. When you break a mineral, you break chemical bonds. Because of the way the atoms are arranged, some bonds are weaker than other bonds. A mineral is more likely to break where the bonds between the atoms are weaker.

Cleavage

Cleavage is the tendency of a mineral to break along certain planes. When a mineral breaks along a plane it makes a smooth surface. Minerals with different crystal structures will break or cleave in different ways, as in **Figure** 13.14. Halite tends to form cubes with smooth surfaces. Mica tends to form sheets. Fluorite can form octahedrons.

FIGURE 13.14
Minerals with different crystal structures have a tendency to break along certain planes.

Minerals can form various shapes. Polygons are shown in **Figure** 13.15. The shapes form as the minerals are broken along their cleavage planes. Cleavage planes determine how the crystals can be cut to make smooth surfaces. People who cut gemstones follow cleavage planes. Diamonds and emeralds can be cut to make beautiful gemstones.

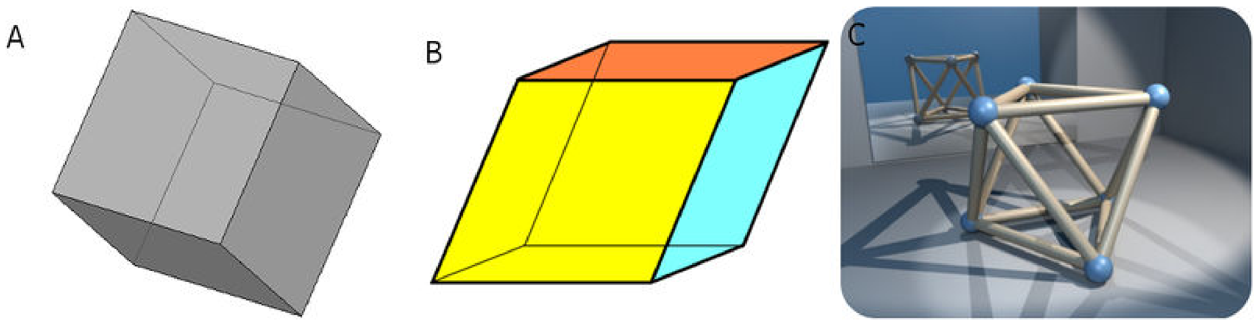

FIGURE 13.15

Cubes have six sides that are all the same size square. All of the angles in a cube are equal to 90°. Rhombohedra also have six sides, but the sides are diamond-shaped. Octahedra have eight sides that are all shaped like triangles.

Fracture

Fracture describes how a mineral breaks without any pattern. A fracture is uneven. The surface is not smooth and flat. You can learn about a mineral from the way it fractures. If a mineral splinters like wood, it may be fibrous. Some minerals, such as quartz, fracture to form smooth, curved surfaces. A mineral that broke forming a smooth, curved surface is shown in **Figure** 13.16.

Other Identifying Characteristics

Minerals have other properties that can be used for identification. For example, a mineral's shape may indicate its crystal structure. Sometimes crystals are too small to see. Then a mineralogist may use a special instrument to find the crystal structure.

Some minerals have unique properties. These can be used to the minerals. Some of these properties are listed in **Table** 13.3. An example of a mineral that has each property is also listed.

TABLE 13.3: Special Mineral Properties

Property	Description	Example of Mineral
Fluorescence	Mineral glows under ultraviolet light	Fluorite
Magnetism	Mineral is attracted to a magnet	Magnetite
Radioactivity	Mineral gives off radiation that can be measured with Geiger counter	Uraninite
Reactivity	Bubbles form when mineral is exposed to a weak acid	Calcite
Smell	Some minerals have a distinctive smell	Sulfur (smells like rotten eggs)

FIGURE 13.16
This mineral formed a smooth, curved surface when it fractured.

Lesson Summary

- You can identify a mineral by its appearance and other properties.
- The color and luster describe the appearance of a mineral, and streak describes the color of the powdered mineral.
- Each mineral has a characteristic density.
- Mohs Hardness Scale is used to compare the hardness of minerals.
- The way a mineral cleaves or fractures depends on the crystal structure of the mineral.
- Some minerals have special properties that can be used to help identify the mineral.

Lesson Review Questions

Recall

1. What is cleavage? What is fracture? If you are looking at a mineral face, how can you tell them apart?

2. What is color? When would you use color to identify a mineral?

3. What is streak? Why would you use streak instead of color to identify a mineral?

Apply Concepts

4. What type of luster do gemstones mostly have? Why do you think this type of luster is popular for jewelry?

5. If a mineral has a unique property that only that type of mineral has is it good for identifying that mineral? Is there any time that it might not be?

Think Critically

6. You are trying to identify a mineral sample. Apatite scratches the surface of the mineral. Which mineral would you use next to text the mineral's hardness—fluorite or feldspar? Explain your reasoning.

7. You have two mineral samples that are about the size of a golf ball. Mineral A has a density of 5 g/cm^3. Mineral B is twice as dense as Mineral A. What is the density of Mineral B?

Points to Consider

- Some minerals are colored because they contain chemical impurities. How did the impurities get into the mineral?
- What two properties of a mineral sample would you have to measure to calculate its density?

13.3 Formation of Minerals

Lesson Objectives

- Describe how melted rock produces minerals.
- Explain how minerals form from solutions.

Vocabulary

- lava
- magma
- rocks

Introduction

Minerals are all around you. They are used to make your house, your computer, even the buttons on your jeans. But where do minerals come from? There are many types of minerals, and they do not all form in the same way. Some minerals form when salt water on Earth's surface evaporates. Others form from water mixtures that are seeping through rocks far below your feet. Still others form when molten rock cools.

Formation from Magma and Lava

You are on vacation at the beach. You take your flip-flops off so you can go swimming. The sand is so hot it hurts your feet. You have to run to the water. Now imagine if it were hot enough for the sand to melt.

Some places inside Earth are so hot that rock melts. Melted rock inside the Earth is called magma. **Magma** can be hotter than 1,000°C. When magma erupts onto Earth's surface, it is known as **lava**, as **Figure** 13.17 shows. Minerals form when magma and lava cool.

Formation from Solutions

Most water on Earth, like the water in the oceans, contains elements. The elements are mixed evenly through the water. Water plus other substances makes a solution. The particles are so small that they will not come out when you filter the water. But the elements in water can form solid mineral deposits.

FIGURE 13.17
Lava is melted rock that erupts onto Earth's surface.

Minerals from Salt Water

Fresh water contains a small amount of dissolved elements. Salt water contains a lot more dissolved elements. Water can only hold a certain amount of dissolved substances. When the water evaporates, it leaves behind a solid layer of minerals, as **Figure** 13.18 shows. At this time, the particles come together to form minerals. These solids sink to the bottom. The amount of mineral formed is the same as the amount dissolved in the water. Seawater is salty enough for minerals to precipitate as solids. Some lakes, such as Mono Lake in California, or Utah's Great Salt Lake, can also precipitate salts.

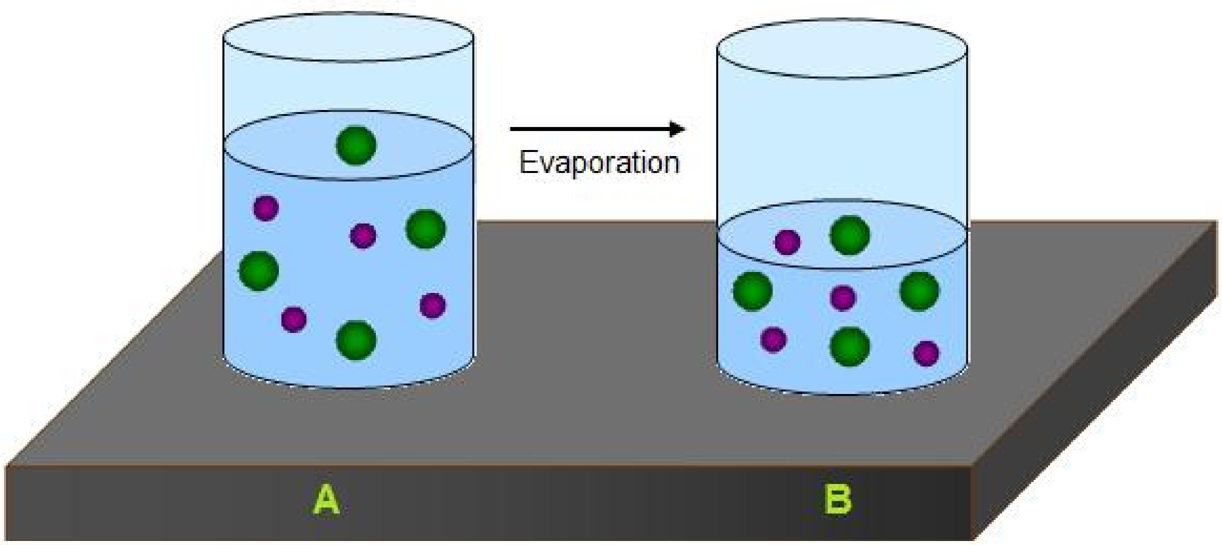

FIGURE 13.18
When the water in glass A evaporates, the dissolved mineral particles are left behind.

Salt easily precipitates out of water, as does calcite, as **Figure** 13.19 shows. The limestone towers in the figure are made mostly of the mineral calcite. The calcite was deposited in the salty and alkaline water of Mono Lake, in California. Calcium-rich spring water enters the bottom of the lake. The water bubbles up into the alkaline lake. The calcite "tufa" towers form. When the lake level drops, the tufa towers are revealed.

FIGURE 13.19
Tufa towers are found in interesting formations at Mono Lake, California.

Minerals from Hot Underground Water

Underground water can be heated by magma. The hot water moves through cracks below Earth's surface. Hot water can hold more dissolved particles than cold water. The hot, salty solution has chemical reactions with the rocks around it. The water picks up more dissolved particles. As it flows through open spaces in rocks, the water deposits solid minerals. When a mineral fills cracks in rocks, the deposits are called "veins." **Figure** 13.20 shows a white quartz vein. When the minerals are deposited in open spaces, large crystals grow. These rocks are called geodes. **Figure** 13.20 shows a "geode" that was formed when amethyst crystals grew in an open space in a rock.

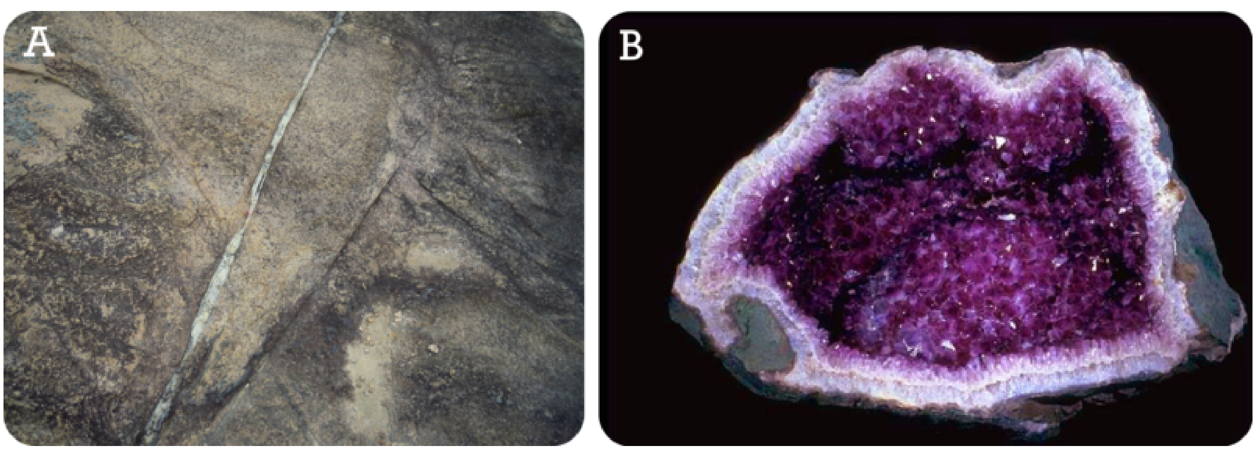

FIGURE 13.20
(A) A quartz vein formed in this rock. (B) Geodes form when minerals evaporate out in open spaces inside a rock.

Lesson Summary

- Mineral crystals that form when magma cools are usually larger than crystals that form when lava cools.
- Minerals are deposited from salty water solutions on Earth's surface and underground.

Lesson Review Questions

Recall

1. How does magma differ from lava?

2. What happens to elements in salt water when the water evaporates?

Apply Concepts

3. Describe how minerals can form out of salt water. What are all the steps in the process?

Think Critically

4. You are handed a rock with large and form beautiful crystals. Another rock is made of the same mineral type but the crystals are small and not well formed. How is the way the two sets of that mineral formed different?

Points to Consider

- When most minerals form, they combine with other minerals to form rocks. How can these minerals be used?
- The same mineral can be formed by different processes. How can the way a mineral forms affect how the mineral is used?

13.4 Mining and Using Minerals

Lesson Objectives

- Explain how minerals are mined.
- Describe how metals are made from mineral ores.
- Summarize the ways in which gemstones are used.
- Identify some useful minerals.

Vocabulary

- gemstone
- ore

Introduction

When you use a roll of aluminum foil or some baby powder, you probably don't think about how the products were made. We use minerals in many everyday items.

Minerals have to be removed from the ground and made into the products. All the metals we use start out as an ore. Mining the ore is just the first step. Next, the ore must be separated from the rest of the rock that is mined. Then, the minerals need to be separated out of the ore.

Ore Deposits

A mineral deposit that contains enough minerals to be mined for profit is called an **ore**. Ores are rocks that contain concentrations of valuable minerals. The bauxite shown in the **Figure** 13.21 is a rock that contains minerals that are used to make aluminum.

Finding and Mining Minerals

Ores have high concentrations of valuable minerals. Certain places on Earth are more likely to have certain ores. Geologists search for the places that might have ore deposits. Some of the valuable deposits may be hidden underground. To find an ore deposit, geologists will go to a likely spot. They then test the physical and chemical properties of soil and rocks. Ore deposits contain valuable minerals. They may also contain other chemical elements that indicate an ore deposit is nearby.

FIGURE 13.21
Aluminum is made from the minerals in rocks known as bauxite.

After a mineral deposit is found, geologists determine how big it is. They outline the deposit and the surrounding geology on a map. The miners calculate the amount of valuable minerals they think they will get from the deposit. The minerals will only be mined if it is profitable. If it is profitable, they must then decide on the way it should be mined. The two main methods of mining are surface mining and underground mining. Placers are a type of surface deposit.

Surface Mining

Surface mining is used to obtain mineral ores that are near the surface. Blasting breaks up the soil and rocks that contain the ore. Enormous trucks haul the broken rocks to locations where the ores can be removed. Surface mining includes open-pit mining, quarrying, and strip mining.

As the name suggests, open-pit mining creates a big pit from which the ore is mined. **Figure** 13.22 shows an open-pit diamond mine in Russia. The size of the pit grows as long as the miners can make a profit. Strip mines are similar to open-pit mines, but the ore is removed in large strips. A quarry is a type of open-pit mine that produces rocks and minerals that are used to make buildings and roads.

Placer Mining

Placer minerals collect in stream gravels. They can be found in modern rivers or ancient riverbeds. California was nicknamed the Golden State. This can be traced back to the discovery of placer gold in 1848. The amount of placer gold brought in miners from around the world. The gold formed in rocks in the Sierra Nevada Mountains. The rocks also contained other valuable minerals. The gold weathered out of the hard rock. It washed downstream and then settled in gravel deposits along the river. Currently, California has active gold and silver mines. California also has mines for non-metal minerals. For example, sand and gravel are mined for construction.

FIGURE 13.22
This diamond mine is more than 500 m deep.

Underground Mining

If an ore is deep below Earth's surface it may be too expensive to remove all the rock above it. These deposits are taken by underground mining. Underground mines can be very deep. The deepest gold mine in South Africa is more than 3,700 m deep (that is more than 2 miles)! There are various methods of underground mining. Underground mining is more expensive than surface mining. Tunnels must be blasted into the rock so that miners and equipment can get to the ore. Underground mining is dangerous work. Fresh air and lights must be brought in to the tunnels for the miners. The miners breathe in lots of particles and dust while they are underground. The ore is drilled, blasted, or cut away from the surrounding rock and taken out of the tunnels. Sometimes there are explosions as ore is being drilled or blasted. This can lead to a mine collapse. Miners may be hurt or killed in a mining accident.

Making Metals from Minerals

Most minerals are a combination of metal and other elements. The rocks that are taken from a mine are full of valuable minerals plus rock that isn't valuable. This is called waste rock. The valuable minerals must be separated from the waste rock. One way to do this is with a chemical reaction. Chemicals are added to the ores at very high temperatures.

For example, getting aluminum from waste rock uses a lot of energy. This is because temperatures greater than 900^oC are needed to separate out the aluminum. It also takes a huge amount of electricity. If you recycle just 40 aluminum cans, you will save the energy in one gallon of gasoline. We use over 80 billion cans each year. If all of these cans were recycled, we would save the energy in 2 billion gallons of gasoline!

Uses of Ore Minerals

We rely on metals, such as aluminum, copper, iron, and gold. Look around the room. How many objects have metal parts? Metals are used in the tiny parts inside your computer, in the wires of anything that uses electricity, and to make the structure of a large building, such as the one shown in the **Figure** 13.23.

FIGURE 13.23
The dome of the capital building in Hartford, Connecticut is coated with gold leaf.

Gemstones and Their Uses

Some minerals are valuable simply because they are beautiful. Jade has been used for thousands of years in China. Native Americans have been decorating items with turquoise since ancient times. Minerals like jade, turquoise, diamonds, and emeralds are gemstones. A **gemstone** is a material that is cut and polished to use in jewelry. Many gemstones, such as those shown in **Figure** 13.24, are minerals.

FIGURE 13.24
Gemstones come in many colors.

Gemstones are beautiful, rare, and do not break or scratch easily. Generally, rarer gems are more valuable. If a gem is popular, unusually large or very well cut, it will be more valuable.

Most gemstones are not used exactly as they are found in nature. Usually, gems are cut and polished. **Figure** 13.25 shows an uncut piece of ruby and a ruby that has been cut and polished. The way a mineral splits along a surface allows it to be cut to produce smooth surfaces. Notice that the cut and polished ruby sparkles more. Gems sparkle because light bounces back when it hits them. These gems are cut so that the most amount of light possible bounces back. Other gemstones, such as turquoise, are opaque, which means light does not pass through them. These gems are not cut in the same way.

FIGURE 13.25

Ruby is cut and polished to make the gemstone sparkle. Left: Ruby Crystal. Right: Cut Ruby.

Gemstones also have other uses. Most diamonds are actually not used as gemstones. Diamonds are used to cut and polish other materials, such as glass and metals, because they are so hard. The mineral corundum, which makes the gems ruby and sapphire, is used in products like sandpaper. Synthetic rubies and sapphires are also used in lasers.

Other Useful Minerals

Metals and gemstones are often shiny, so they catch your eye. Many minerals that we use everyday are not so noticeable. For example, the buildings on your block could not have been built without minerals. The walls in your home might use the mineral gypsum for the sheetrock. The glass in your windows is made from sand, which is mostly the mineral quartz. Talc was once commonly used to make baby powder. The mineral halite is mined for rock salt. Diamond is commonly used in drill bits and saw blades to improve their cutting ability. Copper is used in electrical wiring, and the ore bauxite is the source for the aluminum in your soda can.

Mining and the Environment

Mining provides people with many resources they need, but mining can be hazardous to people and the environment. Miners should restore the mined region to its natural state. It is also important to use mineral resources wisely. Most ores are non-renewable resources.

Land Reclamation

After the mining is finished, the land is greatly disturbed. The area around the mine needs to be restored to its natural state. This process of restoring the area is called “reclamation.“ Native plants are planted. Pit mines may be refilled or reshaped so that they can become natural areas again. The mining company may be allowed to fill the pit with water to create a lake. The pits may be turned into landfills. Underground mines may be sealed off or left open as homes for bats.

Mine Pollution

Mining can cause pollution. Chemicals released from mining can contaminate nearby water sources. **Figure** 13.26 shows water that is contaminated from a nearby mine. The United States government has mining standards to protect water quality.

FIGURE 13.26
Scientists test water that has been contaminated by a mine.

Lesson Summary

- Geologists look for mineral deposits that will be profitable to mine.
- Ores that are close to the surface are mined by surface mining methods. Ores that are deep in Earth are mined using underground methods.
- Metals ores must be melted to make metals.
- Many gems are cut and polished to increase their beauty.
- Minerals are used in a variety of ways.

Lesson Review Questions

Recall

1. What are placers? How do placer deposits form?

2. What makes an ore deposit valuable?

Apply Concepts

3. Why would a mining company choose to do a surface mine? Why would it choose to do an underground mine?

4. Once the ore rocks are taken to a refinery, what happens to get the ore out?

Thinking Critically

5. What are some disadvantages of underground mining?
6. What is the bottom line when it comes to deciding how what and how to mine?
7. How is land reclaimed after mining? Is it ever fully recovered?
8. How might the history of the Golden State been different if placers had not been found in its rivers?

Points to Consider

- Are all mineral deposits ores?
- An open-pit diamond mine may one day be turned into an underground mine. Why would this happen?
- Diamonds are not necessarily the rarest gem. Why do people value diamonds more than most other gems?

13.5 References

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CHAPTER 14 MS Rocks

Chapter Outline

Have you ever heard the phrase "rock solid?" Something is rock solid if it does not and cannot change. It will not fail or go wrong. A rock-solid plan is a sure bet. A rock-solid idea is sure to be doable. Devil's Tower in Wyoming looks rock solid. It looks like it would not change or move. Even in a million years it would look just like it does now.

In this chapter you will find out that rocks do change. Rocks can change from one type to another. Rocks can alter to have different characteristics but still be the same type. Most changes in rocks take place over long periods of time. More rarely the changes take only a short time. This rock formation's days are numbered… and a diamond is not forever.

User:Example/Wikimedia Commons. commons.wikimedia.org/wiki/File:Devils_Tower_CROP.jpg. Public Domain.

14.1 Types of Rocks

Lesson Objectives

- Define rock and describe what rocks are made of.
- Know the three main groups of rocks.
- Explain how each of these three rock types are formed.
- Describe the rock cycle.

Vocabulary

- deposited
- sediments

Introduction

There are three major rock types. Rock of any of these three rock types can become rock of one of the other rock types. Rock can also change to a different rock of the same type. Rocks give good clues as to what was happening in a region during the time that rock formed.

The Rock Cycle

All rocks on Earth change, but these changes usually happen very slowly. Some changes happen below Earth's surface. Some changes happen above ground. These changes are all part of the rock cycle. The rock cycle describes each of the main types of rocks, how they form and how they change. **Figure** 14.1 shows how the three main rock types are related to each other. The arrows within the circle show how one type of rock may change to rock of another type. For example, igneous rock may break down into small pieces of sediment and become sedimentary rock. Igneous rock may be buried within the Earth and become metamorphic rock. Igneous rock may also change back to molten material and re-cool into a new igneous rock.

Rocks are made of minerals. The minerals may be so tiny that you can only see them with a microscope. The minerals may be really large. A rock may be made of only one type of mineral. More often rocks are made of a mixture of different minerals. Rocks are named for the combinations of minerals they are made of and the ways those minerals came together. Remember that different minerals form under different environmental conditions. So the minerals in a rock contain clues about the conditions in which the rock formed (**Figure** 14.2).

FIGURE 14.1
The rock cycle.

FIGURE 14.2
Rocks contain many clues about the conditions in which they formed. The minerals contained within the rocks also contain geological information.

Three Main Categories of Rocks

Geologists group rocks based on how they were formed. The three main kinds of rocks are:

1. Igneous rocks form when magma cools below Earth's surface or lava cools at the surface (**Figure** 14.3).

2. Sedimentary rocks form when sediments are compacted and cemented together (**Figure** 14.4). These sediments may be gravel, sand, silt or clay. Sedimentary rocks often have pieces of other rocks in them. Some sedimentary rocks form the solid minerals left behind after a liquid evaporates.

3. Metamorphic rocks form when an existing rock is changed by heat or pressure. The minerals in the rock change but do not melt (**Figure** 14.5). The rock experiences these changes within the Earth.

FIGURE 14.3
Lava is molten rock. This lava will harden into an igneous rock.

FIGURE 14.4
This sandstone is an example of a sedimentary rock. It formed when many small pieces of sand were cemented together to form a rock.

Rocks can be changed from one type to another, and the rock cycle describes how this happens.

Processes of the Rock Cycle

Any type of rock can change and become a new type of rock. Magma can cool and crystallize. Existing rocks can be weathered and eroded to form sediments. Rock can change by heat or pressure deep in Earth's crust. There are three main processes that can change rock:

- Cooling and forming crystals. Deep within the Earth, temperatures can get hot enough to melt rock. This molten material is called magma. As it cools, crystals grow, forming an igneous rock. The crystals will grow larger if the magma cools slowly, as it does if it remains deep within the Earth. If the magma cools quickly, the crystals will be very small.
- Weathering and erosion. Water, wind, ice, and even plants and animals all act to wear down rocks. Over time

FIGURE 14.5
This mica schist is a metamorphic rock. It was changed from a sedimentary rock like shale.

they can break larger rocks into smaller pieces called sediments. Moving water, wind, and glaciers then carry these pieces from one place to another. The sediments are eventually dropped, or **deposited**, somewhere. The sediments may then be compacted and cemented together. This forms a sedimentary rock. This whole process can take hundreds or thousands of years.

- Metamorphism. This long word means "to change form." A rock undergoes metamorphism if it is exposed to extreme heat and pressure within the crust. With metamorphism, the rock does not melt all the way. The rock changes due to heat and pressure. A metamorphic rock may have a new mineral composition and/or texture.

An interactive rock cycle diagram can be found here: http://www.classzone.com/books/earth_science/terc/content/investigations/es0602/es0602page02.cfm?chapter_no=investigation

The rock cycle really has no beginning or end. It just continues. The processes involved in the rock cycle take place over hundreds, thousands, or even millions of years. Even though for us rocks are solid and unchanging, they slowly change all the time.

Lesson Summary

- There are three main types of rocks: igneous, sedimentary, and metamorphic.
- Melting and later cooling, erosion and sedimentation, and metamorphism transform one type of rock into another type of rock or change sediments into rock.
- The rock cycle describes the transformations of one type of rock to another.

Lesson Review Questions

Recall

1. What is the difference between magma and lava?

2. What are igneous rocks? How do igneous rocks form?
3. What are metamorphic rocks? How do metamorphic rocks form?
4. What are sedimentary rocks? How do sedimentary rocks form?

Apply Concepts

5. How do minerals combine to form an igneous rock?
6. How do minerals combine to form a metamorphic rock?
7. How do minerals combine to form a sedimentary rock?

Think Critically

8. What clues do the minerals in an igneous rock give about how the rock formed? A metamorphic rock? A sedimentary rock?
9. Describe how an igneous rock can change to a metamorphic rock.
10. If Earth's interior was cool, how would this change the types of rocks formed on Earth?

Points to Consider

- What processes on Earth are involved in forming rocks?
- What rocks are important to modern humans and for what purposes?

14.2 Igneous Rocks

Lesson Objectives

- Describe how igneous rocks are formed.
- Describe the properties of some common types of igneous rocks.
- Relate some common uses of igneous rocks.

Vocabulary

- extrusive
- intrusive

Introduction

Most of the Earth is made of igneous rock. The entire mantle is igneous rock, as are some areas of the crust. One of the most common igneous rocks is granite (**Figure** 14.6). Many mountain ranges are made of granite. People use granite for countertops, buildings, monuments and statues. Pumice is also an igneous rock. Perhaps you have used a pumice stone to smooth your skin. Pumice stones are put into giant washing machines with new jeans and tumbled around. The result is stone-washed jeans!

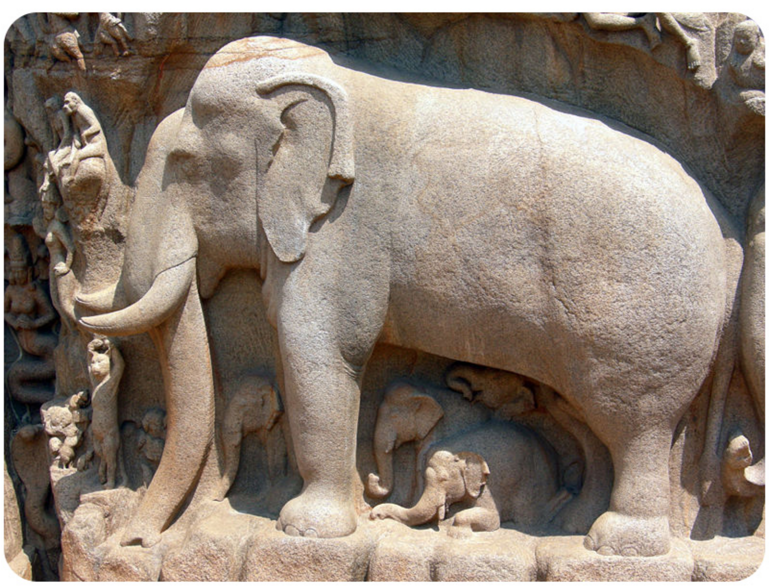


FIGURE 14.6
This life-size elephant is carved from granite.

Forming Crystals

Igneous rocks form when magma cools and forms crystals. These rocks can form at Earth's surface or deep underground. **Figure** 14.7 shows a landscape in California's Sierra Nevada that consists entirely of granite.

FIGURE 14.7
The Sierra Nevada of California are composed mainly of granite. These rocks are beautifully exposed in the Yosemite Valley.

Intrusive igneous rocks cool and form into crystals beneath the surface. Deep in the Earth, magma cools slowly. Slow cooling gives large crystals a chance to form. Intrusive igneous rocks have relatively large crystals that are easy to see. Granite is the most common intrusive igneous rock. **Figure** 14.8 shows four types of intrusive rocks.

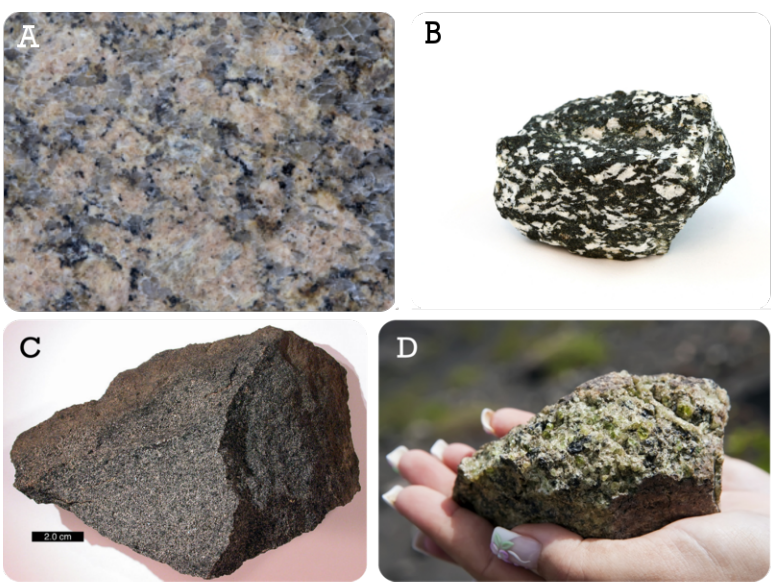


FIGURE 14.8
(A) This granite has more plagioclase feldspar than many granites. (B) Diorite has more dark-colored minerals than granite. (C) Gabbro. (D) Peridotite is an intrusive igneous rock with olivine and other mafic minerals.

Extrusive igneous rocks form above the surface. The lava cools quickly as it pours out onto the surface (**Figure** 14.9). Extrusive igneous rocks cool much more rapidly than intrusive rocks. They have smaller crystals, since the rapid cooling time does not allow time for large crystals to form. Some extrusive igneous rocks cool so rapidly that crystals do not develop at all. These form a glass, such as obsidian. Others, such as pumice, contain holes where gas bubbles were trapped in the lava. The holes make pumice so light that it actually floats in water. The most common extrusive igneous rock is basalt. It is the rock that makes up the ocean floor. **Figure** 14.10 shows four types of extrusive igneous rocks.

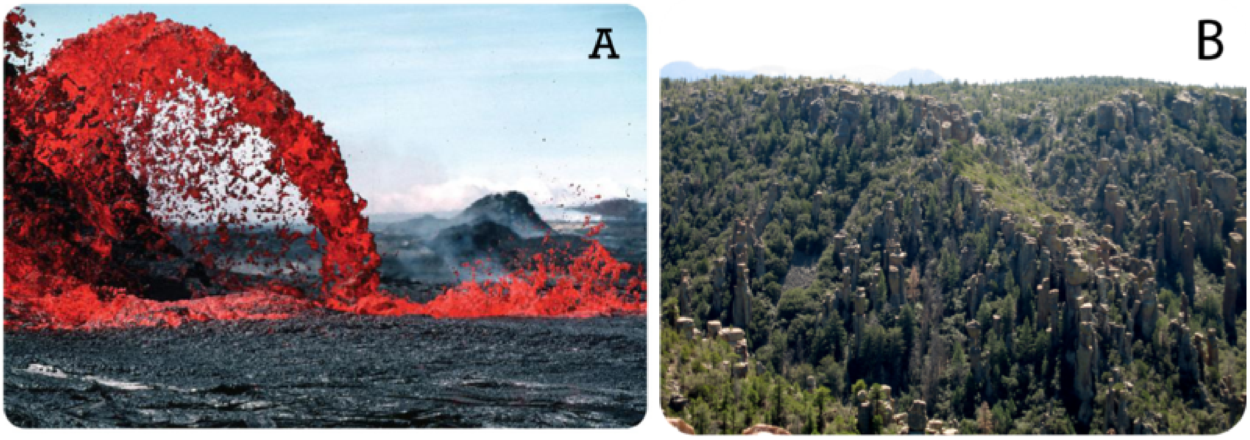


FIGURE 14.9

(A) Lava cools to form extrusive igneous rock. The rocks here are basalts. (B) The strange rock formations of Chiricahua National Monument in Arizona are formed of the extrusive igneous rock rhyolite.

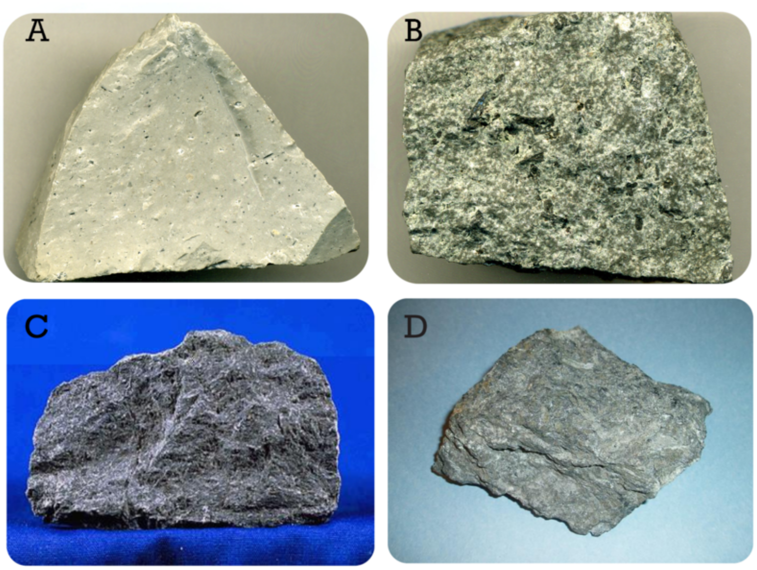


FIGURE 14.10

(A) This rhyolite is light colored. Few minerals are visible to the naked eye. (B) Andesite is darker than rhyolite. (C) Since basalt crystals are too small to see, the rock looks dark all over. (D) Komatiite is a very rare ultramafic rock. This rock is derived from the mantle.

Composition

Igneous rocks are grouped by the size of their crystals and the minerals they contain. The minerals in igneous rocks are grouped into families. Some contain mostly lighter colored minerals, some have a combination of light and dark minerals, and some have mostly darker minerals. The combination of minerals is determined by the composition of the magma. Magmas that produce lighter colored minerals are higher in silica. These create rocks such as granite and rhyolite. Darker colored minerals are found in rocks such as gabbro and basalt.

There are actually more than 700 different types of igneous rocks. Diorite is extremely hard and is commonly used for art. It was used extensively by ancient civilizations for vases and other decorative art work (**Figure** 14.11).

FIGURE 14.11
This sarcophagus is housed at the Vatican Museum. The rock is the igneous extrusive rock porphyry. Porphyry has large crystals because the magma began to cool slowly, then erupted.

Lesson Summary

- Igneous rocks form either when they cool very slowly deep within the Earth or when magma cools rapidly at the Earth's surface.
- Composition of the magma will determine the minerals that will crystallize forming different types of igneous rocks.

Lesson Review Questions

Recall

1. What is the difference between an intrusive and an extrusive igneous rock?

2. List three common uses of igneous rocks.

Apply Concepts

3. Why do extrusive igneous rocks usually have smaller crystals than intrusive igneous rocks?

4. How are igneous rocks classified?

Think Critically

5. Occasionally, igneous rocks will contain both large crystals and tiny mineral crystals. Propose a way that both these sizes of crystals might have formed in the rock.

6. Why is the ocean floor more likely to have extrusive rocks than intrusive rocks?

Points to Consider

- Do you think igneous rocks could form where you live?
- Would all igneous rocks with the same composition have the same name? Explain why they might not.
- Could an igneous rock cool at two different rates? What would the crystals in such a rock look like?

14.3 Sedimentary Rocks

Lesson Objectives

- Describe how sedimentary rocks are formed.
- Describe the properties of some common sedimentary rocks.
- Relate some common uses of sedimentary rocks.

Vocabulary

- cemented
- compacted
- fossils

Introduction

FIGURE 14.12
Layers of sand turned to rock are seen in the Navajo sandstone. The geologic feature is a slot canyon called Antelope Canyon.

Did you know that the White House, the official home and workplace of the President of the United States of America, is made out of the same material as the rock faces in **Figure** 14.12? This material is a sedimentary rock called sandstone. Sandstone is very porous. Water can easily move through it. So the sandstone of the White House could have been water damaged. But during construction workers covered the sandstone in a mixture of salt, rice, and glue. This mixture protects the sandstone and is what gives the White House its distinct white color.

Sediments

Most sedimentary rocks form from sediments. Sediments are small pieces of other rocks, like pebbles, sand, silt, and clay. Sedimentary rocks may include fossils. **Fossils** are materials left behind by once-living organisms. Fossils can be pieces of the organism, like bones. They can also be traces of the organism, like footprints.

Most often, sediments settle out of water (**Figure** 14.13). For example, rivers carry lots of sediment. Where the water slows, it dumps these sediments along its banks, into lakes and the ocean. When sediments settle out of water, they form horizontal layers. A layer of sediment is deposited. Then the next layer is deposited on top of that layer. So each layer in a sedimentary rock is younger than the layer under it. It is older than the layer over it.

FIGURE 14.13
Cobbles, pebbles, and sands are the sediments that are seen on this beach.

Sediments are deposited in many different types of environments. Beaches and deserts collect large deposits of sand. Sediments also continuously wind up at the bottom of the ocean and in lakes, ponds, rivers, marshes, and swamps. Avalanches produce large piles of sediment. The environment where the sediments are deposited determines the type of sedimentary rock that can form.

Sedimentary Rock Formation

Sedimentary rocks form in two ways. Particles may be cemented together. Chemicals may precipitate.

Clastic Rocks

Over time, deposited sediments may harden into rock. First, the sediments are **compacted**. That is, they are squeezed together by the weight of sediments on top of them. Next, the sediments are **cemented** together. Minerals fill in the spaces between the loose sediment particles. These cementing minerals come from the water that moves through the sediments. These types of sedimentary rocks are called "clastic rocks." Clastic rocks are rock fragments that are compacted and cemented together.

Clastic sedimentary rocks are grouped by the size of the sediment they contain. Conglomerate and breccia are made of individual stones that have been cemented together. In conglomerate, the stones are rounded. In breccia, the stones are angular. Sandstone is made of sand-sized particles. Siltstone is made of smaller particles. Silt is smaller than sand but larger than clay. Shale has the smallest grain size. Shale is made mostly of clay-sized particles and hardened mud.

Chemical Sedimentary Rocks

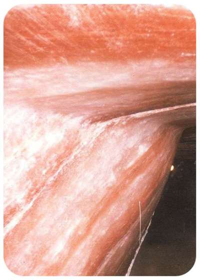
Chemical sedimentary rocks form when crystals precipitate out from a liquid. The mineral halite, also called rock salt, forms this way. You can make halite! Leave a shallow dish of salt water out in the Sun. As the water evaporates, salt crystals form in the dish. There are other chemical sedimentary rocks, like gypsum.

Table 14.1 shows some common types of sedimentary rocks and the types of sediments that make them up.

TABLE 14.1: Common Sedimentary Rocks

Picture	Rock Name	Type of Sedimentary Rock
	Conglomerate	Clastic
	Breccia	Clastic
	Sandstone	Clastic
	Siltstone	Clastic
	Limestone	Bioclastic
	Coal	Organic

TABLE 14.1: (continued)

Picture	Rock Name	Type of Sedimentary Rock
	Rock Salt	Chemical precipitate

Lesson Summary

- Most sedimentary rocks form from sediments. These sediments are deposited, forming layers.
- The youngest layers are found on top, with older layers below.
- Sediments must be compacted and cemented to make sedimentary rock.
- Chemical sedimentary rocks are made of precipitated minerals.

Lesson Review Questions

Recall

1. What are three things that sedimentary rocks may be made of?

2. Describe the two processes necessary for sediments to harden into rock.

Apply Concepts

3. If you see a sedimentary rock outcrop and red layers of sand are on top of pale yellow layers of sand, what do you know for sure about the ages of the two layers?

Think Critically

4. What type of sedimentary rock is coal?

5. Why do you think sandstone allows water to move through it easily?

Points to Consider

- If you were interested in learning about Earth's history, which type of rocks would give you the most information?

- Could a younger layer of sedimentary rock ever be found under an older layer? How do you think this could happen?
- Could a sedimentary rock form only by compaction from intense pressure?

14.4 Metamorphic Rocks

Lesson Objectives

- Describe how metamorphic rocks are formed.
- Describe the properties of some common metamorphic rocks.
- Relate some common uses of metamorphic rocks.

Vocabulary

- contact metamorphism
- foliation
- regional metamorphism
- stable

Introduction

Metamorphism changes rocks by heat and pressure. These agents create an entirely new type of rock. Metamorphism changes rocks physically and/or chemically.

Metamorphism

Metamorphic rocks start off as some kind of rock. The starting rock can be igneous, sedimentary or even another metamorphic rock. Heat and/or pressure then change the rock's physical or chemical makeup.

During metamorphism a rock may change chemically. Ions move and new minerals form. The new minerals are more stable in the new environment. Extreme pressure may lead to physical changes like **foliation**. Foliation forms as the rocks are squeezed. If pressure is exerted from one direction, the rock forms layers. This is foliation. If pressure is exerted from all directions, the rock usually does not show foliation.

There are two main types of metamorphism:

1. **Contact metamorphism** results when magma contacts a rock, changing it by extreme heat (**Figure** 14.14).

2. **Regional metamorphism** occurs over a wide area. Great masses of rock are exposed to pressure from rock and sediment layers on top of it. The rock may also be compressed by other geological processes.

Metamorphism does not cause a rock to melt completely. It only causes the minerals to change by heat or pressure.

Hornfels is a rock with alternating bands of dark and light crystals. Hornfels is a good example of how minerals rearrange themselves during metamorphism (**Figure** 14.14). The minerals in hornfels separate by density. The

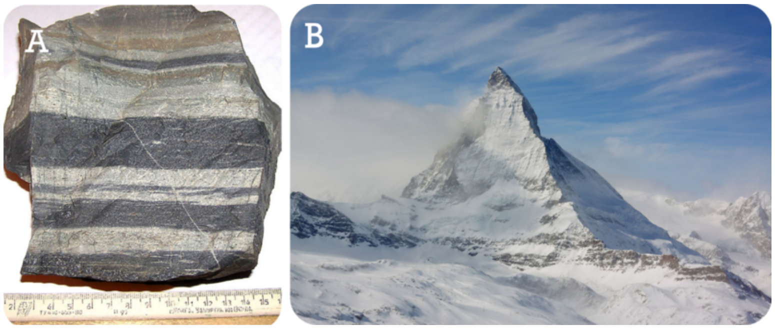


FIGURE 14.14
(A) Hornfels is a rock that is created by contact metamorphism. (B) Hornfels is so hard that it can create peaks like the Matterhorn.

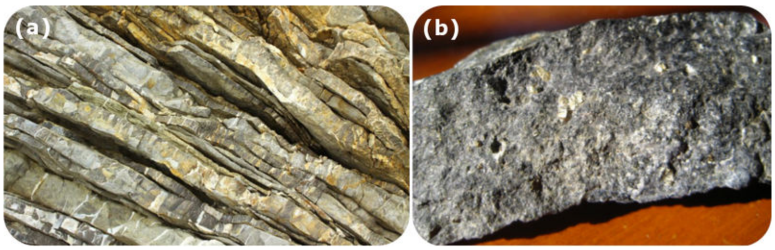


FIGURE 14.15
(A) Regional metamorphic rocks often display layering called foliation. (B) Regional metamorphism with high pressures and low temperatures can result in blue schist.

result is that the rock becomes banded. Gneiss forms by regional metamorphism from extremely high temperature and pressure.

Uses of Metamorphic Rocks

Quartzite and marble are the most commonly used metamorphic rocks. They are frequently chosen for building materials and artwork. Marble is used for statues and decorative items like vases (**Figure** 14.16). Quartzite is very hard and is often crushed and used in building railroad tracks. Schist and slate are sometimes used as building and landscape materials.

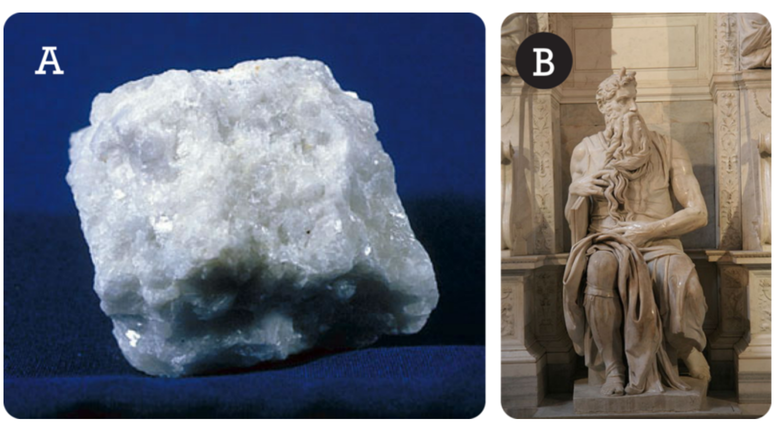


FIGURE 14.16
(A) Marble is a beautiful rock that is commonly used for buildings. (B) Many of the great statues of the Renaissance were carved from marble. Michelangelo created this Moses between 1513 and 1515.

Lesson Summary

- Metamorphic rocks form when heat and pressure transform an existing rock into a new rock.
- Contact metamorphism occurs when hot magma transforms rock that it contacts.
- Regional metamorphism transforms large areas of existing rocks under the tremendous heat and pressure created by tectonic forces.

Lesson Review Questions

Recall

1. Why do the minerals in a rock sometimes rearrange themselves when exposed to heat or pressure?
2. List and describe the two main types of metamorphism.

Apply Concepts

3. How does layering form in metamorphic rocks?
4. What clues in metamorphic rocks tell you how they were formed?

Think Critically

5. Suppose a phyllite sample was exposed to even more heat and pressure. What metamorphic rock would form?

Points to Consider

- What type of plate boundary would produce the most intense metamorphism of rock?
- Do you think new minerals could form when an existing rock is metamorphosed?

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CHAPTER 15 MS Earth's Energy

Chapter Outline

In these light blue pipes flows energy. Energy, or the ability to do work, is necessary for everything from plants performing photosynthesis to you chewing your lunch. It can come from many sources, including the Sun, wind, flowing water, and fossil fuels, and in many forms. While energy cannot be created or destroyed, however, there is a fast-approaching limit on how quickly humans can keep using up energy sources like oil and coal. In this chapter, you will learn about how energy comes to be stored in those forms and about energy alternatives that are sustainable for the future.

15.1 Earth's Energy

Lesson Objectives

- Compare ways in which energy is changed from one form to another.
- Discuss what happens when we burn a fuel.
- Describe the difference between renewable and non-renewable resources.
- Classify different energy resources as renewable or non-renewable.

Vocabulary

- chemical energy
- energy
- fuel
- kinetic energy
- Law of Conservation of Energy
- potential energy

Introduction

Did you know that everything you do takes energy? Even while you are sitting still, your body is using energy to breathe and to keep your blood circulating. Energy controls all of the different processes in your body. But it's not just the human body that needs energy. Everything that moves or changes in any way, from plants to animals to machines, needs energy. Have you ever wondered where all of this energy comes from?

The Sources of Earth's Energy

Almost all energy comes from the Sun. Plants make food energy from sunlight. Fossil fuels are made of the remains of plants and animals that stored the Sun's energy millions of years ago.

The Sun heats some areas more than others, which causes wind. The Sun's energy also drives the water cycle, which moves water over the surface of the Earth. Both wind and water power can be used as renewable resources.

Earth's internal heat does not depend on the Sun for energy. This heat comes from remnant heat when the planet formed. It also comes from the decay of radioactive elements. Radioactivity is an important source of energy.

The Need for Energy

Energy provides the ability to move or change matter from one state to another (for example, from solid to liquid). Every living thing needs energy to live and grow. Your body gets its energy from food, but that is only a small part of the energy you use every day. Cooking your food takes energy, and so does keeping it cold in the refrigerator or the freezer. The same is true for heating or cooling your home. Whether you are turning on a light in the kitchen or riding in a car to school, you are using energy. Billions of people all around the world use energy, so there is a huge demand for resources to provide all of this energy. Why do we need so much energy? The main reason is that almost everything that happens on Earth involves energy.

Conservation of Energy

Energy changes form when something happens. But the total amount of energy always stays the same. The **Law of Conservation of Energy** says that energy cannot be created or destroyed. Scientists observed that energy could change from one form to another. They also observed that the overall amount of energy did not change.

Energy Changes

Here is an example of how energy changes form: kicking a soccer ball. Your body gets energy from food. Where does the food get its energy? If you're eating a plant, then the energy comes directly from the Sun. If you're eating an animal, then the energy comes from a plant that got its energy from the Sun.

Your body breaks down the food. It converts the food to chemical energy and stores it. When you are about to kick the ball, the energy must be changed again. **Potential energy** has the potential to do work. When your leg is poised to kick the ball but is not yet moving, your leg has potential energy. A ball at the top of a hill has the potential energy of location.

Kinetic energy is the energy of anything in motion. Your muscles move your leg, your foot kicks the ball, and the ball gains kinetic energy (**Figure** 15.1). The kinetic energy was converted from potential energy that was in your leg before the kick. The action of kicking the ball is energy changing forms. The same is true for anything that involves change.

Energy, Fuel, and Heat

Energy is the ability to do work. Fuel stores energy and can be released to do work. Heat is given off when fuel is burned.

Energy

What makes energy available whenever you need it? If you unplug a lamp, the light goes off. The lamp does not have a supply of energy to keep itself lit. The lamp uses electricity that comes through the outlet as its source of energy. The electricity comes from a power plant. The power plant has a source of energy to produce this electricity.

Fuel

The energy to make the electricity comes from fuel. Fuel stores the energy and releases it when it is needed. **Fuel** is any material that can release energy in a chemical change. The food you eat acts as a fuel for your body. Gasoline

FIGURE 15.1
Kicking a soccer ball takes energy from your food and gives it to the soccer ball.

and diesel fuel are fuels that provide the energy for most cars, trucks, and buses. But there are many different kinds of fuel.

For fuel to be useful, its energy must be released in a way that can be controlled.

Heat

When fuel is burned, most of the energy is released as heat. Some of this heat can be used to do work. Heat cooks food or warms your house. Sometimes the heat is just waste heat. It still heats the environment, though.

Heat from a fire can boil a pot of water. If you put an egg in the pot, you can eat a hard boiled egg in 15 minutes (cool it down first!). The energy to cook the egg was stored in the wood. The wood got that energy from the Sun when it was part of a tree. The Sun generated the energy by nuclear fusion. You started the fire with a match. The head of the match stores energy as chemical energy. That energy lights the wood on fire. The fire burns as long as there is energy in the wood. Once the wood has burned up, there is no energy left in it. The fire goes out.

Types of Energy Resources

Energy resources can be put into two categories —renewable or non-renewable. Nonrenewable resources are used faster than they can be replaced. Renewable resources can be replaced as quickly as they are used. Renewable resources may also be so abundant that running out is impossible.

The difference between non-renewable and renewable resources is like the difference between ordinary batteries and rechargeable ones. If a flashlight when ordinary batteries goes dead, the batteries need to be replaced. But if the flashlight has rechargeable batteries, the batteries can be placed in a charger. The charger transfers energy from an outlet into the batteries. Once recharged, the batteries can be put back into the flashlight. Rechargeable batteries can be used again and again (**Figure** 15.2). In this way, the energy in the rechargeable batteries is renewable.

FIGURE 15.2
Rechargeable batteries are renewable because they can be refilled with energy. Is the energy they are refilled with always renewable?

Types of Nonrenewable Resources

Fossil fuels include coal, oil, and natural gas. Fossil fuels are the greatest energy source for modern society. Millions of years ago, plants used energy from the Sun to form carbon compounds. These compounds were later transformed into coal, oil, or natural gas. Fossil fuels take millions of years to form. For this reason, they are non-renewable. We will use most fossil fuels up in a matter of decades. Burning fossil fuels releases large amounts of pollution. The most important of these may be the greenhouse gas carbon dioxide.

Types of Renewable Resources

Renewable energy resources include solar, water, wind, biomass, and geothermal power. These resources are usually replaced at the same rate that we use them. Scientists know that the Sun will continue to shine for billions of years. So we can use the solar energy without it ever running out. Water flows from high places to lower ones. Wind blows from areas of high pressure to areas of low pressure. We can use the flow of wind and water to generate power. We can count on wind and water to continue to flow! Burning wood is an example of biomass energy. Changing grains into biofuels is biomass energy. Biomass is renewable because we can plant new trees or crops to replace the ones we use. Geothermal energy uses water that was heated by hot rocks. There are always more hot rocks available to heat more water.

Even renewable resources can be used unsustainably. We can cut down too many trees without replanting. We might need grains for food rather than biofuels. Some renewable resources are too expensive to be widely used. As the technology improves and more people use renewable energy, the prices will come down. The cost of renewable resources will go down relative to fossil fuels as we use fossil fuels up. In the long run renewable resources will need to make up a large amount of what we use.

Important Things to Consider About Energy Resources

Before we put effort into increasing the use of an energy source, we should consider two things. Is there a practical way to turn the resource into useful form of energy? For example, it is not practical if we don't get much more energy from burning a fuel than we put into making it.

What happens when we turn the resource into energy? What happens when we use that resource? Mining the resource may cause a lot of health problems or environmental damage. Using the resource may create a large amount of pollution. In this case, that fuel may also not be the best choice for an energy resource.

KQED: Climate Watch: Unlocking the Grid

Today we rely on electricity more than ever, but the resources that currently supply our power are finite. The race is on to harness more renewable resources, but getting all that clean energy from production sites to homes and businesses is proving to be a major challenge. Learn more by watching the resource below: http://www.kqed.org/quest/television/climate-watch-unlocking-the-grid

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Click image to the left or use the URL below.

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Lesson Summary

- According to the Law of Conservation of Energy, energy is neither created nor destroyed.
- Renewable resources can be replaced at the rate they are being used.
- Nonrenewable resources are available in limited amounts or are being used faster than they can be replaced.

Lesson Review Questions

Recall

1. Define energy, fuel and heat. How are they interrelated?

Apply Concepts

2. Think of getting on a roller coaster. What time of energy is used as use walk onto the coaster? What type of energy does the coaster use as it climbs up the hill? As it sits at the top? As it flies down?

Think Critically

3. Where does most energy come from? Where else does energy come from?

4. What substances burn? If a substance doesn't burn, why not? Could it burn? For example, how could you get orange juice to burn?

5. Is it worth developing non-renewable resources? Should we just develop renewable resources?

Points to Consider

- How long do fossil fuels take to form?
- Are all fossil fuels non-renewable resources?
- Do all fossil fuels affect the environment equally?

15.2 Nonrenewable Energy Resources

Lesson Objectives

- Describe how fossil fuels are formed.
- Describe different fossil fuels, and understand why they are non-renewable resources.
- Explain how fossil fuels are turned into useful forms of energy.
- Understand that when we burn a fossil fuel, most of its energy is released as heat.
- Describe how the use of fossil fuels affects the environment.

Vocabulary

- hydrocarbons

Introduction

Have you ever seen dinosaur fossils at a museum? The same processes that formed dinosaur fossils created fossil fuels. Fossil fuels are now our most important energy resources. Most of the energy we use for industry comes from them. Most energy to heat and cool homes and to get us around does, too. Fossil fuels provide high-quality energy. But the use of fossil fuels has consequences. Burning fossil fuel releases pollutants, including greenhouse gases. Also, we are using up these resources much faster than they can be replaced.

Formation of Fossil Fuels

Fossil fuels are made from plants and animals that lived hundreds of millions of years ago. The plants and animals died. Their remains settled onto the ground and at the bottom of the sea. Layer upon layer of organic material was laid down. Eventually, the layers were buried very deeply. They experienced intense heat and pressure. Over millions of years, the organic material turned into fossil fuels.

Fossil fuels are compounds of carbon and hydrogen, called **hydrocarbons**. Hydrocarbons can be solid, liquid, or gas. The solid form is coal. The liquid form is petroleum, or crude oil. The gaseous form is natural gas.

Coal

Coal is a solid hydrocarbon. Coal is useful as a fuel, especially for generating electricity.

How Coal Forms

Coal forms from dead plants that settled at the bottom of swamps millions of years ago. Water and mud in the swamp kept oxygen away from the plant material. Sand and clay settled on top of the decaying plants. The weight of this material squeezed out the water and some other substances. Over time, the organic material became a carbon-rich rock. This rock is coal.

What Coal Is

Coal is a black or brownish-black rock that burns easily (**Figure** 15.3). Most coal is sedimentary rock. The hardest type of coal, anthracite, is a metamorphic rock. That is because it is exposed to higher temperature and pressure as it forms. Coal is mostly carbon, but some other elements can be found in coal, including sulfur.

FIGURE 15.3
Coal is a solid hydrocarbon formed from decaying plant material over millions of years.

Mining Coal

Around the world, coal is the largest source of energy for electricity. The United States is rich in coal. Pennsylvania and the region to the west of the Appalachian Mountains are some of the most coal-rich areas of the United States.

Coal has to be mined to get it out of the ground. Coal mining affects the environment and human health. Coal mining can take place underground or at the surface. Each method has some advantages and disadvantages.

- Surface mining exposes minerals that were underground to air and water at the surface. These minerals contain the chemical element sulfur. Sulfur mixes with air and water to make sulfuric acid. This acid is a highly corrosive chemical. Sulfuric acid gets into nearby streams and can kill fish, plants, and animals. Surface mining is safer for the miners.
- Coal mining underground is dangerous for the coal miners. Miners are sometimes killed if there is an explosion or a mine collapse. Miners breathe in coal dust and can get terrible lung diseases after a number of years in the mines.

Using Coal

To prepare coal for use, the coal is first crushed into powder and burned in a furnace. Like other fuels, coal releases most of its energy as heat when it burns. The heat from the burning coal is used to boil water. This makes steam. The steam spins turbines, which creates electricity.

Oil

Oil is a thick, dark brown or black liquid. It is found in rock layers of the Earth's crust. Oil is currently the most commonly used source of energy in the world.

How Oil Forms

The way oil forms is similar in many ways to coal. Tiny organisms like plankton and algae die and settle to the bottom of the sea. Sediments settle over the organic material. Oxygen is kept away by the sediments. When the material is buried deep enough, it is exposed to high heat and pressure. Over millions of years, the organic material transforms into liquid oil.

Mining Oil

The United States produces only about one-quarter as much oil as it uses. The main oil producing regions in the U.S. are the Gulf of Mexico, Texas, Alaska, and California.

Geologists look for oil in folded layers of rock called anticlines. Oil moves through permeable rock and is trapped by the impermeable cap rock.

FIGURE 15.4
This oil refinery processes crude oil into usable energy sources, such as gasoline.

Types of Oil

Oil comes out of the ground as crude oil. Crude oil is a mixture of many different hydrocarbons. Oil is separated into different compounds at an oil refinery (**Figure** 15.4). This is done by heating the oil. Each hydrocarbon compound in crude oil boils at a different temperature. We get gasoline, diesel, and heating oil, plus waxes, plastics, and fertilizers from crude oil.

These fuels are rich sources of energy. Since they are mostly liquids they can be easily transported. These fuels provide about 90% of the energy used for transportation around the world.

Gasoline

Gasoline is a concentrated resource. It contains a large amount of energy for its weight. This is important because the more something weighs, the more energy is needed to move it. If gasoline could only provide a little energy, a car would have to carry a lot of it to be able to travel very far. Or the car would need to be filled up frequently. So a highly concentrated energy resource is a practical fuel to power cars and other forms of transportation.

Let's consider how gasoline powers a car. As gasoline burns, it releases most of its energy as heat. It also releases carbon dioxide gas and water vapor. The heat makes the gases expand. This forces the pistons inside the engine to move. The engine makes enough power to move the car.

Using Oil

Using gasoline to power automobiles affects the environment. The exhaust fumes from burning gasoline cause air pollution. These pollutants include smog and ground-level ozone. Air pollution is a big problem for cities where large numbers of people drive every day. Burning gasoline also produces carbon dioxide. This is a greenhouse gas and is a cause of global warming. Similar pollutants come from other forms of oil.

Natural Gas

Natural gas is mostly methane.

How Natural Gas Forms

Natural gas is often found along with coal or oil in underground deposits. This is because natural gas forms with these other fossil fuels. One difference between natural gas and oil is that natural gas forms at higher temperatures.

Natural Gas Use

The largest natural gas reserves in the United States are located in the Rocky Mountain states, Texas, and the Gulf of Mexico region. California also has natural gas, mostly in the northern Sacramento Valley and the Sacramento Delta.

Natural gas must be processed before it can be used as a fuel. Poisonous chemicals and water must be removed.

Natural gas is delivered to homes, where it is used for cooking and heating. Natural gas is also a major energy source for powering turbines to make electricity. Natural gas releases most of its energy as heat when it burns. The power plant is able to use this heat, either in the form of hot gases or steam, to spin turbines. The spinning turbines turn generators, and the generators create electricity.

Consequences of Natural Gas Use

Processing natural gas has harmful effects on the environment, just like oil. Natural gas burns cleaner than other fossil fuels. As a result, it causes less air pollution. It also produces less carbon dioxide than the other fossil fuels. Still, natural gas does emit pollutants.

Problems with Fossil Fuels

Fossil fuels present many problems. These fuels are non-renewable resources, so our supplies of them will eventually run out. Safety can be a problem, too. Since these fuels burn so easily, a natural gas leak in a building or an underground pipe can lead to a deadly explosion.

Using fossil fuels affects the environment in a variety of ways. There are impacts to the environment when we extract these resources. Burning these fuels causes air pollution. These fuels release carbon dioxide, which is a major factor in global warming (**Figure** 15.5).

FIGURE 15.5
Burning fossil fuels releases pollutants into the air.

Many of the problems with fossil fuels are worse for coal than for oil or natural gas. Burning coal releases more carbon dioxide than either oil or natural gas. Yet coal is the most common fossil fuel, so we continue to burn large amounts of it. That makes coal the biggest contributor to global warming.

Another problem with coal is that most coal contains sulfur. As it burns, the sulfur goes into the air as sulfur dioxide. Sulfur dioxide is the main cause of acid rain. Acid rain can be deadly to plants, animals, and whole ecosystems. Burning coal also puts a large number of small solid particulates into the air. These particles are dangerous to people, especially those who have asthma. People with asthma may end up in the hospital on days when particulate pollution is high.

Nuclear Energy

Nuclear energy is produced by splitting the nucleus of an atom. This releases a huge amount of energy.

How Nuclear Power Plants Work

Nuclear power plants use uranium that has been concentrated in fuel rods (**Figure** 15.6). The uranium atoms are split apart when they are hit by other extremely tiny particles. These particles must be controlled or they would cause a dangerous explosion.

Nuclear power plants use the energy they produce to heat water. The water turns into steam, which causes a turbine to spin. This in turn produces electricity.

Nuclear Power and a Resource

Many countries around the world use nuclear energy as a source of electricity. For example, France gets about 80% of its electricity from nuclear energy. In the United States, a little less than 20% of electricity comes from nuclear energy.

FIGURE 15.6
Nuclear power plants like this one provide France with almost 80% of its electricity.

Nuclear energy does not pollute. If there are no accidents, a nuclear power plant releases nothing but steam into the air. But nuclear energy does create other environmental problems. Splitting atoms creates dangerous radioactive waste. These wastes can remain dangerous for hundreds of thousands of years. Scientists and engineers are still looking for ways to keep this waste safely away from people.

KQED: Nuclear Energy Use

Nuclear power is a controversial subject in California and most other places. Nuclear power has no pollutants including carbon emissions, but power plants are not always safe and the long-term disposal of wastes is a problem that has not yet been solved. The future of nuclear power is murky. Find out more at: http://science.kqed.org/quest/audio/new-nuclear/

MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/5730

Lesson Summary

- Coal, oil and natural gas are all fossil fuels formed from the remains of once living organisms.
- Coal is our largest source of energy for producing electricity.
- Mining and using coal produce many environmental impacts, including carbon dioxide emissions and acid rain.
- Oil and natural gas are important sources of energy for many types of vehicles and uses in our homes and industry.
- Fossil fuels are non-renewable sources of energy that produce environmental damage.

- Nuclear energy is produced by splitting atoms. It also produces radioactive wastes that are very dangerous for many years.

Lesson Review Questions

Recall

1. How does coal form? How are the formation of oil and natural gas different from coal?
2. Waxes can be made from the processing of which fossil fuel?

Apply Concepts

3. What environmental problems are caused by surface coal mining?
4. What health problems are caused by underground coal mining?

Think Critically

5. Anthracite is the hardest type of coal because it is metamorphic. Anthracite causes less pollution when it burns. Why do you think that is?
6. What properties would a fuel have to have for it to be a good replacement for gasoline? Explain.

Points to Consider

- How are renewable sources of energy different from non-renewable sources of energy?
- Are all renewable energy sources equally practical?
- Are all renewable energy sources equally good for the environment?

15.3 Renewable Energy Resources

Lesson Objectives

- Describe different renewable resources, and explain why they are renewable.
- Describe how the Sun is the source of most of Earth's energy.
- Describe how energy is carried from one place to another as heat and by moving objects.
- Understand how conduction, convection, and radiation transfer energy as heat when renewable energy sources are used.
- Understand that some renewable energy sources cost less than others and some cause less pollution than others.
- Explain how renewable energy resources are turned into useful forms of energy.
- Describe how the use of different renewable energy resources affects the environment.
- Describe how a nuclear power plant produces energy.

Vocabulary

- conduction
- convection
- radiation

Introduction

What if we could have all of the energy we needed and never run out of it? What if we could use this energy without polluting the air and water? In the future, renewable sources of energy may be able to provide all of the energy we need. Some of these resources can give us "clean" energy that causes little or no pollution.

There are plenty of clean energy options available for us to use. The largest amount of energy to reach Earth's surface is from the Sun. Earth receives 174 petawatts (1.74 x 1017 W) of energy from the Sun each year. Another 23 terawatts (2.3 x 1013 W) of energy flows outward from the Earth's interior. By contrast, the total world power consumption is around 16 terawatts (1.6 x 1013W) per year. So solar or geothermal energy alone could provide all of the energy people need if it could be harnessed.

Solar Energy

Energy from the Sun

The Sun is Earth's main source of energy. The Sun gives us both light and heat. The Sun changes hydrogen into helium through nuclear fusion. This releases huge amounts of energy. The energy travels to the Earth mostly

FIGURE 15.7
Solar energy is clean and renewable. Solar panels are needed to collect the sunlight for use.

as visible light. The energy is carried through the empty space by **radiation**. We can use sunlight as an energy resource, called solar energy (**Figure** 15.7).

Solar Energy as a Resource

Solar energy has been used on a small scale for hundreds of years. Today we are using solar energy for more of our power demands. Solar power plants are being built in many locations around the world. In the United States, the southwestern deserts are well suited for solar plants.

Solar Power Plants

Sunlight is turned into electricity at a solar power plant. These power plants use a large group of mirrors to focus sunlight on one place. This place is called a receiver (**Figure** 15.8). At the receiver, a liquid such as oil or water is heated to a high temperature. The liquid transfers its heat by **conduction**. In conduction, energy moves between two objects that are in contact. The higher temperature object transfers heat to the lower temperature object. For example, when you heat a pot of water on a stove top, energy moves from the pot to its metal handle by conduction. At a solar power plant, the energy conducted by the heated liquid is used to make electricity.

Solar Energy Use

Solar energy is used to heat homes and water, and to make electricity. Scientists and engineers have many ways to get energy from the Sun (**Figure** 15.9). One is by using solar cells. Solar cells are devices that turn sunlight directly into electricity. Lots of solar cells make up an individual solar panel. You may have seen solar panels on roof tops. The Sun's heat can also be trapped in your home by using south facing windows and good insulation.

Consequences of Solar Energy Use

Solar energy has many benefits. It does not produce any pollution. There is plenty of it available, much more than we could possibly use.

FIGURE 15.8
A solar power tower is used to concentrate the solar energy collected by many solar panels.

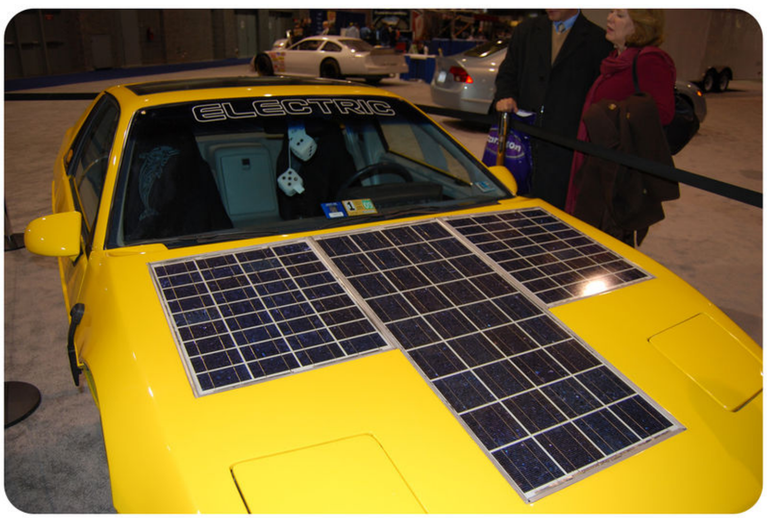

FIGURE 15.9
Solar panels on top of a car could power the car. This technology is a long way from being practical.

But solar energy has problems. The Sun doesn't shine at night. A special battery is needed to store extra energy during the day for use at night. The technology for most uses of solar energy is still expensive. Until solar technology becomes more affordable, most people will prefer to get their energy from other sources.

Water Power

Moving water has energy (**Figure** 15.10). That energy is used to make electricity. Hydroelectric power harnesses the energy of water moving down a stream. Hydropower is the most widely used form of renewable energy in the world. This abundant energy source provides almost one fifth of the world's electricity. The energy of waves and tides can also be used to produce water power. At this time, wave and tidal power are rare.

FIGURE 15.10
Glen Canyon Dam harnesses the power of flowing water to generate electricity.

Hydropower Plants

To harness water power, a stream must be dammed. Narrow valleys are the best for dams. While sitting in the reservoir behind the dam, the water has potential energy. Water is allowed to flow downhill into a large turbine. While flowing downhill, the water has kinetic energy. Kinetic energy makes the turbine spin. The turbine is connected to a generator, which makes electricity.

Hydropower as a Resource

Many of the suitable streams in the United States have been developed for hydroelectric power. Many streams worldwide also have hydroelectric plants. Hydropower is a major source of California's electricity. It accounts for about 14.5 percent of the total. Most of California's nearly 400 hydroelectric power plants are located in the Sierra Nevada mountains.

Benefits and Problems of Hydropower

Water power does not burn a fuel. So it causes less pollution than many other kinds of energy. Water power is also a renewable resource. Water keeps flowing downhill. Although we use some of the energy from this movement, we are not using up the water.

Water power does have problems. A large dam stops a stream's flow, which floods the land upstream. A beautiful location may be lost. People may be displaced. The dams and turbines also change the downstream environment. Fish and other living things may not be able to survive. Dams slow the release of silt. Downstream deltas retreat and beaches may be starved of sand. Seaside cities may become exposed to storms and rising sea levels.

Tidal power stations may need to close off a narrow bay or estuary. Wave power plants must withstand coastal storms and the corrosion of seawater.

KQED: Harnessing Power from the Sea

Although not yet widely used, many believe tidal power has more potential than wind or solar power for meeting alternative energy needs. Quest radio looks at plans for harnessing power from the sea by San Francisco and along the northern California coast. Learn more at: http://science.kqed.org/quest/audio/harnessing-power-from-the-sea/

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Wind Power

FIGURE 15.11

Winds are funneled through passes in mountain ranges. Altamont Pass in California is the site of many wind turbines.

The energy from the Sun creates wind (**Figure** 15.11). Wind energy moves by **convection**. The Sun heats some locations more than others. Warm air rises, so other air rushes in to fill the hole left by the rising air. This horizontal movement of air is called wind.

Wind as a Resource

Wind power uses moving air as a source of energy. Some types of wind power have been around for a long time. People have used windmills to grind grain and pump water for hundreds of years. Sailing ships have depended on wind for millennia. Wind is now used to generate electricity. Moving air can make a turbine spin, just like moving water can. Moving air has kinetic energy. When wind hits the blades of the turbine, the kinetic energy makes the blades move. The turbine spins and creates electricity.

Wind Power Advantages and Disadvantages

Wind power has many advantages. It is clean: it does not release pollutants or carbon dioxide. It is plentiful almost everywhere. The technology to harness wind energy is being developed rapidly.

Wind power also has problems. Wind does not blow all of the time, so wind energy must be stored for later use. Alternatively, another energy source needs to be available when the wind is not blowing. Wind turbines are expensive. They can wear out quickly. Finally, windmills are not welcomed by residents of some locations. They say that they are unattractive. Yet even with these problems, wind turbines are a competitive form of renewable energy.

Many states are currently using wind power. Wind turbines are set up in mountain passes. This is common in California, where cool Pacific Ocean air is sucked across the passes and into the warmer inland valleys.

Biomass

Biomass is another renewable source of energy. Biomass includes wood, grains, and other plant materials or waste materials. People can burn wood directly for energy in the form of heat. Biomass can also be processed to make biofuel. Biofuel is a fairly new type of energy that is becoming more popular. Biomass is useful because it can be made liquid. This means that they can be used in cars and trucks. Some car engines can be powered by pure vegetable oil or even recycled vegetable oil. Sometimes the exhaust from these cars smells like French fries!

By using biofuels, we can cut down on the amount of fossil fuel that we use. Because living plants take carbon dioxide out of the air, growing plants for biofuel can mean that we will put less of this gas into the air overall. This could help us do something about the problem of global warming.

Geothermal Energy

Geothermal energy comes the Earth's internal heat. Hot springs and geysers are produced by water that is heated by magma or hot rock below the surface.

At a geothermal power plant, engineers drill wells into the hot rocks. Hot water or steam may come up through the wells. Alternatively, water may be put down into the well to be heated. It then comes up. The hot water or steam makes a turbine spin. This makes electricity.

Geothermal Energy as a Resource

Because the hot water or steam can be used directly to make a turbine spin, geothermal energy can be used without processing. Geothermal energy is clean and safe. It is renewable. There will always be hot rocks and water can be pumped down into a well. There, the water can be heated again to make more steam.

Geothermal energy is an excellent resource in some parts of the world. Iceland is gets about one fourth of its electricity from geothermal sources. In the United States, California leads all states in producing geothermal energy. Geothermal energy in California is concentrated in the northern part of the state. The largest plant is in the Geysers Geothermal Resource Area. Geothermal energy is not economical everywhere. Many parts of the world do not have underground sources of heat that are close enough to the surface for building geothermal power plants.

KQED: Geothermal Heats Up

Where Earth's internal heat gets close to the surface, geothermal power is a clean source of energy. In California, The Geysers supplies energy for many nearby homes and businesses. Learn more at: http://science.kqed.org/quest/video/geothermal-heats-up/

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Lesson Summary

- Solar energy, water power, wind power, biomass energy, and geothermal energy are renewable energy sources.
- Solar energy can be used either by passively storing and holding the Sun's heat, converting it to electricity, or concentrating it.
- There are many ways to use the energy of moving water, including hydroelectric dams.
- Wind power uses the energy of moving air to turn turbines.
- Biomass energy uses renewable materials like wood or grains to produce energy.
- Geothermal energy uses heat from magma within the Earth to heat homes or produce steam that turns turbines.

Lesson Review Questions

Recall

1. Explain how convection works.

2. Explain how conduction works.

3. Explain how radiation works.

Apply Concepts

4. Electricity is made when some type of energy turns a turbine. Explain how this happens and give two examples.

5. Explain how mirrors are used in some solar energy plants.

Think Critically

6. What are the tradeoffs for renewable and non-renewable energy sources? Which way do you think society should go? Should we find every last bit of fossil fuels to use? Should we develop renewables more rapidly?

7. Mining is one of the hidden costs of resources, both renewable and non-renewable. How does mining figure in to the cost/benefit considerations of resources?

Points to Consider

- What areas do you think would be best for using solar energy?
- What causes the high temperatures deep inside the Earth that make geothermal energy possible?
- Do you think your town or city could use wind or water power?

15.4 References

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Chapter 16 MS Ecosystems and Human Populations

Chapter Outline

A sea of people throngs the street of La Plaine Saint-Denis, France. How many people do you see? Are there too many to count? This photo shows just a tiny fraction of the billions of people who live on Earth today. Our vast numbers show that we are a very successful species. But our numbers are also a problem. We are harming the environment. We are affecting ecosystems all over the planet.

How did the human population become so large? How are we affecting Earth's ecosystems? In this chapter, you'll find out.

James Cridland. www.flickr.com/photos/jamescridland/613445810/. CC BY 2.0.

16.1 Ecosystems

Lesson Objectives

- Define ecosystem, and give examples.
- Identify abiotic factors in ecosystems.
- Describe biotic factors in ecosystems.
- Explain how energy flows through ecosystems.
- Outline how matter moves through ecosystems.

Vocabulary

- abiotic factor
- biotic factor
- carnivore
- community
- consumer
- decomposer
- ecosystem
- food chain
- food web
- grazer
- habitat
- herbivore
- niche
- nutrients
- omnivore
- population
- predator
- prey
- producer
- scavenger
- species

Introduction

You open your front door and step outside. It doesn't matter where you live, you are in your ecosystem. All around you are living and nonliving things. You're surrounded by air. You feel warm sunlight on your face. There's soil under your feet. You see plants and hear a bird singing. Your own body is covered with billions of bacteria. All of these things are part of your ecosystem.

What Is an Ecosystem?

An **ecosystem** is a group of living things and their environment. The word ecosystem is short for "ecological system." Like any system, an ecosystem is a group of parts that work together. You can see examples of ecosystems in **Figure** 16.1. The forest pictured is a big ecosystem. Besides trees, what living things do you think are part of the forest ecosystem? The dead tree stump in the same forest is a small ecosystem. It includes plants, mosses, and fungi. It also includes insects and worms.

FIGURE 16.1
An ecosystem can be big or small. A small ecosystem can be part of a larger ecosystem.

Abiotic Factors

Abiotic factors are the nonliving parts of ecosystems. They include air, sunlight, soil, water, and minerals. These are all things that are needed for life. They determine which living things — and how many of them — an ecosystem can support. **Figure** 16.2 shows an ecosystem and its abiotic factors.

Biotic Factors

Biotic factors are the living parts of ecosystems. They are the species of living things that reside together.

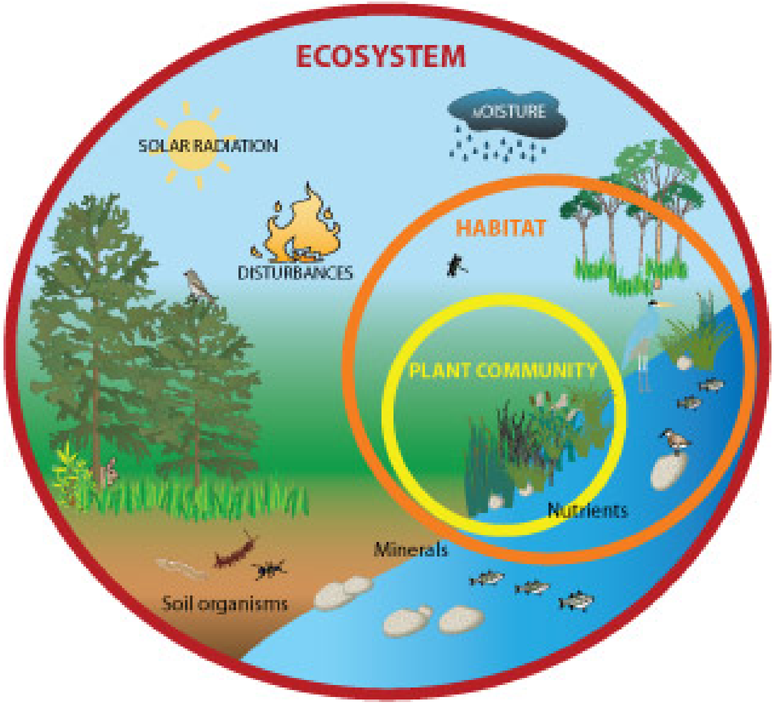

FIGURE 16.2
Which abiotic factors do you see here?

Species, Niche, and Habitat

A **species** is a unique type of organism. Members of a species can interbreed and produce offspring that can breed (they are fertile). Organisms that are not in the same species cannot do this. Examples of species include humans, lions, and redwood trees. Can you name other examples?

Each species has a particular way of making a living. This is called its **niche**. You can see the niche of a lion in **Figure** 16.3. A lion makes its living by hunting and eating other animals. Each species also has a certain place where it is best suited to live. This is called its **habitat**. The lion's habitat is a grassland. Why is a lion better off in a grassland than in a forest?

How a Lion "Makes a Living"

FIGURE 16.3
A lion hunts a water buffalo. What is the water buffalo's niche?

Living Together

All the members of a species that live in the same area form a **population**. Many different species live together in an ecosystem. All their populations make up a **community**. What populations live together in the grassland in **Figure** 16.3?

Roles in Ecosystems

All ecosystems have living things that play the same basic roles. Some organisms must be producers. Others must be consumers. Decomposers are also important.

Producers

Producers are living things that use energy to make food. Producers make food for themselves and other living things. There are two types of producers:

- By far the most common producers use the energy in sunlight to make food. This is called photosynthesis. Producers that photosynthesize include plants and algae. These organisms must live where there is plenty of sunlight. Which living things are producers in **Figure** 16.3?
- Other producers use the energy in chemicals to make food. This is called chemosynthesis. Only a very few producers are of this type, and all of them are microbes. These producers live deep under the ocean where there is no sunlight. You can see an example in **Figure** 16.4.

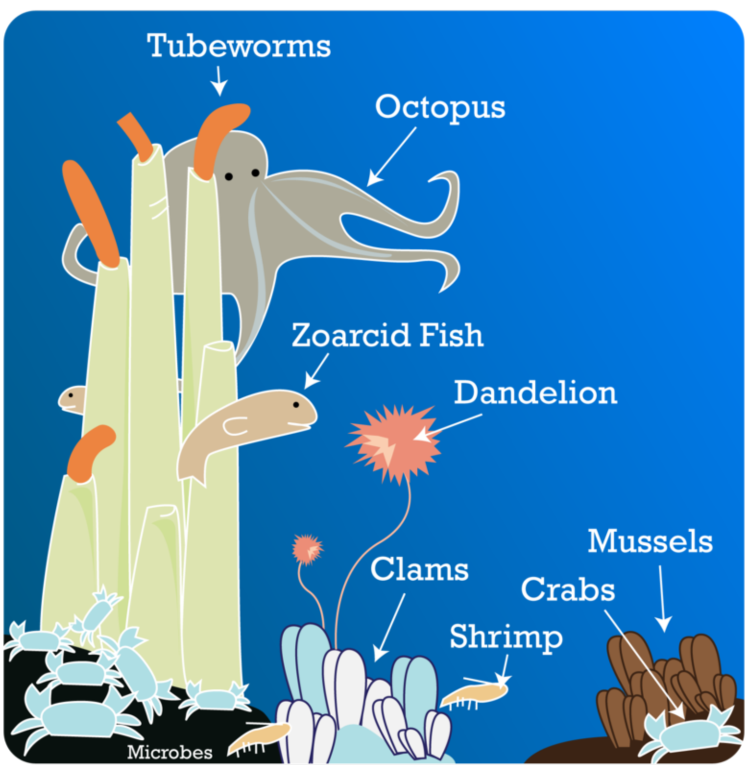

FIGURE 16.4
Microbes use chemicals to make food. The chemicals pour out of a crack on the ocean floor at a mid-ocean ridge. What consumers live in this ecosystem?

Consumers

Consumers can't make their own food. Consumers must eat producers or other consumers. **Figure** 16.5 lists the three main types of consumers. Which type are you?

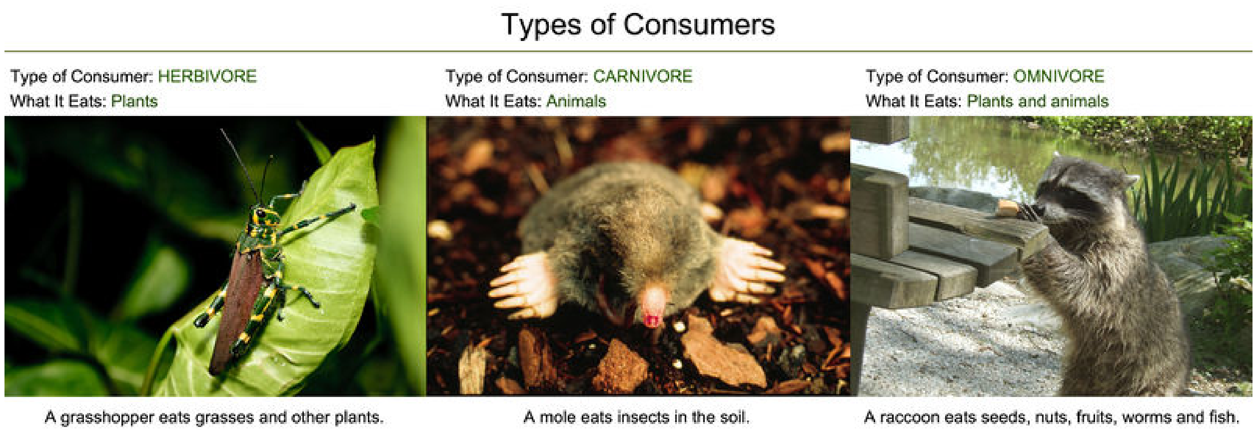

FIGURE 16.5
Examples of the main types of consumers. Can you name other consumers of each type?

Consumers get their food in different ways **Figure** 16.6. **Grazers** feed on living organisms without killing them. A rabbit nibbles on leaves and a mosquito sucks a drop of blood. **Predators**, like lions, capture and kill animals for food. The animals they eat are called **prey**. Even some plants are consumers. Pitcher plants trap insects in their sticky fluid in their "pitchers." The insects are their prey. **Scavengers** eat animals that are already dead. This hyena is eating the remains of a lion's prey. **Decomposers** break down dead organisms and the wastes of living things. This dung beetle is rolling a ball of dung (animal waste) back to its nest. The beetle will use the dung to feed its young. The mushrooms pictured are growing on a dead log. They will slowly break it down. This releases its nutrients to the soil.

How Energy Flows Through Ecosystems

All living things need energy. They need it to power the processes of life. For example, it takes energy to grow. It also takes energy to produce offspring. In fact, it takes energy just to stay alive. Remember that energy can't be created or destroyed. It can only change form. Energy changes form as it moves through ecosystems.

The Flow of Energy

Most ecosystems get their energy from the Sun. Only producers can use sunlight to make usable energy. Producers convert the sunlight into chemical energy or food. Consumers get some of that energy when they eat producers. They also pass some of the energy on to other consumers when they are eaten. In this way, energy flows from one living thing to another.

FIGURE 16.6
Ways consumers get food. Do you know how earthworms get food?

Food Chains

A **food chain** is a simple diagram that shows one way energy flows through an ecosystem. You can see an example of a food chain in **Figure** 16.7. Producers form the base of all food chains. The consumers that eat producers are called primary consumers. The consumers that eat primary consumers are secondary consumers. This chain can continue to multiple levels.

At each level of a food chain, a lot of energy is lost. Only about 10 percent of the energy passes to the next level. Where does that energy go? Some energy is given off as heat. Some energy goes into animal wastes. Energy also goes into growing things that another consumer can't eat, like fur. It's because so much energy is lost that most food chains have just a few levels. There's not enough energy left for higher levels.

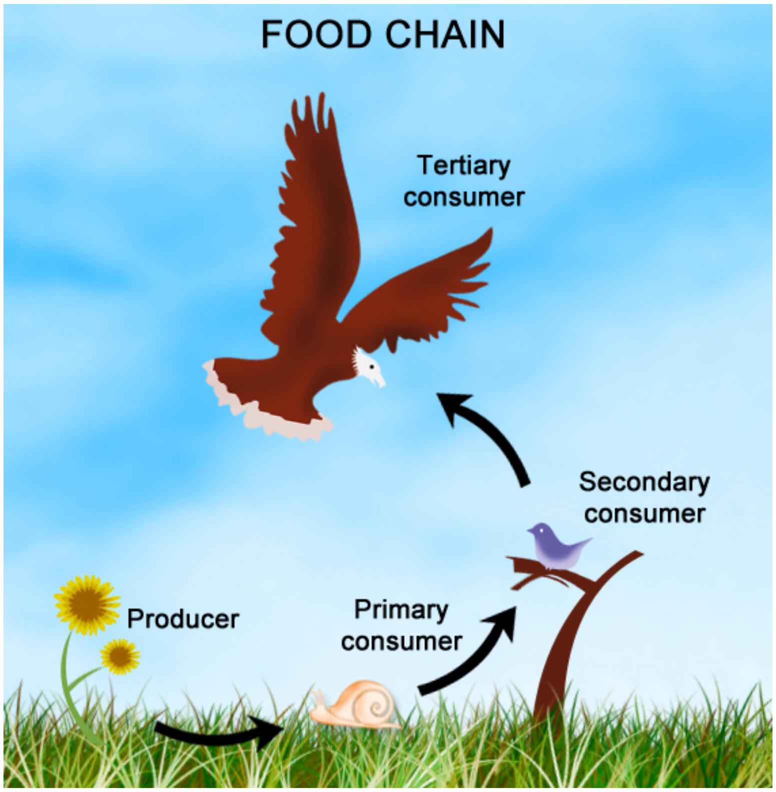

FIGURE 16.7
What do the arrows stand for in a food chain?

Food Webs

Food chains are too simple to represent the real world. They don't show all the ways that energy flows through an ecosystem. A more complex diagram is called a **food web**. You can see an example in **Figure** 16.8. A food web consists of many overlapping food chains. Can you identify the food chains in the figure? How many food chains include the mouse?

How Matter Moves Through Ecosystems

Living things need nonliving matter as well as energy. What do you think matter is used for? One thing is to build bodies. They also need it to carry out the processes of life. Any nonliving matter that living things need is called a **nutrient**. Carbon and nitrogen are examples of nutrients. Unlike energy, matter is recycled in ecosystems. You can see how in **Figure** 16.9.

- Decomposers release nutrients when they break down dead organisms.
- The nutrients are taken up by plants through their roots.
- The nutrients pass to primary consumers when they eat the plants.
- The nutrients pass to higher level consumers when they eat lower level consumers.
- When living things die, the cycle repeats.

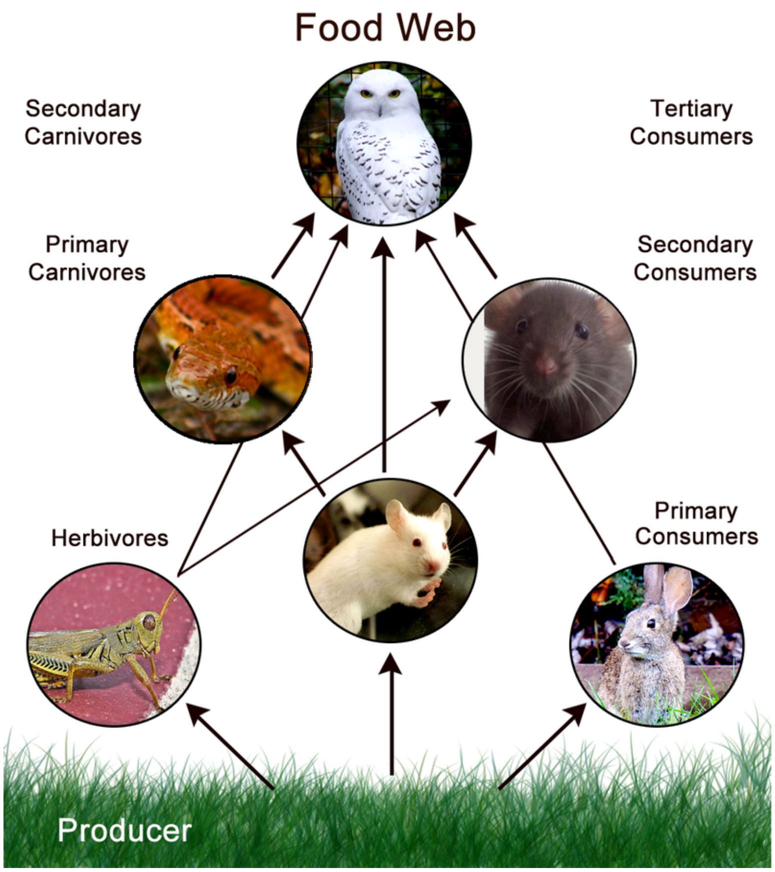

FIGURE 16.8
The owl in this food web consumes at two different levels. What are they?

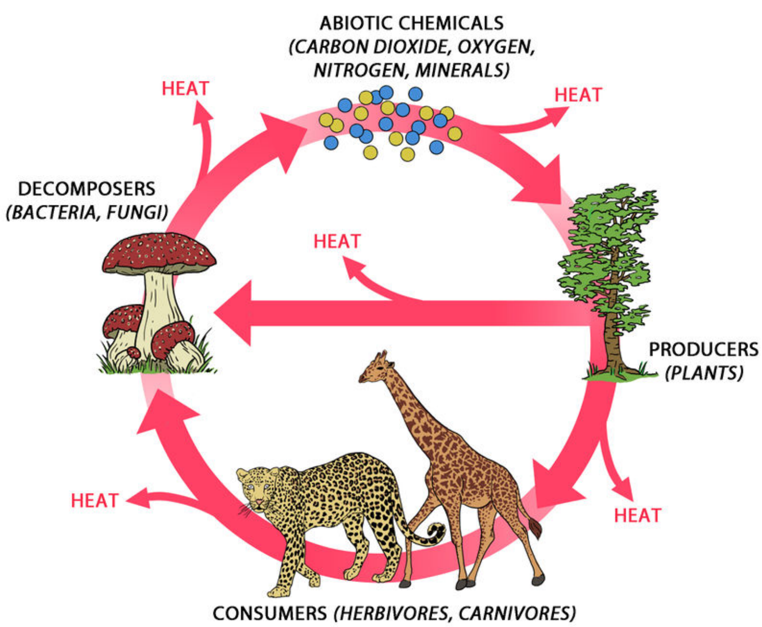

FIGURE 16.9
This diagram shows two cycles. One is the cycle of energy, the other is the cycle of matter. Compare the two cycles. Do you see how the Sun keeps adding energy? That's because energy is lost at each step of the cycle. Matter doesn't have to be added. Can you explain why?

Lesson Summary

- An ecosystem is a group of living things and their environment. It is made up of both living and nonliving things.
- Abiotic factors are the nonliving parts of ecosystems. They include air, soil, and other things organisms need. They determine which organisms — and how many of them — can live in an ecosystem.
- Biotic factors are the living parts of ecosystems. They include species of living things.
- All ecosystems have organisms that play the same roles. They all have producers and consumers.
- All living things need energy. Most ecosystems get energy from the Sun. Producers use the energy to make food. They pass some of the energy to consumers. Food chains and food webs show how energy flows through ecosystems.
- Living things also need matter. Unlike energy, matter is recycled in ecosystems.

Lesson Review Questions

Recall

1. Define ecosystem. Give two examples.

2. List four abiotic factors in ecosystems.

3. Identify three types of consumers, based on what they eat.

4. Give an example of each of these types of organisms: predator, scavenger, and decomposer.

5. What is a nutrient?

Apply Concepts

6. Look at the plants in **Figure** 16.2. Describe their habitat and niche.

7. Draw a food chain that consists of the following organisms: fox, grass, mountain lion, and rabbit. Label each living thing with its role in the food chain. Show how energy enters the food chain.

Think Critically

8. Explain how these concepts are related: species, population, and community.

9. Compare and contrast the two types of producers.

Points to Consider

In this lesson, you read that matter is recycled in ecosystems. You already know how water is recycled. Its cycle includes living things, the air, and the oceans. In the next lesson, you'll read about the cycles of two important nutrients, starting with carbon.

- Can you predict how carbon cycles?
- Do you think carbon cycles between living and nonliving things?

16.2 Cycles of Matter

Lesson Objectives

- Explain why carbon is important to life.
- Outline the carbon cycle.
- Give an overview of the nitrogen cycle.

Vocabulary

- carbon cycle
- dead zone
- nitrogen cycle

Introduction

Did you know that carbon is the basis of life on Earth? Living things consist mainly of carbon. Carbon compounds also control life processes. Your own body is mostly carbon. But do you know what carbon is?

The Element Carbon

Carbon is an element. By itself, it's a black solid. You can see a lump of carbon in **Figure** 16.10. Carbon is incredibly important because of what it makes when it combines with many other elements. Carbon can form a wide variety of substances. For example, in the air, carbon combines with oxygen to form the gas carbon dioxide.

FIGURE 16.10
This piece of carbon looks like a lump of coal. Coal is mostly carbon.

In living things, carbon combines with several other elements. For example, it may combine with nitrogen and hydrogen. Then it forms compounds such as sugars and proteins. How do living things get the carbon they need? Carbon moves through ecosystems in the carbon cycle.

The Carbon Cycle

In the **carbon cycle**, carbon moves through living and nonliving things. Carbon actually moves through two cycles that overlap. One cycle is mainly biotic; the other cycle is mainly abiotic. Both cycles are shown in **Figure** 16.11.

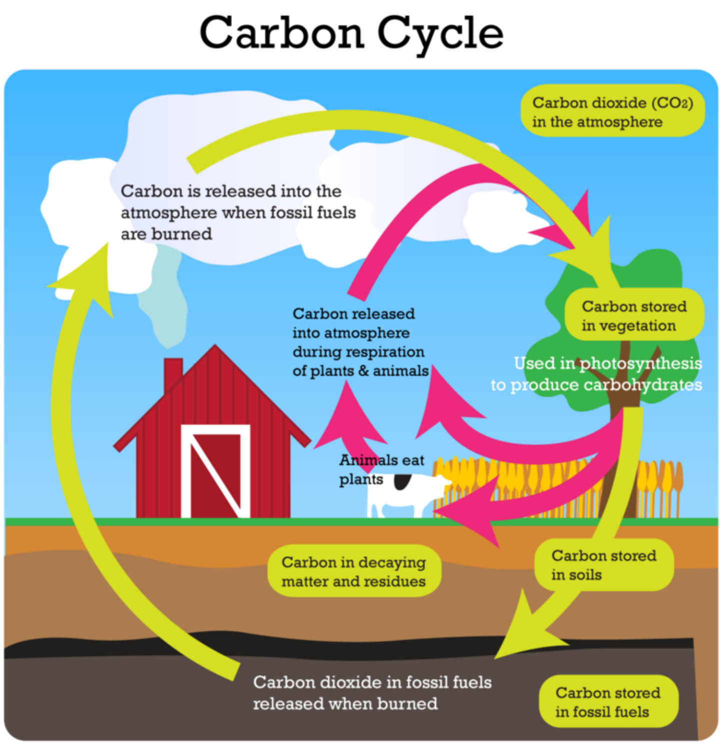

FIGURE 16.11
Carbon changes form as it moves through its cycle. Follow carbon through the diagram as you read about the cycle below.

How Carbon Cycles Through Living Things

Producers such as plants or algae use carbon dioxide in the air to make food. The organisms combine carbon dioxide with water to make sugar. They store the sugar as starch. Both sugar and starch are carbohydrates. Consumers get carbon when they eat producers or other consumers.

Carbon doesn't stop there. Living things get energy from food in a process called respiration. This releases carbon dioxide back into the atmosphere. The cycle then repeats.

How Carbon Cycles Through Nonliving Things

Carbon from decaying organisms enters the ground. Some carbon is stored in the soil. Some carbon may be stored underground for millions of years. This will form fossil fuels. When volcanoes erupt, carbon from the mantle is released as carbon dioxide into the air. Producers take in the carbon dioxide to make food. Then the cycle repeats.

The oceans also play an important role in the carbon cycle. Ocean water absorbs carbon dioxide from the air. In fact, the oceans contain 50 times more carbon than the atmosphere. Much of the carbon sinks to the bottom of the oceans, where it may stay for hundreds of years.

Human Actions and the Carbon Cycle

Human actions are influencing the carbon cycle. Burning of fossil fuels releases the carbon dioxide that was stored in ancient plants. Carbon dioxide is a greenhouse gas and is a cause of global warming.

Forests are also being destroyed. Trees may be cut down for their wood, or they may be burned to clear the land for farming. Burning wood releases more carbon dioxide into the atmosphere. You can see how a tropical rainforest was cleared for farming in **Figure** 16.12. With forests shrinking, there are fewer trees to remove carbon dioxide from the air. This makes the greenhouse effect even worse.

FIGURE 16.12
Large parts of this Amazon rainforest have been cleared to grow crops. How does this affect the carbon cycle?

The Nitrogen Cycle

Living things also need nitrogen. Nitrogen is a key element in proteins. Like carbon, nitrogen cycles through ecosystems. You can see the **nitrogen cycle** in **Figure** 16.13.

Fixing Nitrogen

Air is about 78 percent nitrogen. Decomposers release nitrogen into the air from dead organisms and their wastes. However, producers such as plants can't use these forms of nitrogen. Nitrogen must combine with other elements before producers can use it. This is done by certain bacteria in the soil. It's called "fixing" nitrogen.

Human Actions and the Nitrogen Cycle

Nitrogen is one of the most important nutrients needed by plants. That's why most plant fertilizers contain nitrogen. Adding fertilizer to soil allows more plants to grow. As a result, a given amount of land can produce more food. So far, so good. But what happens next?

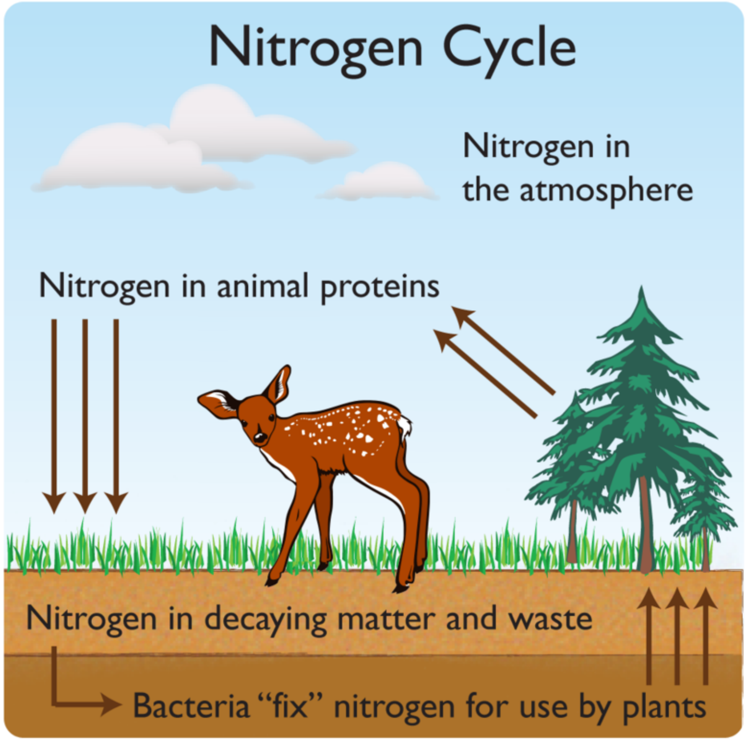

FIGURE 16.13
The nitrogen cycle includes air, soil, and living things.

Rain dissolves fertilizer in the soil. Runoff carries it away. The fertilizer ends up in bodies of water, from ponds to oceans. The nitrogen is a fertilizer in the water bodies. Since there is a lot of nitrogen it causes algae to grow out of control. **Figure** 16.14 shows a pond covered with algae. Algae may use up so much oxygen in the water that nothing else can grow. Soon, even the algae die out. Decomposers break down the dead tissue and use up all the oxygen in the water. This creates a dead zone. A **dead zone** is an area in a body of water where nothing grows because there is too little oxygen. There is a large dead zone in the Gulf of Mexico. You can see it **Figure** 16.14.

Lesson Summary

- Carbon is an element. Carbon is the basis of all life on Earth. Since carbon can combine with many other elements it forms a variety of different substances.
- Carbon moves through ecosystems in two cycles that overlap. In the biotic cycle, it moves between living things and the air. In the abiotic cycle, it moves between the air, ground, and oceans. By burning fossil fuels, humans have increased the amount of carbon dioxide in the air.
- Living things also need nitrogen. It cycles between the air, soil, and living things. By using fertilizers, humans have increased the amount of nitrogen in bodies of water.

Lesson Review Questions

Recall

1. Describe carbon.

Pond covered with algae

Dead zone in the Gulf of Mexico

FIGURE 16.14

Effects of Too Much Nitrogen. The pond on the left is covered with algae because of fertilizer in the water. The red-shaded area in the map on the right is a dead zone in the Gulf of Mexico. It's called the hypoxic ("low oxygen") zone in the figure. The U.S. states outlined on the map have rivers that drain into the Gulf of Mexico. The rivers carry fertilizer from these areas into the Gulf. Pond Covered with Algae; Dead Zone in the Gulf of Mexico.

2. State why carbon is important to life.
3. Describe the biotic carbon cycle.
4. Outline the abiotic carbon cycle.
5. Describe how human actions have affected the carbon cycle.

Apply Concepts

6. How could you model the nitrogen cycle? Think of a creative way and describe it.

7. Look at the colorful organisms in **Figure** 16.15. Explain how they are involved in both biotic and abiotic carbon cycles.

Think Critically

8. Dead zones occur in many places around the world. They usually occur where rivers flow into oceans. Explain why.

Points to Consider

In this lesson, you read how human actions influence the carbon and nitrogen cycles. Human actions influence many natural processes. The influence may be great. One reason is that there are so many people on the planet.

FIGURE 16.15

- Do you know how many people live in the world today?
- Why has the human population grown so large?

16.3 The Human Population

Lesson Objectives

- Explain how populations grow.
- Describe how the human population has grown.
- State how the human population affects the environment.

Vocabulary

- carrying capacity
- demographic transition
- green revolution
- population growth rate (*r*)
- sustainable development

Introduction

Right now, there are almost 7 billion people in the world. As you read this sentence, at least three more people will be added. Think about that for second or so, and there's another three. You can actually watch the number of people increase, second by the second, at this link: http://www.intmath.com/Exponential-logarithmic-functions/world-population-live.php

Why is the human population growing so fast? Has it always grown this fast? What causes populations to grow? In this lesson, you'll find answers to all these questions.

How Populations Grow

A population usually grows when it has what it needs. If there's plenty of food and other resources, the population will get bigger. Look at **Table** 16.1. It shows how a population of bacteria grew. A single bacteria cell was added to a container of nutrients. Conditions were ideal. The bacteria divided every 30 minutes. After just 10 hours, there were more than a million bacteria! Assume the bacteria population keeps growing at this rate. How many bacteria will there be at 10.5 hours? Or at 12 hours?

TABLE 16.1: Growth of a Bacterial Population

Time (hours)	Number of Bacteria
0	1
0.5	2

TABLE 16.1: (continued)

Time (hours)	Number of Bacteria
1.0	4
1.5	8
2.0	16
2.5	32
3.0	64
3.5	128
4.0	256
4.5	512
5.0	1,024
5.5	2,048
6.0	4,096
6.5	8,192
7.0	16,384
7.5	32,768
8.0	65,536
8.5	131,072
9.0	262,144
9.5	524,288
10	1,048,576

Population Growth Rate

The **population growth rate** is how fast a population is growing. The letter r stands for the growth rate. The growth rate equals the number of new members added to the population in a year for each 100 members already in the population. The growth rate includes new members added to the population and old members removed from the population. Births add new members to the population. Deaths remove members from the population. The formula for population growth rate is:

$r = b - d$, where

b = birth rate (number of births in 1 year per 100 population members)
d = death rate (number of deaths in 1 year per 100 population members)

If the birth rate is greater than the death rate, r is positive. This means that the population is growing bigger. For example, if $b = 10$ and $d = 8$, $r = 2$. This means that the population is growing by 2 individuals per year for every 100 members of the population. This may not sound like much, but it's a fairly high rate of growth. A population growing at this rate would double in size in just 35 years!

If the birth rate is less than the death rate, r is negative. This means that the population is becoming smaller. What do you think might cause this to happen?

Carrying Capacity

A population can't keep growing bigger and bigger forever. Sooner or later, it will run out of things it needs. For a given species, there is a maximum population that can be supported by the environment. This maximum is called the **carrying capacity**. When a population gets close to the carrying capacity, it usually grows more slowly. You can see this in **Figure** 16.16. When the population reaches the carrying capacity, it stops growing.

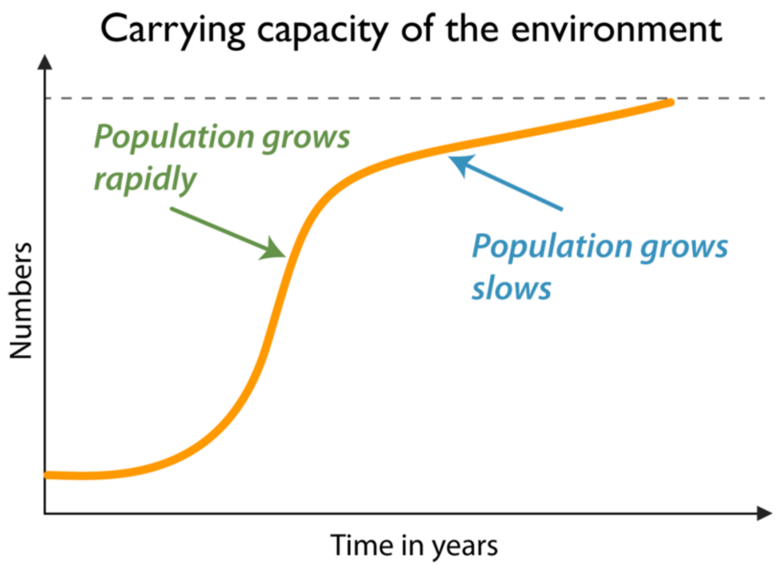

FIGURE 16.16
A population can't get much larger than the carrying capacity. What might happen if it did?

Human Population Growth

Figure 16.17 shows how the human population has grown. It grew very slowly for tens of thousands of years. Then, in the 1800s, something happened to change all that. The human population started to grow much faster.

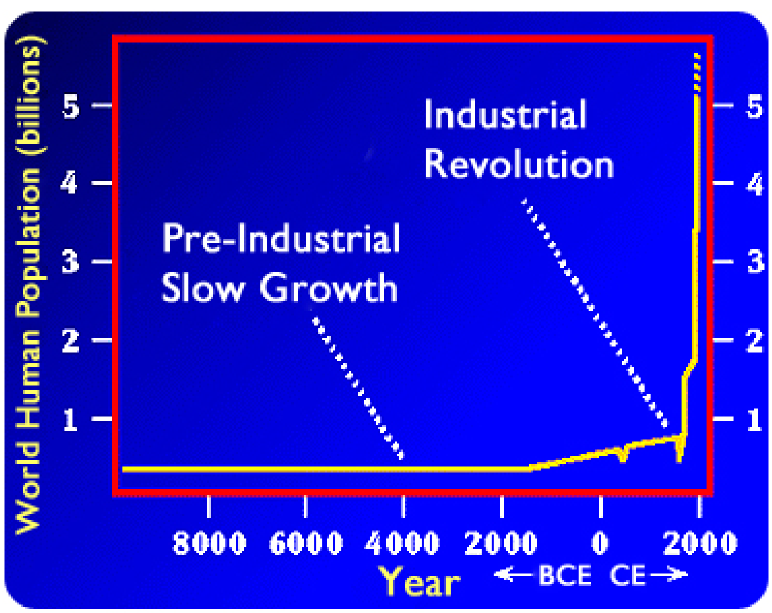

FIGURE 16.17
Growth of the human population. Until recently, the human population grew very slowly.

The Demographic Transition

The industrial revolution is what happened. The industrial revolution began in the late 1700s in Europe, North America, and a few other places. In these places, the human population grew faster. While there had always been a lot of births, the population grew because the death rate fell. It fell for several reasons:

1. New farm machines were invented. They increased the amount of food that could be produced. With more food, people were healthier and could live longer.
2. Steam engines and railroads were built. These machines could quickly carry food long distances. This made food shortages less likely.
3. Sanitation was improved. Sewers were dug to carry away human wastes (see **Figure** 16.18). This helped reduce the spread of disease.

FIGURE 16.18
Digging a London sewer (1840s). Before 1800, human wastes were thrown into the streets of cities such as London. In the early 1800s, sewers were dug to carry away the wastes.

With better food and less chance of disease, the death rate fell. More children lived long enough to reach adulthood and have children of their own. As the death rate fell, the birth rate stayed high for a while. This caused rapid population growth. However, the birth rate in these countries has since fallen to a rate close to that of the low death rate.

The result was slow population growth once again. These changes are called the **demographic transition**.

Recent Population Growth

More recently, the death rate has fallen because of the availability of more food and medical advances:

- A **green revolution** began in the mid 1900s. New methods and products increased how much food could be grown. For example, chemicals were developed that killed weeds without harming crops. Pesticides were developed that killed pests that destroyed crops.
- Vaccinations were developed that could prevent many diseases (see **Figure** 16.19). Antibiotics were discovered that could cure most infections caused by bacteria. Together, these two advances saved countless lives.

FIGURE 16.19
This child is getting a polio vaccine. He will never get sick with polio, which could save his live or keep him from becoming crippled.

Today in many countries, death rates have gone down but birth rates remain high. This means that the population is growing. **Figure** 16.20 shows the growth rates of human populations all over the world.

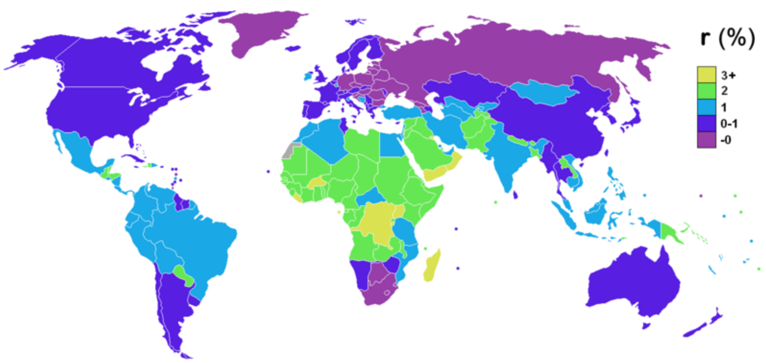

FIGURE 16.20
World population growth rates. Is the population growing faster in the wealthiest countries or the poorest countries?

Future Population Growth

The growth of the human population has started to slow down. You can see this in **Figure** 16.21. It may stop growing by the mid 2000s. Scientists think that the human population will peak at about 9 billion people. What will need to change for the population to stop growing then?

Human Population and the Environment

Are 9 billion people the human carrying capacity? It looks that way in **Figure** 16.21. But some people think there are too many of us already. That's because we are harming the environment.

- Supplying all those people with energy creates a lot of pollution. For example, huge oil spills have killed millions of living things.

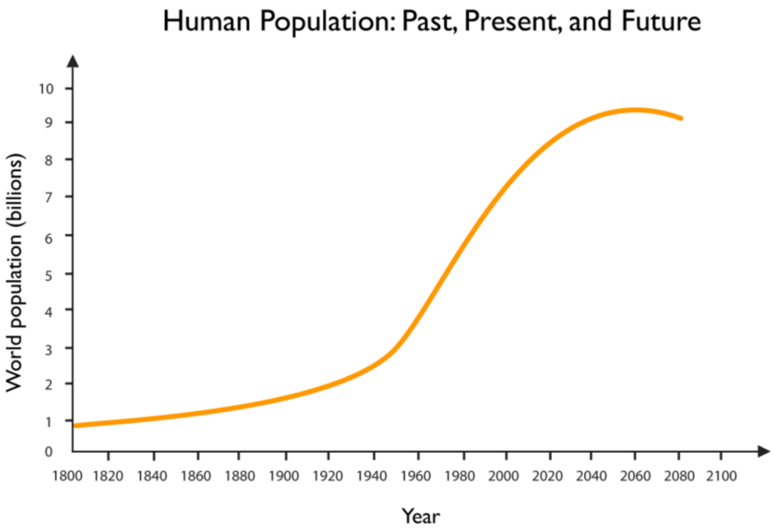

FIGURE 16.21
Compare this graph with the graph of the carrying capacity. What do you think is the carrying capacity of the human population?

- Burning fossil fuels pollutes the air. This also increases causes global warming.
- Fossil fuels and other resources are being used up. We may run out of oil by the mid 2000s. Many other resources will run out sooner or later.
- People are killing too many animals for food. For example, some of the best fishing grounds in the oceans have almost no fish left.
- People have destroyed many habitats. For example, they've drained millions of acres of wetlands. Wetlands have a great diversity of species. As wetlands shrink, species go extinct.
- People have allowed alien or invasive species - species originally from a different area - to invade new habitats. Often, the aliens have no natural enemies in their new home. They may drive native species extinct. **Figure** 16.22 gives an example.

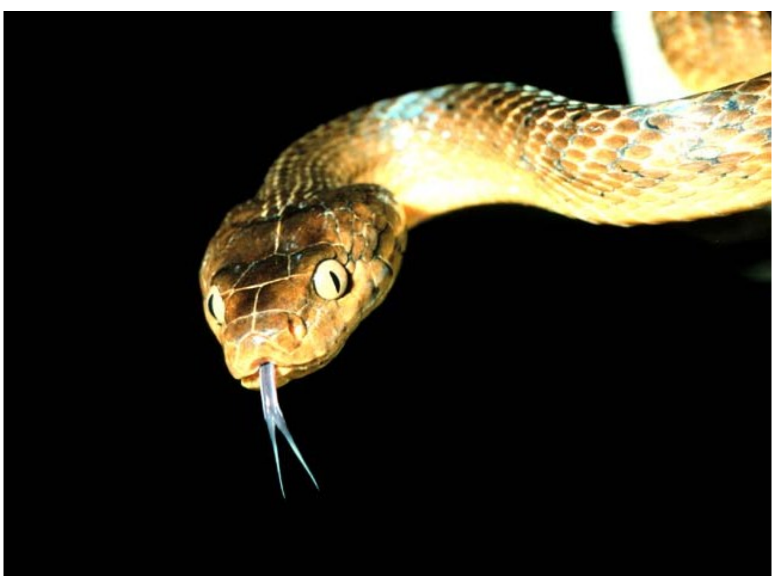

FIGURE 16.22
In the mid 1900s, Australian tree snakes invaded Guam and other islands in the Pacific. The snakes "stowed away" on boats and planes. Tree snakes had no natural enemies on the islands. Their populations exploded and they drove several island species extinct.

People themselves are also affected by the large size of the human population. A minority of people use most of the world's energy and other resources. Many other people lack resources. Many don't have enough to eat or live with the threat of hunger. Many also do not have safe, clean water. Some people live in crowded, run-down housing or something that is barely considered housing.

Sustainable Development

Is it possible for all the world's people to live well and still protect the planet? That's the aim of **sustainable development**. Its goals are to:

1. Distribute resources fairly.
2. Conserve resources so they won't run out.
3. Use resources in ways that won't harm ecosystems.

A smaller human population may be part of the solution. Better use of resources is another part. For example, when forests are logged, new trees should be planted. Everyone can help in the effort. What will you do?

Lesson Summary

- Populations usually grow bigger when they have what they need. How fast they grow depends on birth and death rates. They grow more slowly as they get close to the carrying capacity. This is the biggest population the environment can support.
- Human population growth was slow until the 1800s. Both birth and death rates were high. Then, the death rate started to fall. In industrial countries, the birth rate soon fell as well. However, in many other places, the birth rate is still high. As a result, the human population is growing rapidly. It may reach 9 billion by the mid 2000s.
- The human population is already harming the environment. Many people don't get enough resources. They may lack shelter, food, or clean water.
- Sustainable development is needed. This means using resources in such a way that they won't run out and the planet won't be harmed.

Lesson Review Questions

Recall

1. Define carrying capacity.

2. Describe how the human population grew up until the 1800s.

3. List two reasons the death rate fell in industrial countries in the 1800s.

4. What was the green revolution? When did happen? How did it affect the human population?

5. How is the human population harming the environment?

Apply Concepts

6. Compare the three populations in the **Table** 16.2. Which one is growing fastest? Explain your answer.

TABLE 16.2: Population Data for Question 6

Population	Birth Rate (per 100 people)	Death rate (per 100 people)
A	14	3
B	16	6
C	18	8

7. Draw a graph of population growth for North America. It should show how the rate of growth changed during the demographic transition.

Think Critically

8. Do you think the human population is already too big? Has it reached its carrying capacity? Why or why not?

9. What could you do to help sustainable development?

Points to Consider

In this chapter, you read how humans are harming the environment. For example, we are quickly using up many natural resources. Soil is one of our most precious natural resources. It takes a very long time to form. But it can be washed away in a single rainstorm.

- How do you think human actions are affecting the soil?
- What can people do to protect this important resource?

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CHAPTER 17 MS Weathering and Formation of Soil

Chapter Outline

Soil is a precious resource. It allows us to grow food and the materials we use to make everything from the shirt you have on to the medicine you took this morning. Soil is made up of small pieces of rock that have broken down over hundreds, if not thousands, of years. Soil is also partly made up of the remains of plants and animals, and is home to many organisms, from earthworms to ants. But soil can be damaged by unsustainable farming practices and clear-cut logging. In this chapter, you will learn how soil forms, what it contains, and how to protect it.

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17.1 Weathering

Lesson Objectives

- Define mechanical and chemical weathering.
- Discuss agents of weathering.
- Give examples of each type of weathering.

Vocabulary

- abrasion
- chemical weathering
- erosion
- ice wedging
- mechanical weathering

Introduction

Weathering breaks rocks apart. Some types of weathering alter some minerals. **Erosion** moves the broken pieces.

What is Weathering?

Weathering changes solid rock into sediments. Sediments are different sizes of rock particles. Boulders are sediments; so is gravel. At the other end, silt and clay are also sediments. Weathering causes rocks at the Earth's surface to change form. The new minerals that form are stable at the Earth's surface.

It takes a long time for a rock or mountain to weather. But a road can do so much more quickly. If you live in a part of the world that has cold winters, you may only have to wait one year to see a new road start to weather (**Figure** 17.1).

Mechanical Weathering

Mechanical weathering breaks rock into smaller pieces. These smaller pieces are just like the bigger rock; they are just smaller! The rock has broken without changing its composition. The smaller pieces have the same minerals in the same proportions. You could use the expression "a chip off the old block" to describe mechanical weathering! The main agents of mechanical weathering are water, ice, and wind.

FIGURE 17.1
A hard winter has damaged this road.

Ice Wedging

Rocks can break apart into smaller pieces in many ways. **Ice wedging** is common where water goes above and below its freezing point (**Figure** 17.2). This can happen in winter in the mid-latitudes or in colder climates in summer. Ice wedging is common in mountainous regions.

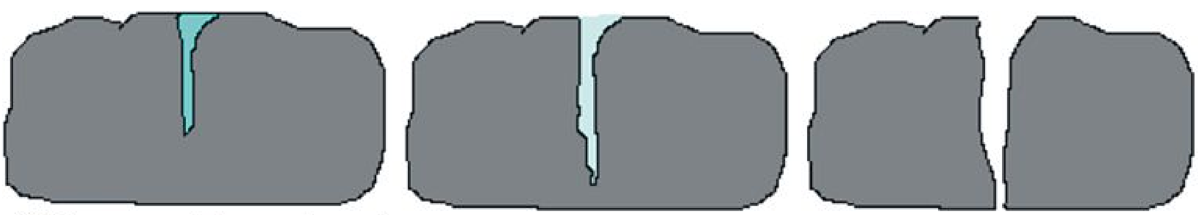

FIGURE 17.2
Diagram showing ice wedging.

This is how ice wedging works. When liquid water changes into solid ice, it increases in volume. You see this when you fill an ice cube tray with water and put it in the freezer. The ice cubes go to a higher level in the tray than the water. You also may have seen this if you put a can of soda into the freezer so that it cools down quickly. If you leave the can in the freezer too long, the liquid expands so much that it bends or pops the can. (For the record, water is very unusual. Most substances get smaller when they change from a liquid to a solid.)

Ice wedging happens because water expands as it goes from liquid to solid. When the temperature is warm, water works its way into cracks in rock. When the temperature cools below freezing, the water turns to ice and expands. The ice takes up more space. Over time, this wedges the rock apart. Ice wedging is very effective at weathering. You can find large piles of broken rock at the base of a slope. These rocks were broken up by ice wedging. Once loose, they tumbled down the slope.

Abrasion

Abrasion is another type of mechanical weathering. With abrasion, one rock bumps against another rock. Gravity causes abrasion as a rock tumbles down a slope. Moving water causes abrasion it moves rocks so that they bump against one another (**Figure** 17.3). Strong winds cause abrasion by blasting sand against rock surfaces. Finally, the ice in glaciers cause abrasion. Pieces of rock embedded in ice at the bottom of a glacier scrape against the rock below. If you have ever collected beach glass or pebbles from a stream, you have witnessed the work of abrasion.

FIGURE 17.3
Rocks on a beach are worn down by abrasion as passing waves cause them to strike each other.

Plants and Animals in Mechanical Weathering

Sometimes biological elements cause mechanical weathering. This can happen slowly. A plant's roots grow into a crack in rock. As the roots grow larger, they wedge open the crack. Burrowing animals can also cause weathering. By digging for food or creating a hole to live in the animal may break apart rock. Today, human beings do a lot of mechanical weathering whenever we dig or blast into rock. This is common when we build homes, roads, and subways, or quarry stone for construction or other uses.

Mechanical Weathering and Chemical Weathering

Mechanical weathering increases the rate of chemical weathering. As rock breaks into smaller pieces, the surface area of the pieces increases. With more surfaces exposed, there are more places for chemical weathering to occur. Let's say you wanted to make some hot chocolate on a cold day. It would be hard to get a big chunk of chocolate to dissolve in your milk or hot water. Maybe you could make hot chocolate from some smaller pieces like chocolate chips, but it is much easier to add a powder to your milk. This is because the smaller the pieces are, the more surface area they have. Smaller pieces dissolve more easily.

Chemical Weathering

Chemical weathering is different than mechanical weathering. The minerals in the rock change. The rock changes composition and becomes a different type of rock. Most minerals form at high pressure or high temperatures deep within Earth. But at Earth's surface, temperatures and pressures are much lower. Minerals that were stable deeper in the crust are not stable at the surface. That's why chemical weathering happens. Minerals that formed at higher temperature and pressure change into minerals that are stable at the surface. Chemical weathering is important. It starts the process of changing solid rock into soil. We need soil to grow food and create other materials we need. Chemical weathering works through chemical reactions that change the rock.

There are many agents of chemical weathering. Remember that water was a main agent of mechanical weathering. Well, water is also an agent of chemical weathering. That makes it a double agent! Carbon dioxide and oxygen are also agents of chemical weathering. Each of these is discussed below.

Water

Water is an amazing molecule. It has a very simple chemical formula, H_2O. It is made of just two hydrogen atoms bonded to one oxygen atom. Water is remarkable in terms of all the things it can do. Lots of things dissolve easily in water. Some types of rock can even completely dissolve in water! Other minerals change by adding water into their structure.

Carbon Dioxide

Carbon dioxide (CO_2) combines with water as raindrops fall through the air. This makes a weak acid, called carbonic acid. This happens so often that carbonic acid is a common, weak acid found in nature. This acid works to dissolve rock. It eats away at sculptures and monuments. While this is normal, more acids are made when we add pollutants to the air. Any time we burn any fossil fuel, it adds nitrous oxide to the air. When we burn coal rich in sulfur, it adds sulfur dioxide to the air. As nitrous oxide and sulfur dioxide react with water, they form nitric acid and sulfuric acid. These are the two main components of acid rain. Acid rain accelerates chemical weathering.

Oxygen

Oxygen strongly reacts with elements at the Earth's surface. You are probably most familiar with the rust that forms when iron reacts with oxygen (**Figure** 17.4). Many minerals are rich in iron. They break down as the iron changes into iron oxide. This makes the red color in soils.

Plants and animals also cause chemical weathering. As plant roots take in nutrients, elements are exchanged.

Weathering Happens at Different Rates

Each type of rock weathers in its own way. Certain types of rock are very resistant to weathering. Igneous rocks tend to weather slowly because they are hard. Water cannot easily penetrate them. Granite is a very stable igneous rock. Other types of rock are easily weathered because they dissolve easily in weak acids. Limestone is a sedimentary rock that dissolves easily. When softer rocks wear away, the more resistant rocks form ridges or hills.

Devil's Tower in Wyoming shows how different types of rock weather at different rates (**Figure** 17.5). The softer materials of the surrounding rocks were worn away. The resistant center of the volcano remains behind.

FIGURE 17.4
Iron ore oxidizes readily.

FIGURE 17.5
Devil's Tower shows differential weathering. Hard rock from inside a volcano makes up the tower.

Minerals also weather differently. Some minerals completely dissolve in water. As less resistant minerals dissolve away, a rock's surface becomes pitted and rough. When a less resistant mineral dissolves, more resistant mineral grains are released from the rock.

Lesson Summary

- Mechanical weathering breaks rocks into smaller pieces. Their composition does not change.
- Ice wedging and abrasion are two important processes of mechanical weathering.

- Chemical weathering breaks down rocks by forming new minerals. These minerals are stable at the Earth's surface.
- Water, carbon dioxide, and oxygen are important agents of chemical weathering.
- Different types of rocks weather at different rates. More resistant types of rocks will remain longer.

Lesson Review Questions

Recall

1. Name two types of mechanical weathering. Explain how each works to break apart rock.

2. What are three agents of chemical weathering? Give an example of each.

Apply Concepts

3. How do acids form in the atmosphere? What increases the acidity of rainfall?

4. What are the effects of acid rain?

Think Critically

5. Describe what you think weathering would be like in an arid region. What would weathering be like in a tropical region?

6. What type of surface weathers faster: a smooth surface or a jagged surface?

Points to Consider

- What types of surfaces other than rock are affected by weathering?
- What might the surface of the Earth look like if weathering did not occur?
- Do you think that you would be alive today if water did not dissolve elements?
- Would the same composition of rock weather the same way in three very different climates?

17.2 Soils

Lesson Objectives

- Discuss why soil is an important resource.
- Describe how soil forms from existing rocks.
- Describe the different textures and components of soil.
- Draw and describe a soil profile.
- Define the three climate-related soils: pedalfer, pedocal and laterite soil.

Vocabulary

- deciduous forest
- humus
- inorganic
- laterite
- loam
- organic
- pedalfer
- pedocal
- residual soil
- soil horizon
- soil profile
- subsoil
- topsoil
- transported soil

Introduction

Without weathering, we would not have any soil on Earth. People could not live on Earth without soil! Your life and the lives of most organisms depend on soil. Soil is only a very thin layer over solid rock. Yet, it is the place where reactions between solid rock, liquid water and air take place. We get wood, paper, cotton, medicines, and even pure water from soil. So soil is a very important resource. Our precious soil needs to be carefully managed and cared for. If we don't take care of the soil we have, we may not be able to use it in the future.

Characteristics and Importance of Soil

We can think about soil as a living resource. Soil is an ecosystem all by itself! Soil is a complex mixture of different materials. Some of them are **inorganic**. Inorganic materials are made from non-living substances like pebbles and sand. Soil also contains bits of **organic** materials from plants and animals. In general, about half of the soil is made of pieces of rock and minerals. The other half is organic materials. In the spaces of soil are millions of living organisms. These include earthworms, ants, bacteria, and fungi. In some soils, the organic portion is entirely missing. This is true of desert sand. At the other extreme, a soil may be completely organic. Peat, found in a bog or swamp, is totally organic soil. Organic materials are necessary for a soil to be fertile. The organic portion provides the nutrients needed for strong plant growth.

Soil Formation

Soil formation requires weathering. Where there is less weathering, soils are thinner. However, soluble minerals may be present. Where there is intense weathering, soils may be thick. Minerals and nutrients would have been washed out. Soil development takes a very long time. It may take hundreds or even thousands of years to form the fertile upper layer of soil. Soil scientists estimate that in the very best soil forming conditions, soil forms at a rate of about 1mm/year. In poor conditions, it may take thousands of years!

How well soil forms and what type of soil forms depends on many factors. These include climate, the original rock type, the slope, the amount of time, and biological activity.

Climate

Climate is the most important factor in soil formation. The climate of a region is the result of its temperature and rainfall. We can identify different climates by the plants that grow there (**Figure** 17.6).

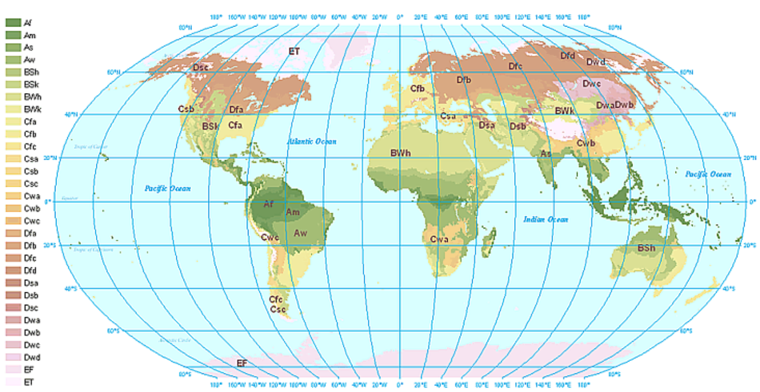

FIGURE 17.6
Climate is the most important factor in determining the type of soil that forms in a particular area.

Given enough time, a climate will produce a particular type of soil. The original rock type does not matter. The same rock type will form a different soil type in each different climate.

Rainfall

Rainfall in an area is important because it influences the rate of weathering. More rain means that more rainwater passes through the soil. The rainwater reacts chemically with the particles. The top layers of soil are in contact with the freshest water, so reactions are greatest there. High rainfall increases the amount of rock that experiences chemical reactions. High rainfall may also carry material away. This means that new surfaces are exposed. This increases the rate of weathering.

In tropical regions with high temperatures and lots of rain, thick soils form with no unstable minerals or nutrients. Conversely, dry regions produce thin soils, rich in unstable minerals.

Temperature

The temperature of a region is the other important part of climate. The rate of chemical reactions increases with higher temperatures. The rate doubles for every 10°C increase in temperature. Plants and bacteria grow and multiply faster in warmer areas.

Time

Soil formation increases with time. The longer the amount of time that soil remains in a particular area, the greater the degree of alteration. The warmer the temperatures, the more rainfall, and the greater the amount of time, the thicker the soils will become.

Parent Rock

The original rock is the source of the inorganic portion of the soil. Mechanical weathering breaks rock into smaller pieces. Chemical reactions change the rock's minerals. A **transported soil** forms from materials brought in from somewhere else. These soils form from sediments that were transported into the area and deposited. The rate of soil formation is faster for transported materials because they have already been weathered.

A soil is a **residual soil** when it forms in place. Only about one third of the soils in the United States form this way. The material comes from the underlying bedrock. Residual soils form over many years since it takes a long time for solid rock to become soil. First, cracks break up the bedrock. This may happen due to ice wedging. Weathering breaks up the rock even more. Then plants, such as lichens or grasses, become established. They cause further weathering. As more time passes and more layers of material weather, the soil develops.

Biological Activity

Biological activity produces the organic material in soil. **Humus** forms from the remains of plants and animals. It is an extremely important part of the soil. Humus coats the mineral grains. It binds them together into clumps that hold the soil together. This gives the soil its structure. Soils with high humus are better able to hold water. Soils rich with organic materials hold nutrients better and are more fertile. These soils are more easily farmed.

The color of soil indicates its fertility. Black or dark brown soils are rich in nitrogen and contain a high percentage of organic materials. Soils that are nitrogen poor and low in organic material might be gray, yellow, or red.

Soil Texture

The inorganic part of soil is made of different amounts of different size particles. This affects the characteristics of a soil. Water flows through soil more easily if the spaces between the particles are large enough and well connected. Sandy or silty soils are light soils because they drain water. Soils rich in clay are heavier. Clay particles allow only very small spaces between them, so clay-rich soils tend to hold water. Clay-rich soils are heavier and hold together more tightly. A soil that contains a mixture of grain sizes is called a **loam**.

Soil scientists measure the percentage of sand, silt, and clay in soil. They plot this information on a triangular diagram, with each type of particle at one corner (**Figure** 17.7).

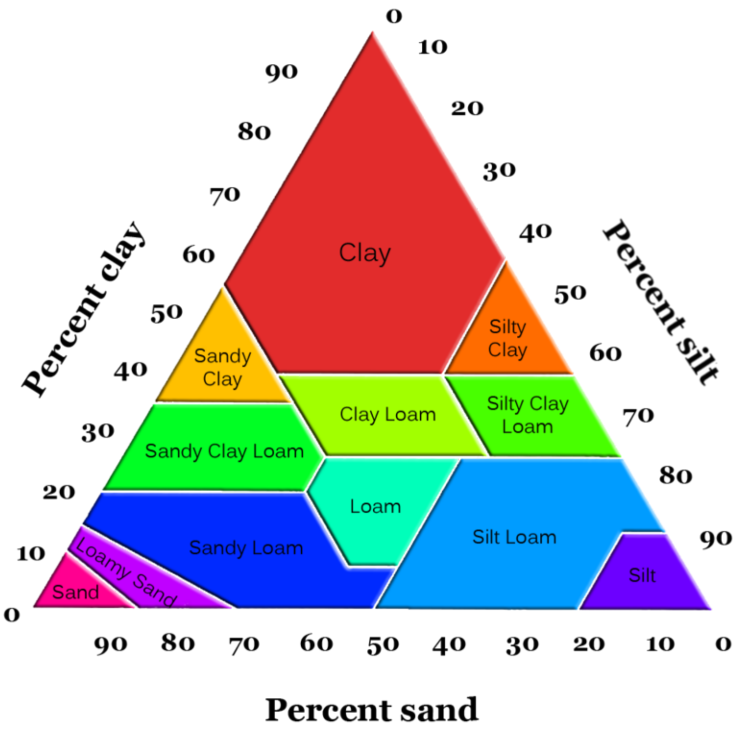

FIGURE 17.7
This diagram plots soil types by particle size.

The soil type is determined by where the soil falls on the diagram. At the top, the soil is clay rich. On the left corner, the soil is sandy. On the right corner, the soil is silty.

Soil Horizons and Profiles

Soil develops over time and forms soil horizons. **Soil horizons** are different layers of soil with depth. The most weathering occurs in the top layer. This layer is most exposed to weather! It is where fresh water comes into contact with the soil. Each layer lower is weathered just a little bit less than the layer above. As water moves down through the layers, it is able to do less work to change the soil.

If you dig a deep hole in the ground, you may see each of the different layers of soil. All together, the layers are a **soil profile**. Each horizon has its own set of characteristics (**Figure** 17.8). In the simplest soil profile, a soil has three horizons.

Topsoil

The first horizon is the "A" horizon. It is more commonly called the **topsoil**. The topsoil is usually the darkest layer of the soil. It is the layer with the most organic material. Humus forms from all the plant and animal debris that falls to or grows on the ground. The topsoil is also the region with the most biological activity. Many organisms live within this layer. Plant roots stretch down into this layer. The roots help to hold the topsoil in place.

Topsoil usually does not have very small particles like clay. Clay-sized particles are carried to lower layers as water seeps down into the ground. Many minerals dissolve in the fresh water that moves through the topsoil. These minerals are carried down to the lower layers of soil.

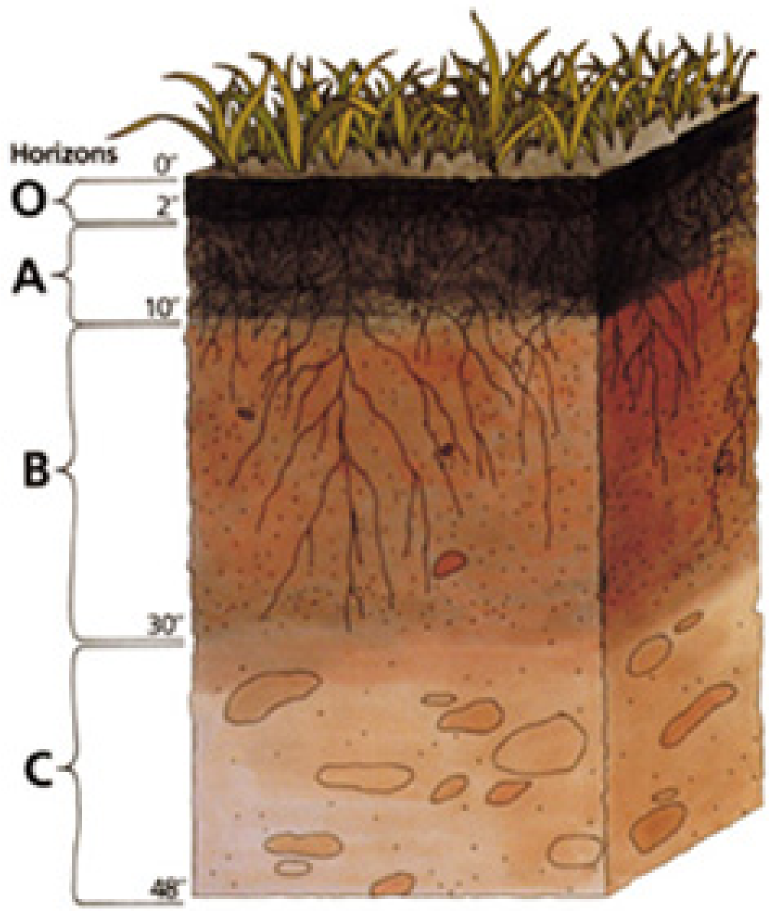

FIGURE 17.8
In this diagram, a cut through soil shows different soil layers.

Subsoil

Below the topsoil is the "B" horizon. This is also called the **subsoil**. Soluble minerals and clays accumulate in the subsoil. Because it has less organic material, this layer is lighter brown in color than topsoil. It also holds more water due to the presence of iron and clay. There is less organic material in this layer.

C-horizon

The next layer down is the "C" horizon. This layer is made of partially altered bedrock. There is evidence of weathering in this layer. Still, it is possible to identify the original rock type from which this soil formed (**Figure** 17.9).

Not all climate regions develop soils. Arid regions are poor at soil development. Not all regions develop the same soil horizons. Some areas develop as many as five or six distinct layers. Others develop only a few.

Types of Soils

For soil scientists, there are thousands of types of soil! Soil scientists put soils into very specific groups with certain characteristics. Each soil type has its own name. Let's consider a much simpler model, with just three types of soil.

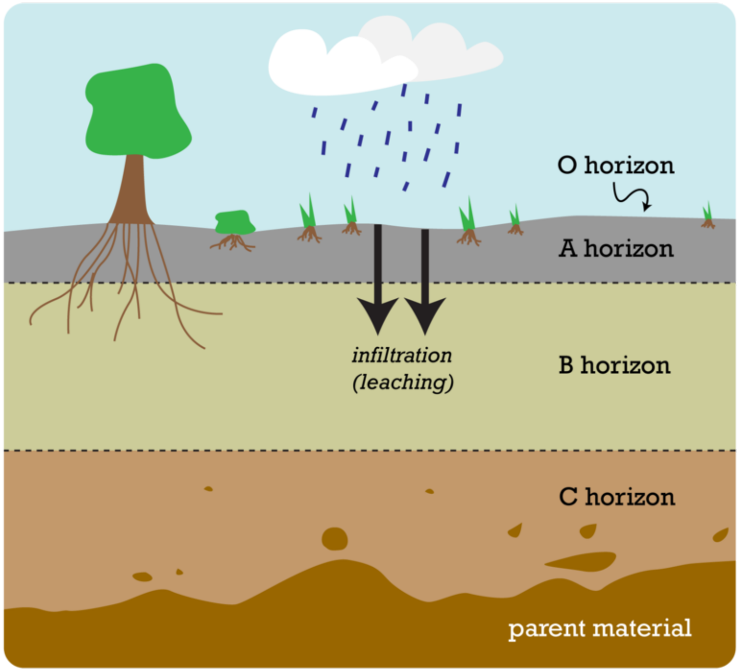

FIGURE 17.9
This image shows the various soil horizons.

These types are based on climate. Just remember that there are many more than just these three types.

Pedalfer

One important type of soil forms in a **deciduous forest**. In these forests, trees lose their leaves each winter. Deciduous trees need lots of rain — at least 65 cm of rainfall per year. Deciduous forests are common in the temperate, eastern United States. The type of soil found in a deciduous forest is a **pedalfer** (**Figure** 17.10). This type of soil is usually dark brown or black in color and very fertile.

FIGURE 17.10
Pedalfer soils support temperate forests, such as in the eastern United States.

Pedocal

Pedocal soil forms where grasses and brush are common (**Figure** 17.11). The climate is drier, with less than 65 cm of rain per year. With less rain, there is less chemical weathering. There is less organic material and the soils are slightly less fertile.

FIGURE 17.11
Grasslands grow on pedocal soils.

Laterite

A third important type of soil is **laterite**. Laterite forms in tropical areas. Temperatures are warm and rain falls every day (**Figure** 17.12). So much rain falls that chemical weathering is intense. All soluble minerals are washed from the soil. Plant nutrients get leached or carried away. There is practically no humus. Laterite soils are often red in color from the iron oxides. If laterites are exposed to the Sun, they bake as hard as a brick.

FIGURE 17.12
The Amazon Rainforest grows on laterite soils.

Soil Conservation

Soil is a renewable resource. But it is only renewable if we take care of it. Natural events can degrade soil. These events include droughts, floods, insect plagues, or diseases that damage soil ecosystems. Human activities can also degrade soil. There are many ways in which people neglect or abuse this important resource.

Harmful Practices

People remove a lot of vegetation. They log forests or prepare the land for farming or construction. Even just walking or riding your bike over the same place can kill the grass. But plants help to hold the soil in place (**Figure** 17.13). Without plants to protect it, soil may be carried away by wind or running water. In many areas, soil is eroding faster than it is forming. In these locations, soil is a non-renewable resource.

FIGURE 17.13
Material that is not held down can blow in the wind. Topsoil is lost this way.

Soils may also remain in place but become degraded. Soil is contaminated if too much salt accumulates. Soil can also be contaminated by pollutants.

Protecting Soil

There are many ways to protect soil. We can add organic material like manure or compost. This increases the soil's fertility. Increased fertility improves the soil's ability to hold water and nutrients. Inorganic fertilizers also increase fertility. These fertilizers are less expensive than natural fertilizers, but they do not provide the same long term benefits.

Careful farming helps to keep up soil quality each season. One way is to plant different crops each year. Another is to alternate the crops planted in each row of the field. These techniques preserve and replenish soil nutrients. Planting nutrient rich cover crops helps the soil. Planting trees as windbreaks, plowing along contours of a field, or building terraces into steeper slopes all help to hold soil in place (**Figure** 17.14). No-till or low-till farming disturbs the ground as little as possible during planting.

FIGURE 17.14
Trees form a windbreak at the edge of these fields.

Lesson Summary

- Soil is an important resource. Life on Earth could not exist as it does today without soil.
- The type of soil that forms depends mostly on climate but to a lesser extent on original parent rock material.
- Soil texture and composition plus the amount of organic material in a soil determine a soil's qualities and fertility.
- Given enough time, existing rock will produce layers within the soil, called a soil profile.
- Ultimately, the climate of a particular region will produce a unique type of soil for that climate.

Lesson Review Questions

Recall

1. What is the role of climate in soil formation?
2. What is the role of the parent rock in the creation of a soil?
3. Compare and contrast residual soils and transported soils.
4. Describe the characteristics of topsoil.

Apply Concepts

5. Describe two ways in which soil is a living resource.
6. Why do people add fertilizers to soil?
7. How does the C-horizon of a residual soil differ from the C-horizon of a transported soil?

Think Critically

8. Where would you choose to buy land for a farm if you wanted fertile soil and did not want to have to irrigate your crops?

Points to Consider

- Why is soil such an important resource?
- Do you think a mature soil would form faster from unaltered bedrock or from transported materials?
- If soil erosion is happening at a greater rate than new soil can form, what will eventually happen to the soil in that region?
- Do you think there are pollutants that could not easily be removed from soil?

17.3 References

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CHAPTER 18 MS Erosion and Deposition

Chapter Outline

This photo shows Horseshoe Bend on the Colorado River as it flows through the Grand Canyon. Notice the trees growing along the river's edge. They look tiny from the top of the canyon. They show how deep the canyon is.

The Colorado River carved this spectacular canyon down through layer upon layer of rock. How can water cut through rock? How did the horseshoe shape form? In this chapter, you'll find answers to questions like these. You'll learn how moving water and other natural forces shape Earth's surface, sometimes in spectacular ways.

18.1 Erosion and Deposition by Flowing Water

Lesson Objectives

- Explain how flowing water causes erosion and deposition.
- Describe how runoff, streams, and rivers change Earth's surface.
- Identify features caused by groundwater erosion and deposition.

Vocabulary

- alluvial fan
- cave
- delta
- deposition
- erosion
- floodplain
- levee
- meander
- oxbow lake
- saltation
- sinkhole
- suspension
- traction

Introduction

Erosion and deposition are responsible for many landforms. **Erosion** is the transport of sediments. Agents of erosion include flowing water, waves, wind, ice, or gravity. Eroded material is eventually dropped somewhere else. This is called **deposition**.

How Flowing Water Causes Erosion and Deposition

Flowing water is a very important agent of erosion. Flowing water can erode rocks and soil. Water dissolves minerals from rocks and carries the ions. This process happens really slowly. But over millions of years, flowing water dissolves massive amounts of rock.

Moving water also picks up and carries particles of soil and rock. The ability to erode is affected by the velocity, or speed, of the water. The size of the eroded particles depends on the velocity of the water. Eventually, the water deposits the materials. As water slows, larger particles are deposited. As the water slows even more, smaller particles are deposited. The graph in **Figure** 18.1 shows how water velocity and particle size influence erosion and deposition.

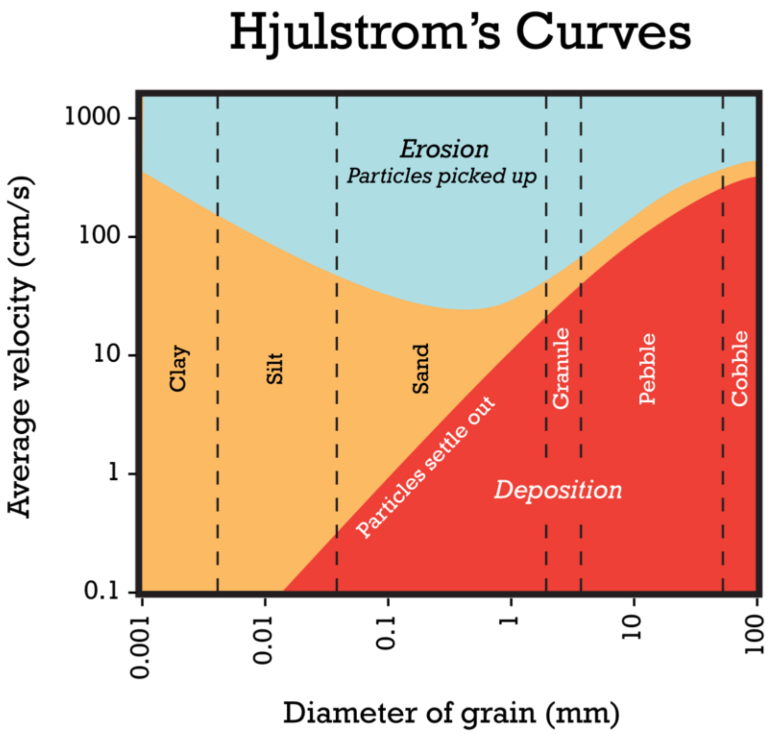

FIGURE 18.1
Flowing water erodes or deposits particles depending on how fast the water is moving and how big the particles are.

Water Speed and Erosion

Faster-moving water has more energy. Therefore, it can carry larger particles. It can carry more particles. What causes water to move faster? The slope of the land over which the water flows is one factor. The steeper the slope, the faster the water flows. Another factor is the amount of water that's in the stream. Streams with a lot of water flow faster than streams that are nearly dry.

Particle Size and Erosion

The size of particles determines how they are carried by flowing water. This is illustrated in **Figure** 18.2.

- Minerals that dissolve in water form salts. The salts are carried in solution. They are mixed thoroughly with the water.
- Small particles, such as clay and silt, are carried in **suspension**. They are mixed throughout the water. These particles are not dissolved in the water.
- Somewhat bigger particles, such as sand, are moved by **saltation**. The particles move in little jumps near the stream bottom. They are nudged along by water and other particles.
- The biggest particles, including gravel and pebbles, are moved by **traction**. In this process, the particles roll or drag along the bottom of the water.

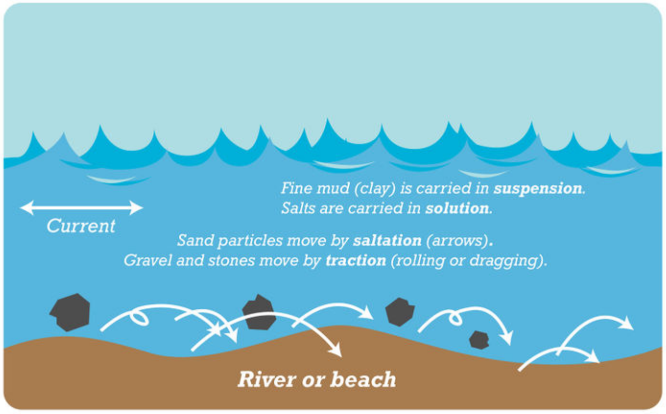

FIGURE 18.2
How Flowing Water Moves Particles. How particles are moved by flowing water depends on their size.

Deposition by Water

Flowing water slows down when it reaches flatter land or flows into a body of still water. What do you think happens then? The water starts dropping the particles it was carrying. As the water slows, it drops the largest particles first. The smallest particles settle out last.

Erosion and Deposition by Surface Water

Water that flows over Earth's surface includes runoff, streams, and rivers. All these types of flowing water can cause erosion and deposition.

Erosion by Runoff

When a lot of rain falls in a short period of time, much of the water is unable to soak into the ground. Instead, it runs over the land. Gravity causes the water to flow from higher to lower ground. As the runoff flows, it may pick up loose material on the surface, such as bits of soil and sand.

Runoff is likely to cause more erosion if the land is bare. Plants help hold the soil in place. The runoff water in **Figure** 18.3 is brown because it eroded soil from a bare, sloping field. Can you find evidence of erosion by runoff where you live? What should you look for?

Much of the material eroded by runoff is carried into bodies of water, such as streams, rivers, ponds, lakes, or oceans. Runoff is an important cause of erosion. That's because it occurs over so much of Earth's surface.

Erosion by Mountain Streams

Streams often start in mountains, where the land is very steep. You can see an example in **Figure** 18.4. A mountain stream flows very quickly because of the steep slope. This causes a lot of erosion and very little deposition. The rapidly falling water digs down into the stream bed and makes it deeper. It carves a narrow, V-shaped channel.

FIGURE 18.3
Erosion by Runoff. Runoff has eroded small channels through this bare field.

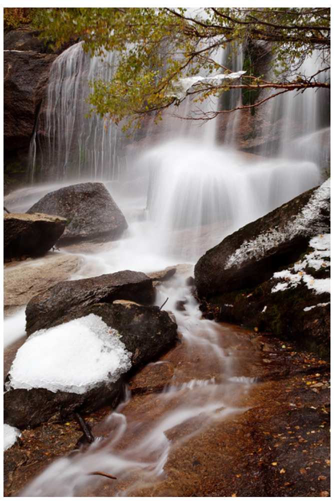

FIGURE 18.4
Mountain Stream. This mountain stream races down a steep slope.

How a Waterfall Forms

Mountain streams may erode waterfalls. As shown in **Figure** 18.5, a waterfall forms where a stream flows from an area of harder to softer rock. The water erodes the softer rock faster than the harder rock. This causes the stream bed to drop down, like a step, creating a waterfall. As erosion continues, the waterfall gradually moves upstream.

Erosion by Slow-Flowing Rivers

Rivers flowing over gentle slopes erode the sides of their channels more than the bottom. Large curves, called **meanders**, form because of erosion and deposition by the moving water. The curves are called meanders because they slowly "wander" over the land. You can see how this happens in **Figure** 18.6.

As meanders erode from side to side, they create a **floodplain**. This is a broad, flat area on both sides of a river. Eventually, a meander may become cut off from the rest of the river. This forms an **oxbow lake**, like the one in **Figure** 18.6.

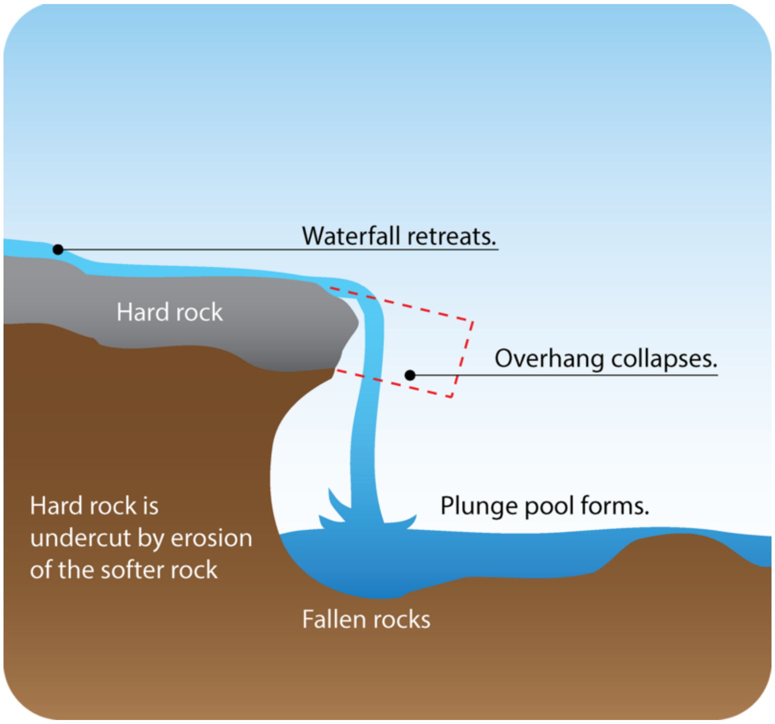

FIGURE 18.5
How a Waterfall Forms and Moves. Why does a waterfall keep moving upstream?

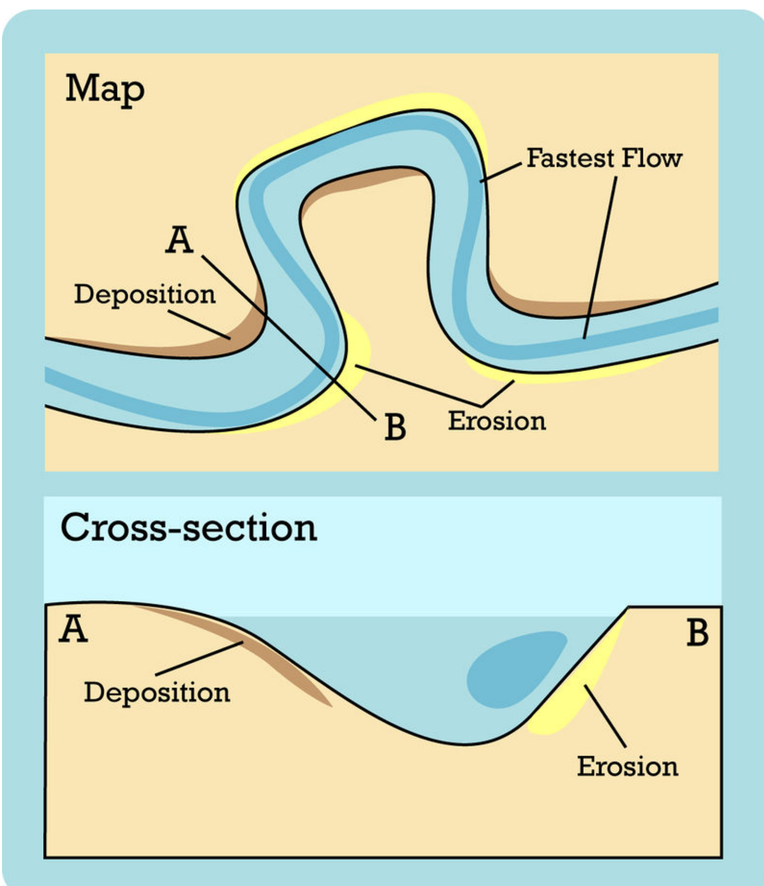

FIGURE 18.6
Meanders form because water erodes the outside of curves and deposits eroded material on the inside. Over time, the curves shift position.

Deposition by Streams and Rivers

When a stream or river slows down, it starts dropping its sediments. Larger sediments are dropped in steep areas, but smaller sediments can still be carried. Smaller sediments are dropped as the slope becomes less steep.

Alluvial Fans

In arid regions, a mountain stream may flow onto flatter land. The stream comes to a stop rapidly. The deposits form an **alluvial fan**, like the one in **Figure** 18.7.

FIGURE 18.7
An alluvial fan in Death Valley, California (left), Nile River Delta in Egypt (right).

Deltas

Deposition also occurs when a stream or river empties into a large body of still water. In this case, a **delta** forms. A delta is shaped like a triangle. It spreads out into the body of water. An example is shown in **Figure** 18.7.

Deposition by Flood Waters

A flood occurs when a river overflows it banks. This might happen because of heavy rains.

Floodplains

As the water spreads out over the land, it slows down and drops its sediment. If a river floods often, the floodplain develops a thick layer of rich soil because of all the deposits. That's why floodplains are usually good places for growing plants. For example, the Nile River in Egypt provides both water and thick sediments for raising crops in the middle of a sandy desert.

Natural Levees

A flooding river often forms natural levees along its banks. A **levee** is a raised strip of sediments deposited close to the water's edge. You can see how levees form in **Figure** 18.8. Levees occur because floodwaters deposit their biggest sediments first when they overflow the river's banks.

Erosion and Deposition by Groundwater

Some water soaks into the ground. It travels down through tiny holes in soil. It seeps through cracks in rock. The water moves slowly, pulled deeper and deeper by gravity. Underground water can also erode and deposit material.

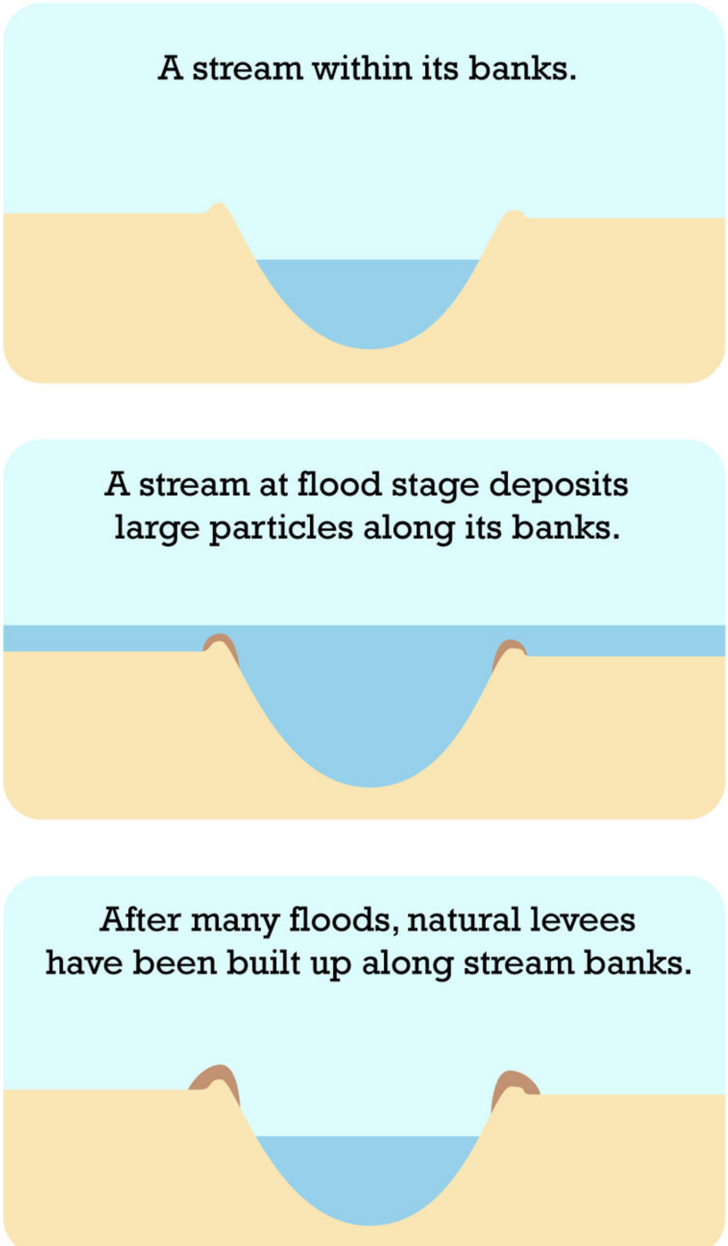

FIGURE 18.8
This diagram shows how a river builds natural levees along its banks.

Caves

As groundwater moves through rock, it dissolves minerals. Some rocks dissolve more easily than others. Over time, the water may dissolve large underground holes, or **caves**. Groundwater drips from the ceiling to the floor of a cave. This water is rich in dissolved minerals. When the minerals come out of solution, they are deposited. They build up on the ceiling of the cave to create formations called stalactites. A stalactite is a pointed, icicle-like mineral deposit that forms on the ceiling of a cave. They drip to the floor of the cave and harden to form stalagmites. A stalagmite is a more rounded mineral deposit that forms on the floor of a cave (**Figure** 18.9). Both types of formations grow in size as water keeps dripping and more minerals are deposited.

FIGURE 18.9
This cave has both stalactites and stalagmites.

Sinkholes

As erosion by groundwater continues, the ceiling of a cave may collapse. The rock and soil above it sink into the ground. This forms a **sinkhole** on the surface. You can see an example of a sinkhole in **Figure** 18.10. Some sinkholes are big enough to swallow vehicles and buildings.

FIGURE 18.10
A sinkhole.

Lesson Summary

- Water flowing over Earth's surface or underground causes erosion and deposition.
- Water flowing over a steeper slope moves faster and causes more erosion.
- How water transports particles depends on their size. When water slows down, it starts depositing sediment,

starting with the largest particles first.
- Runoff erodes the land after a heavy rain. It picks up sediment and carries most of it to bodies of water. Mountain streams erode narrow, V-shaped valleys and waterfalls.
- Erosion and deposition by slow-flowing rivers creates broad floodplains and meanders.
- Deposition by streams and rivers may form alluvial fans and deltas. Floodwaters may deposit natural levees.
- Erosion and deposition by groundwater can form caves and sinkholes. Stalactites and stalagmites are mineral deposits that build up in caves as water continues to drip.

Lesson Review Questions

Recall

1. Define erosion.

2. What is deposition?

3. When does flowing water deposit the sediment it is carrying?

4. What happens to the sediment eroded by runoff?

5. Describe how a waterfall forms?

6. What are meanders?

Apply Concepts

7. Make a table that relates particle size to the way particles are transported by flowing water.

8. Create a sketch that shows effects of groundwater erosion and deposition.

Think Critically

9. Explain why mountain streams erode V-shaped valleys.

10. What might be pros and cons of living on the floodplain of a river?

Points to Consider

Ocean waves are another form of moving water. They also cause erosion and deposition.

- How do waves erode shorelines?
- What landforms are deposited by waves?

18.2 Erosion and Deposition by Waves

Lesson Objectives

- Explain how waves cause erosion of shorelines.
- Describe features formed by wave deposition.
- Identify ways to protect shorelines from wave erosion.

Vocabulary

- barrier island
- breakwater
- groin
- longshore drift
- sandbar
- sea arch
- sea stack
- spit

Introduction

Have you ever stood on a sandy ocean beach and let the waves wash over your feet? If you have, then you probably felt the sand being washed out from under your feet by the outgoing waves. This is an example of wave erosion. What are waves? Why do they cause erosion? And what happens to the sand that waves wash away from the beach?

What Are Waves?

All waves are the way energy travels through matter. Ocean waves are energy traveling through water. They form when wind blows over the surface of the ocean. Wind energy is transferred to the sea surface. Then, the energy is carried through the water by the waves. **Figure** 18.11 shows ocean waves crashing against rocks on a shore. They pound away at the rocks and anything else they strike.

Three factors determine the size of ocean waves:

1. The speed of the wind.
2. The length of time the wind blows.
3. The distance the wind blows.

The faster, longer, and farther the wind blows, the bigger the waves are. Bigger waves have more energy.

FIGURE 18.11
Ocean waves transfer energy from the wind through the water. This gives waves the energy to erode the shore.

Wave Erosion

Runoff, streams, and rivers carry sediment to the oceans. The sediment in ocean water acts like sandpaper. Over time, they erode the shore. The bigger the waves are and the more sediment they carry, the more erosion they cause.

Landforms From Wave Erosion

Erosion by waves can create unique landforms (**Figure** 18.12).

- Wave-cut cliffs form when waves erode a rocky shoreline. They create a vertical wall of exposed rock layers.
- **Sea arches** form when waves erode both sides of a cliff. They create a hole in the cliff.
- **Sea stacks** form when waves erode the top of a sea arch. This leaves behind pillars of rock.

FIGURE 18.12
Over millions of years, wave erosion can create wave-cut cliffs (A), sea arches (B), or sea stacks (C).

Wave Deposition

Eventually, the sediment in ocean water is deposited. Deposition occurs where waves and other ocean motions slow. The smallest particles, such as silt and clay, are deposited away from shore. This is where water is calmer. Larger particles are deposited on the beach. This is where waves and other motions are strongest.

Beaches

In relatively quiet areas along a shore, waves may deposit sand. Sand forms a beach, like the one in **Figure** 18.13. Many beaches include bits of rock and shell. You can see a close-up photo of beach deposits in **Figure** 18.14.

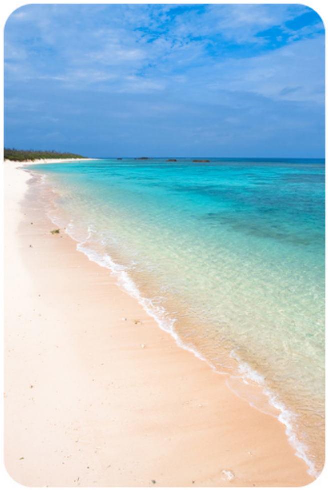

FIGURE 18.13
Sand deposited along a shoreline creates a beach.

FIGURE 18.14
Beach deposits usually consist of small pieces of rock and shell in addition to sand.

Longshore Drift

Most waves strike the shore at an angle. This causes **longshore drift**. Longshore drift moves sediment along the shore. Sediment is moved up the beach by an incoming wave. The wave approaches at an angle to the shore. Water then moves straight offshore. The sediment moves straight down the beach with it. The sediment is again picked up by a wave that is coming in at an angle. This motion is show in **Figure** 18.15 and at the link below.

http://oceanica.cofc.edu/an%20educator'sl%20guide%20to%20folly%20beach/guide/driftanimation.htm

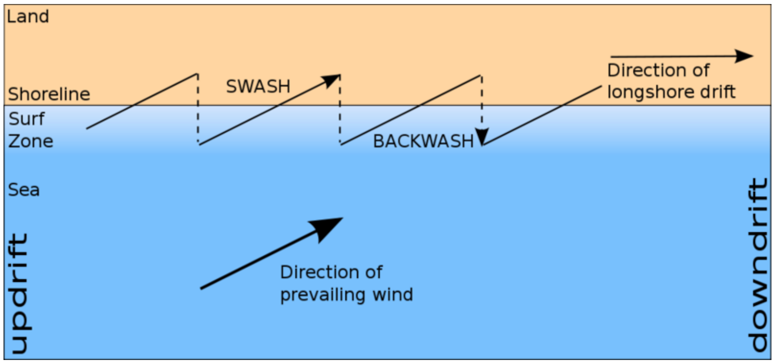

FIGURE 18.15
Longshore drift carries particles of sand and rock down a coastline.

Landforms Deposited by Waves

Deposits from longshore drift may form a spit. A **spit** is a ridge of sand that extends away from the shore. The end of the spit may hook around toward the quieter waters close to shore. You can see a spit in **Figure** 18.16.

FIGURE 18.16
Spit from Space. Farewell Spit in New Zealand is clearly visible from space. This photo was taken by an astronaut orbiting Earth.

Waves may also deposit sediments to form **sandbars** and **barrier islands**. You can see examples of these landforms in **Figure** 18.17.

Protecting Shorelines

Shores are attractive places to live and vacation. But development at the shore is at risk of damage from waves. Wave erosion threatens many homes and beaches on the ocean. This is especially true during storms, when waves may be much larger than normal.

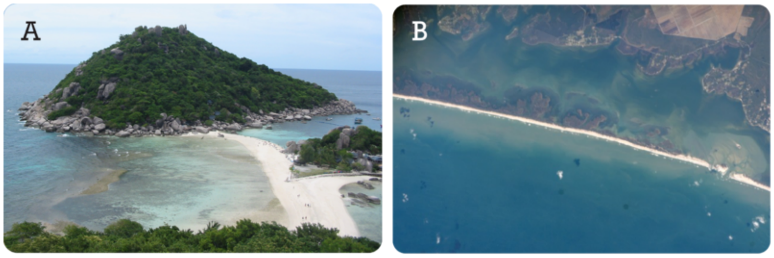

FIGURE 18.17

Wave-Deposited Landforms. These landforms were deposited by waves. (A) Sandbars connect the small islands on this beach on Thailand. (B) A barrier island is a long, narrow island. It forms when sand is deposited by waves parallel to a coast. It develops from a sandbar that has built up enough to break through the water's surface. A barrier island helps protect the coast from wave erosion.

Breakwaters

Barrier islands provide natural protection to shorelines. Storm waves strike the barrier island before they reach the shore. People also build artificial barriers, called **breakwaters**. Breakwaters also protect the shoreline from incoming waves. You can see an example of a breakwater in **Figure** 18.18. It runs parallel to the coast like a barrier island.

FIGURE 18.18

A breakwater is an artificial barrier island. How does it help protect the shoreline?

Groins

Longshore drift can erode the sediment from a beach. To keep this from happening, people may build a series of groins. A **groin** is wall of rocks or concrete that juts out into the ocean perpendicular to the shore. It stops waves from moving right along the beach. This stops the sand on the upcurrent side and reduces beach erosion. You can see how groins work in **Figure** 18.19.

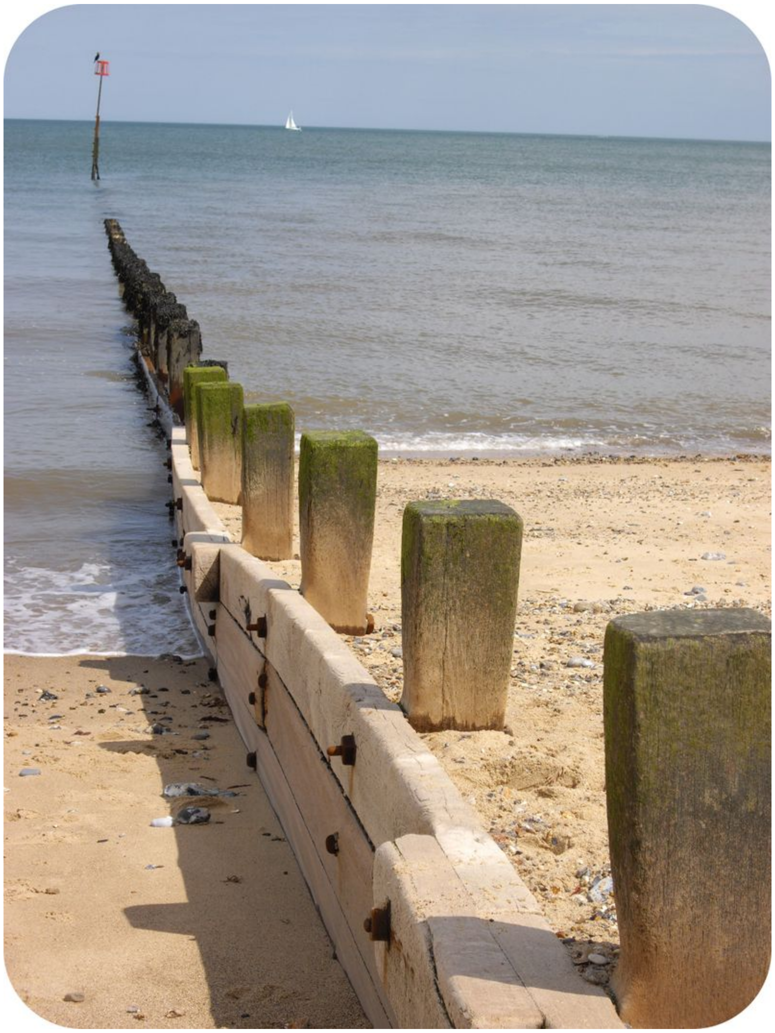

FIGURE 18.19
A groin is built perpendicular to the shoreline. Sand collects on the upcurrent side.

Lesson Summary

- Ocean waves are energy traveling through water. They are caused mainly by wind blowing over the water.
- Sediment in ocean water acts like sandpaper. Over time, it erodes the shore. It can create unique landforms, such as wave-cut cliffs, sea arches, and sea stacks.
- Deposits by waves include beaches. They may shift along the shoreline due to longshore drift. Other wave deposits are spits, sand bars, and barrier islands.
- Breakwaters are structures that protect the coast like barrier islands. Groins are structures that help prevent longshore drift from eroding a beach.

Lesson Review Questions

Recall

1. What are waves?

2. How do ocean waves cause erosion?
3. Identify three types of landforms created by wave erosion.
4. What is a spit? How does it form?

Apply Concepts

5. Create a diagram to illustrate the concept of longshore drift.

Think Critically

6. Why are the smallest particles on a beach usually sand?
7. Explain how a barrier island helps protect the coast from wave erosion.
8. Compare and contrast how breakwaters and groins protect shorelines.

Points to Consider

Moving air, like moving water, causes erosion. Moving air is called wind.

- How does wind cause erosion? Does the wind carry particles in the same ways that moving water does?
- What landforms are deposited by the wind?

18.3 Erosion and Deposition by Wind

Lesson Objectives

- Explain how wind causes erosion.
- Describe sediments deposited by wind.
- Identify ways to prevent wind erosion.

Vocabulary

- loess
- sand dune

Introduction

Wind is only air moving over Earth's surface, but it can cause a lot of erosion. Look at **Figure** 18.20. It will give you an idea of just how much erosion wind can cause. The dust storm in the photo occurred in Arizona. All that dust in the air was picked up and carried by the wind. The wind may carry the dust for hundreds of kilometers before depositing it.

FIGURE 18.20
Dust storm over Arizona desert. Have you ever experienced a dust storm like this one?

Wind Erosion

Dust storms like the one in **Figure** 18.20 are more common in dry climates. The soil is dried out and dusty. Plants may be few and far between. Dry, bare soil is more easily blown away by the wind than wetter soil or soil held in place by plant roots.

How the Wind Moves Particles

Like flowing water, wind picks up and transports particles. Wind carries particles of different sizes in the same ways that water carries them. You can see this in **Figure** 18.21.

- Tiny particles, such as clay and silt, move by suspension. They hang in the air, sometimes for days. They may be carried great distances and rise high above the ground.
- Larger particles, such as sand, move by saltation. The wind blows them in short hops. They stay close to the ground.
- Particles larger than sand move by traction. The wind rolls or pushes them over the surface. They stay on the ground.

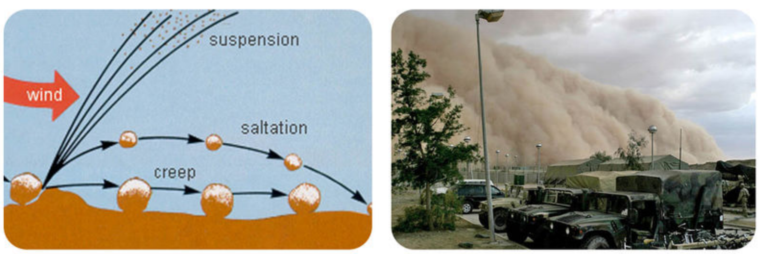

FIGURE 18.21
Wind transports particles in different ways depending on their size (left). A dust storm in the Middle East (right).

Abrasion

Did you ever see workers sandblasting a building to clean it? Sand is blown onto the surface to scour away dirt and debris. Wind-blown sand has the same effect. It scours and polishes rocks and other surfaces. Wind-blown sand may carve rocks into interesting shapes. You can see an example in **Figure** 18.22. This form of erosion is called abrasion. It occurs any time rough sediments are blown or dragged over surfaces. Can you think of other ways abrasion might occur?

Wind Deposition

Like water, when wind slows down it drops the sediment it's carrying. This often happens when the wind has to move over or around an obstacle. A rock or tree may cause wind to slow down. As the wind slows, it deposits the largest particles first. Different types of deposits form depending on the size of the particles deposited.

Deposition of Sand

When the wind deposits sand, it forms small hills of sand. These hills are called **sand dunes**. For sand dunes to form, there must be plenty of sand and wind. Sand dunes are found mainly in deserts and on beaches. You can see

FIGURE 18.22
Sand blown by fierce winds have carved this rock in to an interesting shape.

examples of sand dunes in **Figure** 18.23.

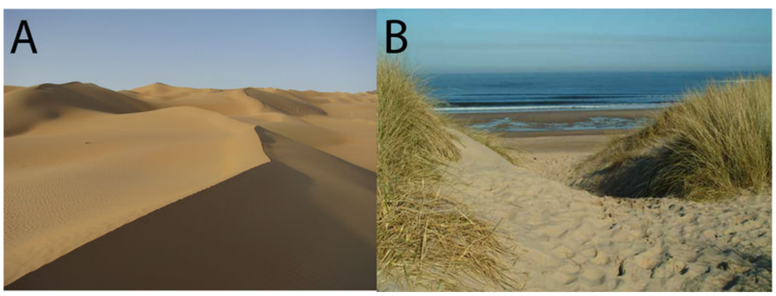

FIGURE 18.23
Sand dunes form where the wind deposits sand. (A) Desert sand dunes. (B) Sand dunes line many beaches like this one in Australia.

How Sand Dunes Form

What causes a sand dune to form? It starts with an obstacle, such as a rock. The obstacle causes the wind to slow down. The wind then drops some of its sand. As more sand is deposited, the dune gets bigger. The dune becomes the obstacle that slows the wind and causes it to drop its sand. The hill takes on the typical shape of a sand dune, shown in **Figure** 18.24.

FIGURE 18.24
A sand dune has a gentle slope on the side the wind blows from. The opposite side has a steep slope. This side is called the slip face.

Migration of Sand Dunes

Once a sand dune forms, it may slowly migrate over the land. The wind moves grains of sand up the gently sloping side of the dune. This is done by saltation. When the sand grains reach the top of the dune, they slip down the steeper side. The grains are pulled by gravity. The constant movement of sand up and over the dune causes the dune to move along the ground. It always moves in the same direction that the wind usually blows. Can you explain why?

Loess

When the wind drops fine particles of silt and clay, it forms deposits called **loess**. Loess deposits form vertical cliffs. Loess can become a thick, rich soil. That's why loess deposits are used for farming in many parts of the world. You can see an example of loess in **Figure** 18.25.

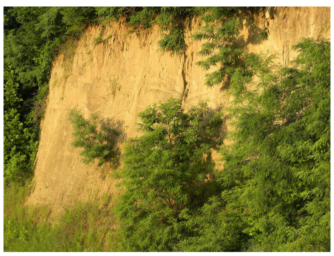

FIGURE 18.25

Loess cliffs in Mississippi.

Preventing Wind Erosion

It's very important to control wind erosion of soil. Good soil is a precious resource that takes a long time to form. Covering soil with plants is one way to reduce wind erosion. Plants and their roots help hold the soil in place. They also help the soil retain water so it is less likely to blow away.

Planting rows of trees around fields is another way to reduce wind erosion. The trees slow down the wind, so it doesn't cause as much erosion. Fences like the one in **Figure** 18.26 serve the same purpose. The fence in the figure is preventing erosion and migration of sand dunes on a beach.

Lesson Summary

- Dry, bare soil is more likely to be eroded by the wind than moist soil or soil covered with plants. How wind carries particles depends on their size. The sediment in wind causes erosion by abrasion.
- Sand dunes form when the wind deposits sand. Loess form when the wind deposits clay and silt.
- Wind erosion can be prevented by keeping the ground covered with plants. They help hold the soil in place. Rows of trees and fences can help by slowing the wind.

FIGURE 18.26
Protecting Sand Dunes from Wind Erosion. Many beaches uses fences like this one to reduce wind erosion of sand. If plants start growing on the dunes, they help hold the sand in place.

Lesson Review Questions

Recall

1. How does the wind carry particles of sand?
2. What is abrasion?
3. What are sand dunes? Where are they found?
4. Describe loess.
5. Identify two ways to reduce wind erosion.

Apply Concepts

6. Wind-blown snow forms drifts that are similar to sand dunes. Apply lesson concepts to infer how you could reduce snowdrifts in a driveway.

Think Critically

7. Compare and contrast how the wind transports clay, sand, and pebbles.
8. Explain why a sand dune migrates.

Points to Consider

Abrasion is the main way that wind causes erosion. The next lesson explains how glaciers cause erosion.

- How do you think glaciers cause erosion?
- Do you think glaciers might erode by abrasion, like the wind?

18.4 Erosion and Deposition by Glaciers

Lesson Objectives

- Describe how continental and valley glaciers form.
- Explain how glaciers cause erosion.
- Identify landforms deposited by glaciers.

Vocabulary

- continental glacier
- glacial till
- glacier
- moraine
- plucking
- valley glacier

Introduction

Glaciers are masses of flowing ice. Today, they cover only about 10 percent of Earth's surface. They are getting smaller and smaller as Earth's temperature rises. But just 12,000 years ago, glaciers dipped as far south as Chicago and New York City. Much of Europe was also covered with glaciers at that time.

Glaciers erode and leave behind telltale landforms. These landforms are like clues. They show the direction a glacier flowed and how far it advanced. Did glaciers leave clues where you live? Would you know what to look for?

How Glaciers Form

Glaciers form when more snow falls than melts each year. Over many years, layer upon layer of snow compacts and turns to ice. There are two different types of glaciers: continental glaciers and valley glaciers. Each type forms some unique features through erosion and deposition. An example of each type is pictured in **Figure** 18.27.

- A **continental glacier** is spread out over a huge area. It may cover most of a continent. Today, continental glaciers cover most of Greenland and Antarctica. In the past, they were much more extensive.
- A **valley glacier** is long and narrow. Valley glaciers form in mountains and flow downhill through mountain river valleys.

FIGURE 18.27
(A) The continent of Antarctica is covered with a continental glacier. (B) A valley glacier in the Canadian Rockies. (C) The surface of a valley glacier.

Erosion by Glaciers

Like flowing water, flowing ice erodes the land and deposits the material elsewhere. Glaciers cause erosion in two main ways: plucking and abrasion.

- **Plucking** is the process by which rocks and other sediments are picked up by a glacier. They freeze to the bottom of the glacier and are carried away by the flowing ice.
- Abrasion is the process in which a glacier scrapes underlying rock. The sediments and rocks frozen in the ice at the bottom and sides of a glacier act like sandpaper. They wear away rock. They may also leave scratches and grooves that show the direction the glacier moved.

Erosion by Valley Glaciers

Valley glaciers form several unique features through erosion. You can see some of them in **Figure** 18.28.

- As a valley glacier flows through a V-shaped river valley, it scrapes away the sides of the valley. It carves a U-shaped valley with nearly vertical walls. A line called the trimline shows the highest level the glacier reached.
- A cirque is a rounded hollow carved in the side of a mountain by a glacier. The highest cliff of a cirque is called the headwall.
- An arête is a jagged ridge that remains when cirques form on opposite sides of a mountain. A low spot in an arête is called a col.
- A horn is a sharp peak that is left behind when glacial cirques are on at least three sides of a mountain.

FIGURE 18.28
Features Eroded by Valley Glaciers. Erosion by valley glaciers forms the unique features shown here.

Deposition by Glaciers

Glaciers deposit their sediment when they melt. They drop and leave behind whatever was once frozen in their ice. It's usually a mixture of particles and rocks of all sizes, called **glacial till**. Water from the melting ice may form lakes or other water features. **Figure** 18.29 shows some of the landforms glaciers deposit when they melt.

- **Moraine** is sediment deposited by a glacier. A ground moraine is a thick layer of sediments left behind by a retreating glacier. An end moraine is a low ridge of sediments deposited at the end of the glacier. It marks the greatest distance the glacier advanced.
- A drumlin is a long, low hill of sediments deposited by a glacier. Drumlins often occur in groups called drumlin fields. The narrow end of each drumlin points in the direction the glacier was moving when it dropped the sediments.
- An esker is a winding ridge of sand deposited by a stream of meltwater. Such streams flow underneath a retreating glacier.
- A kettle lake occurs where a chunk of ice was left behind in the sediments of a retreating glacier. When the ice melted, it left a depression. The meltwater filled it to form a lake.

Lesson Summary

- Glaciers are masses of flowing ice. Continental glaciers are huge. They may spread out over much of a continent. Valley glaciers are long and narrow. They form in mountains and flow through mountain river valleys.

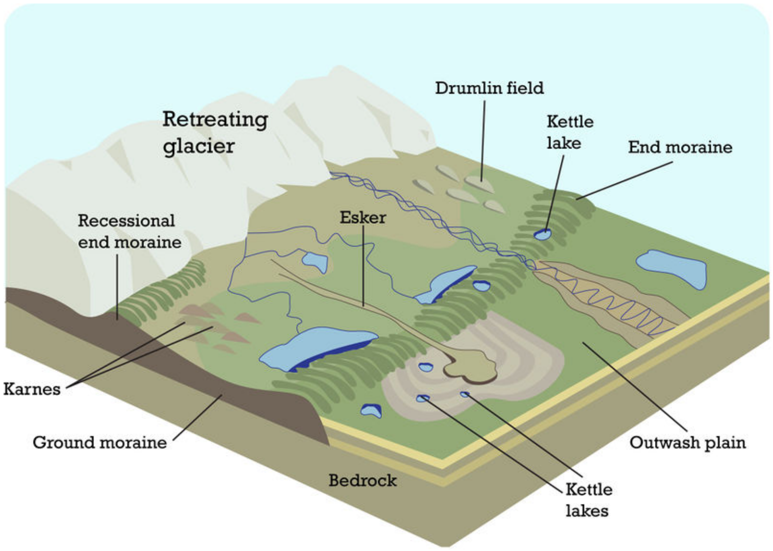

FIGURE 18.29
Take a look at the glacial deposits. How far did the glacier in the diagram advance before it started retreating?

- Glaciers cause erosion by plucking and abrasion. Valley glaciers form several unique features through erosion, including cirques, arêtes, and horns.
- Glaciers deposit their sediment when they melt. Landforms deposited by glaciers include drumlins, kettle lakes, and eskers.

Lesson Review Questions

Recall

1. What is a glacier?
2. Describe how glaciers form.
3. Identify the two main ways glaciers cause erosion.
4. Name and describe three unique features eroded by valley glaciers.
5. What is glacial till?

Apply Concepts

6. Create a lesson to teach younger students how a kettle lake forms. Outline your lesson.

Think Critically

7. Compare and contrast valley and continental glaciers and how they change Earth's surface.
8. Areas once covered by glaciers may have large boulders called erratics, like the one in the photo below. Infer why erratics typically consist of a different type of rock than the bedrock where they are found.

Points to Consider

So far in this chapter, you've read how moving water, air, and ice shape Earth's surface. Water and ice move because of gravity.

- Do you think gravity can erode and deposit sediment without the help of water or ice?
- How might gravity alone shape Earth's surface?

18.5 Erosion and Deposition by Gravity

Lesson Objectives

- Identify causes and effects of landslides and mudslides.
- Explain how slump and creep occur.

Vocabulary

- creep
- landslide
- mass movement
- mudslide
- slump

Introduction

Gravity is responsible for erosion by flowing water and glaciers. That's because gravity pulls water and ice downhill. These are ways gravity causes erosion indirectly. But gravity also causes erosion directly. Gravity can pull soil, mud, and rocks down cliffs and hillsides. This type of erosion and deposition is called **mass movement**. It may happen suddenly. Or it may occur very slowly, over many years.

Landslides and Mudslides

The most destructive types of mass movement are landslides and mudslides. Both occur suddenly.

Landslides

A **landslide** happens when a large amount of soil and rock suddenly falls down a slope because of gravity. You can see an example in **Figure** 18.30. A landslide can be very destructive. It may bury or carry away entire villages.

A landslide is more likely if the soil has become wet from heavy rains. The wet soil becomes slippery and heavy. Earthquakes often trigger landslides. The shaking ground causes soil and rocks to break loose and start sliding. If a landslide flows into a body of water, it may cause a huge wave called a tsunami.

FIGURE 18.30
This 2001 landslide in El Salvador (Central America) was started by an earthquake. Soil and rocks flowed down a hillside and swallowed up houses in the city below.

Mudslides

A **mudslide** is the sudden flow of mud down a slope because of gravity. Mudslides occur where the soil is mostly clay. Like landslides, mudslides usually occur when the soil is wet. Wet clay forms very slippery mud that slides easily. You can see an example of a mudslide in **Figure** 18.31.

FIGURE 18.31
Mudslide. A mudslide engulfs whatever is in its path.

Other Types of Mass Movement

Two other types of mass movement are slump and creep. Both may move a lot of soil and rock. However, they usually aren't as destructive as landslides and mudslides.

Slump

Slump is the sudden movement of large blocks of rock and soil down a slope. You can see how it happens in **Figure** 18.32. All the material moves together in big chunks. Slump may be caused by a layer of slippery, wet clay underneath the rock and soil on a hillside. Or it may occur when a river undercuts a slope. Slump leaves behind crescent-shaped scars on the hillside.

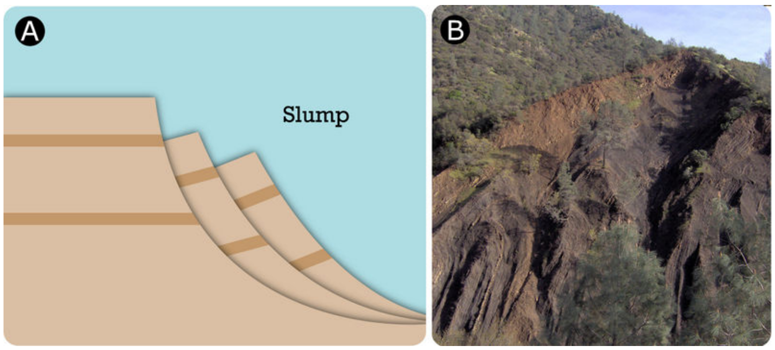

FIGURE 18.32
Slump takes place suddenly, like a landslide. How does slump differ from a landslide?

Creep

Creep is the very slow movement of rock and soil down a hillside. Creep occurs so slowly you can't see it happening. You can only see the effects of creep after years of movement. This is illustrated in **Figure** 18.33. The slowly moving ground causes trees, fence posts, and other structures on the surface to tilt downhill.

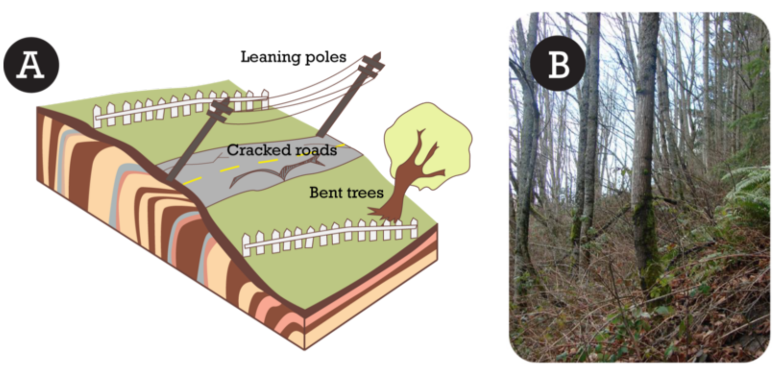

FIGURE 18.33
Creep is seen on a hillside. What evidence shows creep has occurred?

Creep usually takes place where the ground freezes and thaws frequently. Soil and rock particles are lifted up when the ground freezes. When the ground thaws, the particles settle down again. Each time they settle down, they move a tiny bit farther down the slope because of gravity.

Lesson Summary

- Gravity can pull soil, mud, and rocks down cliffs and hillsides. This is called mass movement. The most destructive types of mass movement are landslides and mudslides. They occur suddenly and without warming. They engulf everything in their path.

- Two other types of mass movement are slump and creep. They usually aren't as destructive as landslides and mudslides. Slump is the sudden movement of large blocks of rock and soil down a slope. Creep is the very slow movement of rock and soil down a slope. It causes trees, fence posts, and other structures to tilt downhill.

Lesson Review Questions

Recall

1. Define mass movement.
2. List four types of mass movement.
3. What is a landslide?
4. What factors increase the chances of landslides occurring?
5. What type of soil forms mudslides?

Apply Concepts

6. Assume you are riding in a car down a road or street. Suddenly, you see evidence of creep. Describe it.

Think Critically

7. Relate earthquakes to mass movement.
8. Compare and contrast slump and creep.

Points to Consider

Erosion and deposition are always changing Earth's surface.

- Do you think that the same forces that cause erosion today —moving water, wind, ice, and gravity —were also at work in the past?
- How might observations of erosion and deposition today help us understand Earth's history?

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CHAPTER 19 MS Earth's Fresh Water

Chapter Outline

If you think of freshwater on Earth's surface, lakes and rivers might come to mind. But most of Earth's freshwater is frozen. Much of it occurs in glaciers, like the one pictured here. This massive sheet of ice is Portage Glacier in Alaska. It contains a huge amount of frozen water.

Where else is frozen water found on Earth? Besides solid ice, in what other states does Earth's freshwater exist? And how does water change from one state to another? This chapter answers these and many other questions about Earth's freshwater.

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19.1 Water on Earth

Lesson Objectives

- Describe water and where it occurs on Earth.
- Give an overview of the water cycle.

Vocabulary

- condensation
- evaporation
- freshwater
- infiltration
- precipitation
- runoff
- transpiration
- water
- water cycle

Introduction

Water is all around you —in pipes, in puddles, even in people. Water covers more than 70 percent of Earth's surface. That's a good thing, because all life on Earth depends on water. In fact, without water, life as we know it could not exist. Water is a very special substance. Do you know why?

What Is Water?

Water is a simple chemical compound. Each molecule of water contains two hydrogen atoms (H_2) and one oxygen atom (O). That's why the chemical formula for water is H_2O.

If water is so simple, why is it special? Water is one of the few substances that exists on Earth in all three states of matter. Water occurs as a gas, a liquid and a solid. You drink liquid water and use it to shower. You breathe gaseous water vapor in the air. You may go ice skating on a pond covered with solid water —ice —in the winter.

Where Is Earth's Freshwater?

Earth is often called the "water planet." **Figure** 19.1 shows why. If astronauts see Earth from space, this is how it looks. Notice how blue the planet appears. That's because oceans cover much of Earth's surface. Water is also found in the clouds that rise above the planet.

FIGURE 19.1
Take a look at this image. Do you think that Earth deserves the name "water planet"?

Most of Earth's water is salt water in the oceans. As **Figure** 19.2 shows, only 3 percent of Earth's water is fresh. **Freshwater** is water that contains little or no dissolved salt. Most freshwater is frozen in ice caps and glaciers. Glaciers cover the peaks of some tall mountains. For example, the Cascades Mountains in North America and the Alps Mountains in Europe are capped with ice. Ice caps cover vast areas of Antarctica and Greenland. Chunks of ice frequently break off ice caps. They form icebergs that float in the oceans.

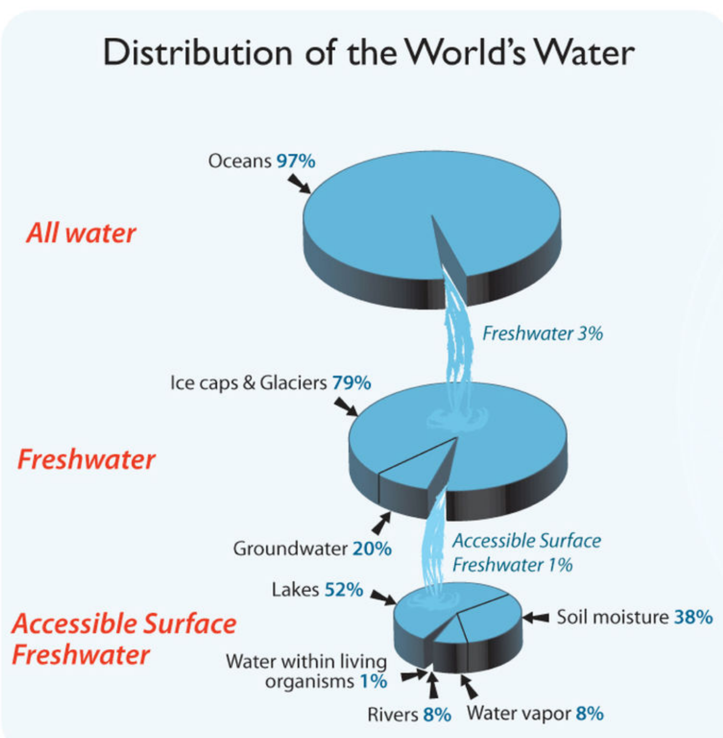


FIGURE 19.2
What percentage of Earth's surface freshwater is water vapor in the air?

Only a tiny fraction of Earth's freshwater is in the liquid state. Most liquid freshwater is under the ground in layers of rock. Of freshwater on the surface, the majority occurs in lakes and soil. What percentage of freshwater on the surface is found in living things?

The Water Cycle

Did you ever wonder where the water in your glass came from or where it's been? The next time you take a drink of water, think about this. Each water molecule has probably been around for billions of years. That's because Earth's water is constantly recycled.

How Water Is Recycled

Water is recycled through the water cycle. The **water cycle** is the movement of water through the oceans, atmosphere, land, and living things. The water cycle is powered by energy from the Sun. **Figure** 19.3 diagrams the water cycle.

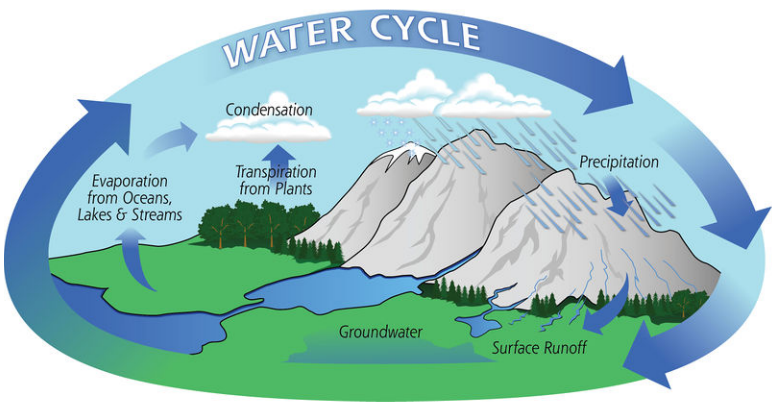


FIGURE 19.3
The water cycle has no beginning or end. Water just keeps moving along.

Processes in the Water Cycle

Water keeps changing state as it goes through the water cycle. This means that it can be a solid, liquid, or gas. How does water change state? How does it keep moving through the cycle? As **Figure** 19.3 shows, several processes are involved.

- **Evaporation** changes liquid water to water vapor. Energy from the Sun causes water to evaporate. Most evaporation is from the oceans because they cover so much area. The water vapor rises into the atmosphere.
- **Transpiration** is like evaporation because it changes liquid water to water vapor. In transpiration, plants release water vapor through their leaves. This water vapor rises into the atmosphere.
- **Condensation** changes water vapor to liquid water. As air rises higher into the atmosphere, it cools. Cool air can hold less water vapor than warm air. So some of the water vapor condenses into water droplets. Water droplets may form clouds.
- **Precipitation** is water that falls from clouds to Earth's surface. Water droplets in clouds fall to Earth when they become too large to stay aloft. The water falls as rain if the air is warm. If the air is cold, the water may freeze and fall as snow, sleet, or hail. Most precipitation falls into the oceans. Some falls on land.

- **Runoff** is precipitation that flows over the surface of the land. This water may travel to a river, lake, or ocean. Runoff may pick up fertilizer and other pollutants and deliver them to the water body where it ends up. In this way, runoff may pollute bodies of water.
- **Infiltration** is the process by which water soaks into the ground. Some of the water may seep deep underground. Some may stay in the soil, where plants can absorb it with their roots.

In all these ways, water keeps cycling. The water cycle repeats over and over again. Who knows? Maybe a water molecule that you drink today once quenched the thirst of a dinosaur.

Lesson Summary

- Water is a simple chemical compound. It exists on Earth in all three states of matter: liquid, gas, and solid. As a gas, water is called water vapor. As a solid, water is called ice.
- Oceans of salt water cover much of Earth's surface. Freshwater is water that contains little or no salt. Most of Earth's freshwater is frozen in ice caps and glaciers.
- Earth's water is constantly recycled through the water cycle. Water keeps changing state as it goes through the cycle. The water cycle includes processes such as evaporation, condensation, and precipitation.

Lesson Review Questions

Recall

1. What is freshwater?

2. Where is most of Earth's freshwater found?

3. What process changes water from a liquid to a gas? From a gas to a liquid?

4. Define infiltration and runoff.

Apply Concepts

5. Describe the substance known as water.

6. Why does most precipitation fall into the oceans?

Think Critically

7. Apply lesson concepts to explain how a forest fire might affect the water cycle.

8. Explain why this statement is true: "The water you drink today may once have quenched the thirst of a dinosaur."

9. How does the Sun drive the water cycle? What would happen to the water cycle if the Sun decreased its intensity by half?

Points to Consider

As water moves through the water cycle, it spends some time on Earth's surface as freshwater.

- Where is freshwater found on Earth's surface?
- How do people use freshwater on Earth's surface?

19.2 Surface Water

Lesson Objectives

- Identify features of streams and rivers.
- Describe ponds and lakes and how they form.
- Explain why wetlands are important.
- State how floods occur.

Vocabulary

- flood
- lake
- pond
- river
- stream
- wetland

Introduction

Only a very small percentage of Earth's water is fresh, liquid water on the surface. But that tiny fraction of water is vital. It is needed by humans, plants, and many other living things. Liquid freshwater flows over Earth's surface in streams and rivers. It also forms ponds, lakes, and wetlands. People use freshwater for drinking, washing, and industry. They also use it for fun. How do you use freshwater for fun?

Streams and Rivers

Look at the pictures of flowing water in **Figure** 19.4. A waterfall tumbles down a mountainside. A brook babbles through a forest. A river slowly meanders through a broad valley. What do all these forms of flowing water have in common? They are all streams.

What Are Streams and Rivers?

A **stream** is a body of freshwater that flows downhill in a channel. The channel of a stream has a bottom, or bed, and sides called banks. Any size body of flowing water can be called a stream. Usually, though, a large stream is called a **river**.

FIGURE 19.4
All these forms of flowing water are streams.

Features of Streams and Rivers

All streams and rivers have several features in common. These features are shown in (**Figure** 19.5). The place where a stream or river starts is its source. The source might be a spring, where water flows out of the ground. Or the source might be water from melting snow on a mountain top. A single stream may have multiple sources. A stream or river probably ends when it flows into a body of water, such as a lake or an ocean. A stream ends at its mouth. As the water flows into the body of water, it slows down and drops the sediment it was carrying. The sediment may build up to form a delta.

Several other features of streams and rivers are also shown in **Figure** 19.5.

- Small streams often flow into bigger streams or rivers. The small streams are called tributaries. A river and all its tributaries make up a river system.
- At certain times of year, a stream or river may overflow its banks. The area of land that is flooded is called the floodplain. The floodplain may be very wide where the river flows over a nearly flat surface.
- A river flowing over a floodplain may wear away broad curves. These curves are called meanders.

River Basins and Divides

All of the land drained by a river system is called its basin, or watershed. One river system's basin is separated from another river system's basin by a divide. The divide is created by the highest points between the two river basins. Precipitation that falls within a river basin always flows toward that river. Precipitation that falls on the other side of the divide flows toward a different river.

Figure 19.6 shows the major river basins in the U.S. You can watch an animation of water flowing through a river basin at this link: http://trashfree.org/btw/graphics/watershed_anim.gif

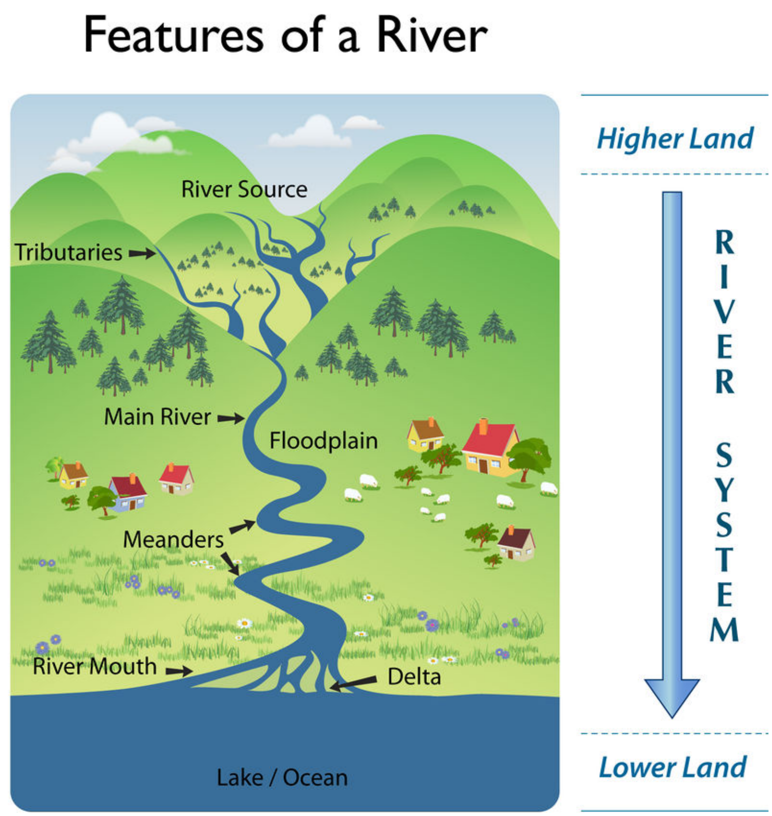


FIGURE 19.5
Water in a stream flows along the ground from higher to lower elevation. What force causes the water to keep flowing?

FIGURE 19.6
River basins in the U.S.

Ponds and Lakes

After a heavy rain, you may find puddles of water standing in low spots. The same principle explains why water collects in ponds and lakes. Water travels downhill, so a depression in the ground fills with standing water. A **pond** is a small body of standing water. A **lake** is a large body of standing water. Most lakes have freshwater, but a few are salty. The Great Salt Lake in Utah is an example of a saltwater lake.

The water in a large lake may be so deep that sunlight cannot penetrate all the way to the bottom. Without sunlight, water plants and algae cannot live on the bottom of the lake. That's because plants need sunlight for photosynthesis.

The largest lakes in the world are the Great Lakes. They lie between the U.S. and Canada, as shown in **Figure** 19.7. How great are they? They hold 22 percent of all the world's fresh surface water!

FIGURE 19.7
The Great Lakes of North America get their name from their great size.

Water in Ponds and Lakes

Ponds and lakes may get their water from several sources. Some falls directly into them as precipitation. Some enters as runoff and some from streams and rivers. Water leaves ponds and lakes through evaporation and also as outflow.

How Lakes Form

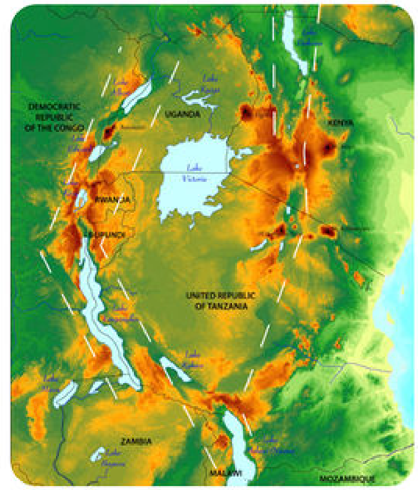
The depression that allows water to collect to form a lake may come about in a variety of ways. The Great Lakes, for example, are glacial lakes. A glacial lake forms when a glacier scrapes a large hole in the ground. When the glacier melts, the water fills the hole and forms a lake. Over time, water enters the lake from the sources mentioned above as well.

Other lakes are crater lakes or rift lakes, which are pictured in **Figure** 19.8. Crater lakes form when volcanic eruptions create craters that fill with water. Rift lakes form when movements of tectonic plates create low places that fill with water.

Wetlands

Some of Earth's freshwater is found in wetlands. A **wetland** is an area that is covered with water, or at least has very soggy soil, during all or part of the year. Certain species of plants thrive in wetlands, and they are rich ecosystems. Freshwater wetlands are usually found at the edges of steams, rivers, ponds, or lakes. Wetlands can also be found at the edges of seas.

This Russian lake formed in the crater created by a volcano.



The dotted white lines on this map mark the rift between tectonic plates in East Africa. Fault movements created depressions that filled with water. This formed many rift lakes, from Lake Malawi in the south to Lake Turkana in the north.

FIGURE 19.8

Craters and rifts become lakes when they fill with water. Where does the water come from?

Types of Freshwater Wetlands

Not all wetlands are alike, as you can see from **Figure** 19.9. Wetlands vary in how wet they are and how much of the year they are soaked. Wetlands also vary in the kinds of plants that live in them. This depends mostly on the climate where the wetland is found. Types of wetlands include marshes, swamps, and bogs.

- A marsh is a wetland that is usually under water. It has grassy plants, such as cattails.
- A swamp is a wetland that may or may not be covered with water but is always soggy. It has shrubs or trees.
- A bog is a wetland that has soggy soil. It is generally covered with mosses.

Importance of Wetlands

People used to think that wetlands were useless. Many wetlands were filled in with rocks and soil to create lands that were then developed with roads, golf courses, and buildings. Now we know that wetlands are very important. Laws have been passed to help protect them. Why are wetlands so important?

- Wetlands have great biodiversity. They provide homes or breeding sites to a huge variety of species. Because so much wetland area has been lost, many of these species are endangered.
- Wetlands purify water. They filter sediments and toxins from runoff before it enters rivers, lakes, and oceans.
- Wetlands slow rushing water. During hurricanes and other extreme weather, wetlands reduce the risk of floods.

Although the rate has slowed, wetlands are still being destroyed today.

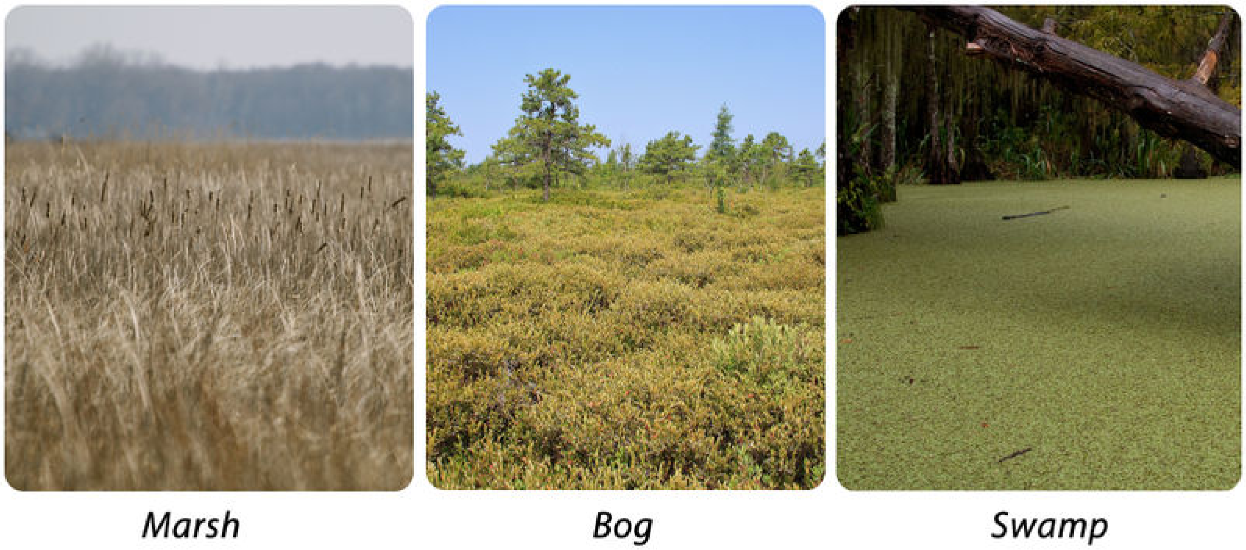


FIGURE 19.9
These are just three of many types of wetlands.

Floods

A **flood** occurs when so much water enters a stream or river that it overflows its banks. Flood waters from a river are shown in **Figure** 19.10. Like this flood, many floods are caused by very heavy rains. Floods may also occur when deep snow melts quickly in the spring.

FIGURE 19.10
A river in Indiana floods after very heavy rains. Some areas received almost a foot of rain in less than 24 hours!

Floods are a natural part of the water cycle, but they can cause a lot of damage. Farms and homes may be lost, and people may die. In 1939, millions of people died in a flood in China. Although freshwater is needed to grow crops and just to live, too much freshwater in the same place at once can be deadly.

Lesson Summary

- A stream is a body of water that flows downhill in a channel. A large stream is usually called a river.
- Standing freshwater forms ponds and lakes. Lakes are generally bigger than ponds. Lakes may form in several different ways.
- A wetland is an area that is wet for all or part of the year. Wetlands are home to certain types of plants.
- Wetlands are very important. They have great biodiversity. They purify water. They slow down rushing water and help prevent floods.
- Floods occur when so much water enters a stream or river that it overflows its banks. Floods may be caused by heavy rains or melting snow. They can cause a lot of damage and loss of life.

Lesson Review Questions

Recall

1. What are the source and mouth of a river?

2. Define tributary and river system.

3. How may water enter a pond or lake?

4. What is a wetland?

5. List three reasons why wetlands should be protected.

Apply Concepts

6. For each stream pictured in **Figure** 19.4, explain where it might be located on the map in **Figure** 19.5.

Think Critically

7. The Nile River in Egypt empties into the Mediterranean Sea. At the mouth of the river, there is a very large delta. Explain how the delta formed.

8. Compare and contrast glacial, crater, and rift lakes.

Points to Consider

- In the desert, water runs in channels after a storm. The channels are dry otherwise. Is this a stream?
- It may seem hard to believe, but most of Earth's freshwater is under our feet. It is stored below the surface of the ground.
  - How do you think water gets under the ground?
  - What happens to water after it goes under the ground? Is it trapped there forever?

19.3 Groundwater

Lesson Objectives

- Explain how water enters an aquifer.
- Explain how water leaves an aquifer.
- Define aquifer, and give an example.
- Define springs and geysers.
- State the purpose of wells and how they work.

Vocabulary

- aquifer
- groundwater
- spring
- water table
- well

Introduction

Rivers and lakes hold a lot of Earth's liquid freshwater. However, far more is hidden from sight. Where is it? It is stored under the ground. In fact, 20 times more of Earth's liquid freshwater is found below the surface than on the surface.

Groundwater

Freshwater below Earth's surface is called **groundwater**. The water infiltrates, or seeps down into, the ground from the surface. How does this happen? And where does the water go?

Porous and Impermeable Rock

Water infiltrates the ground because soil and rock are porous. Between the grains are pores, or tiny holes. Since water can move through this rock it is permeable. Eventually, the water reaches a layer of rock that is not porous and so is impermeable. Water stops moving downward when it reaches this layer of rock.

Look at the diagram in **Figure** 19.11. It shows two layers of porous rock. The top layer is not saturated; it is not full of water. The next layer is saturated. The water in this layer has nowhere else to go. It cannot seep any deeper into the ground because the rock below it is impermeable.

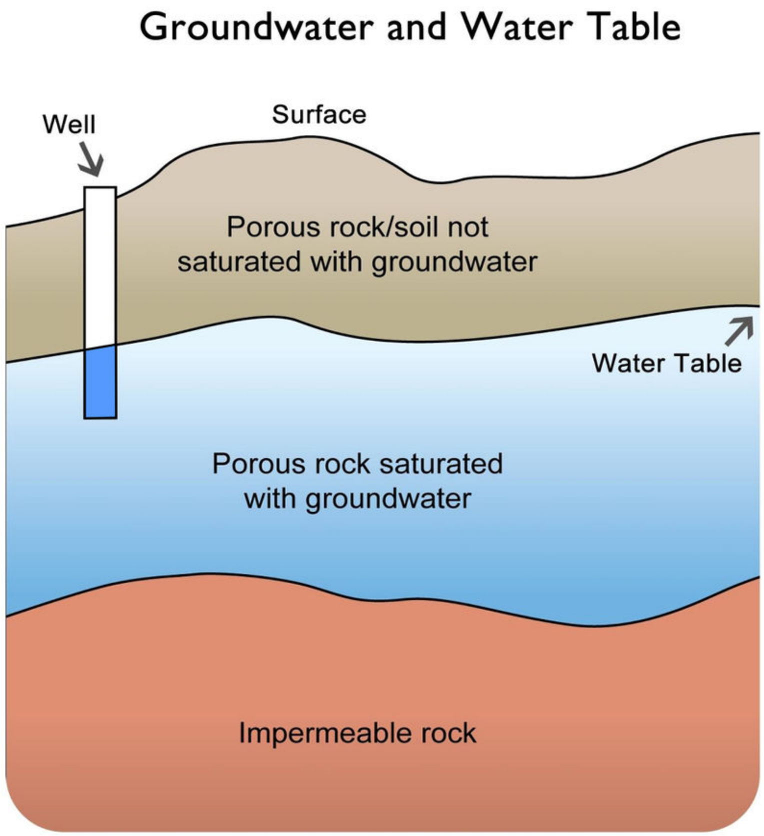


FIGURE 19.11
Water seeps into the ground through permeable material and stops when it reaches an impermeable rock. Predict the purpose of the well in the diagram.

The Water Table

The top of the saturated rock layer in **Figure** 19.11 is called the **water table**. The water table isn't like a real table. It doesn't remain firmly in one place. Instead, it rises or falls, depending on how much water seeps down from the surface. The water table is higher when there is a lot of rain and lower when the weather is dry.

Aquifer

An underground layer of rock that is saturated with groundwater is called an **aquifer**. A diagram of an aquifer is shown in **Figure** 19.12. Aquifers are generally found in porous rock, such as sandstone. Water infiltrates the aquifer from the surface. The water that enters the aquifer is called recharge.

Human Use of Aquifers

Most land areas have aquifers beneath them. Many aquifers are used by people for freshwater. The closer to the surface an aquifer is, the easier it is to get the water. However, an aquifer close to the surface is also more likely to become polluted. Pollutants can seep down through porous rock in recharge water.

An aquifer that is used by people may not be recharged as quickly as its water is removed. The water table may lower and the aquifer may even run dry. If this happens, the ground above the aquifer may sink. This is likely to damage any homes or other structures built above the aquifer.

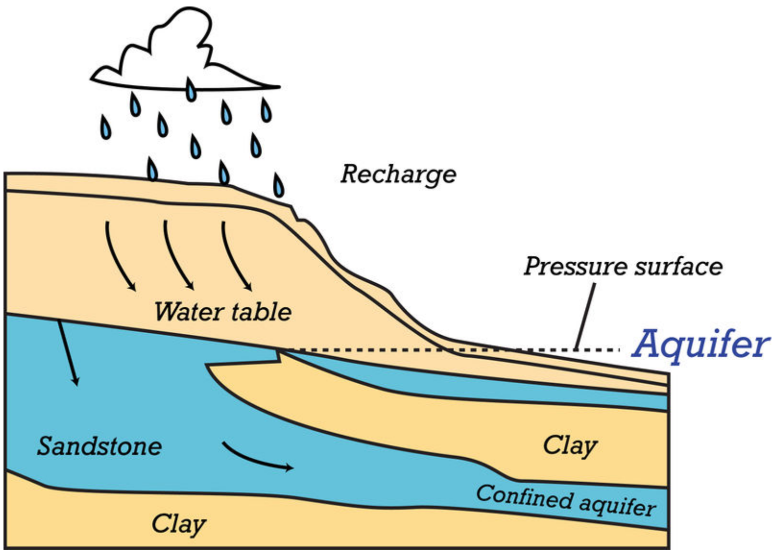


FIGURE 19.12
An aquifer is a layer of saturated porous rock. It lies below the water table. An impermeable layer, such as clay, is below the aquifer.

The Ogallala Aquifer

One of the biggest aquifers in the world is the Ogallala aquifer. As you can see from **Figure** 19.13, this aquifer lies beneath parts of eight U.S. states. It covers a total area of 451,000 square kilometers (174,000 square miles). In some places, it is less than a meter deep. In other places, it is hundreds of meters deep.

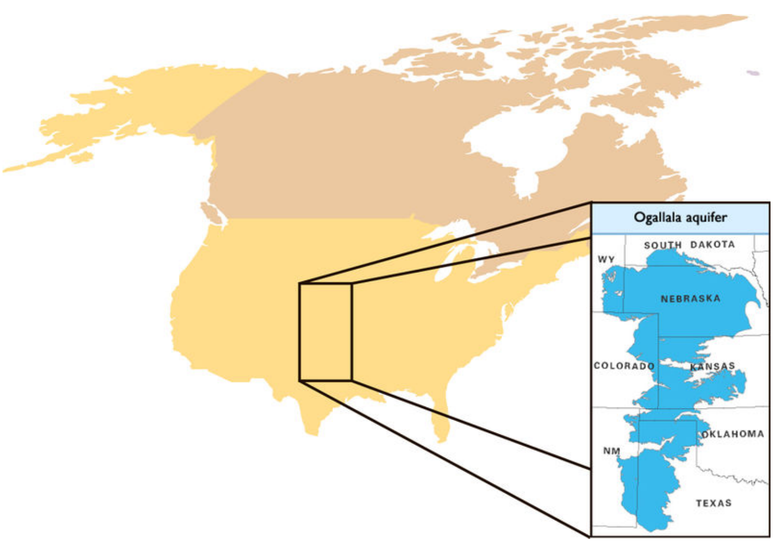


FIGURE 19.13
In this map, the area over the Ogallala aquifer is shaded in blue.

The Ogallala aquifer is an important source of freshwater in the American Midwest. This is a major farming area, and much of the water is used to irrigate crops. The water in this aquifer is being used up ten times faster than it is recharged. If this continues, what might happen to the Ogallala aquifer?

Springs and Geysers

The top of an aquifer may be high enough in some places to meet the surface of the ground. This often happens on a slope. The water flows out of the ground and creates a **spring**. A spring may be just a tiny trickle, or it may be a big gush of water. One of the largest springs in the world is Big Spring in Missouri, seen in **Figure** 19.14.

FIGURE 19.14
Big Spring is named for its large size. It releases more than 12,000 liters of water per second!

Water flowing out of the ground at a spring may flow downhill and enter a stream. That's what happens to the water that flows out of Big Spring in Missouri. If the water from a spring can't flow downhill, it may spread out to form a pond or lake instead. Lake George in New York State, which is pictured in **Figure** 19.15, is a spring-fed lake. The lake basin was carved by a glacier.

FIGURE 19.15
Lake George gets its water from a number of springs.

Mineral Springs and Hot Springs

Some springs have water that contains minerals. Groundwater dissolves minerals out of the rock as it seeps through the pores. The water in some springs is hot because it is heated by hot magma. Many hot springs are also mineral springs. That's because hot water can dissolve more minerals than cold water. Grand Prismatic Spring, shown in **Figure** 19.16, is a hot mineral spring. Dissolved minerals give its water a bright blue color. The edge of the spring is covered with thick orange mats of bacteria. The bacteria use the minerals in the hot water to make food.

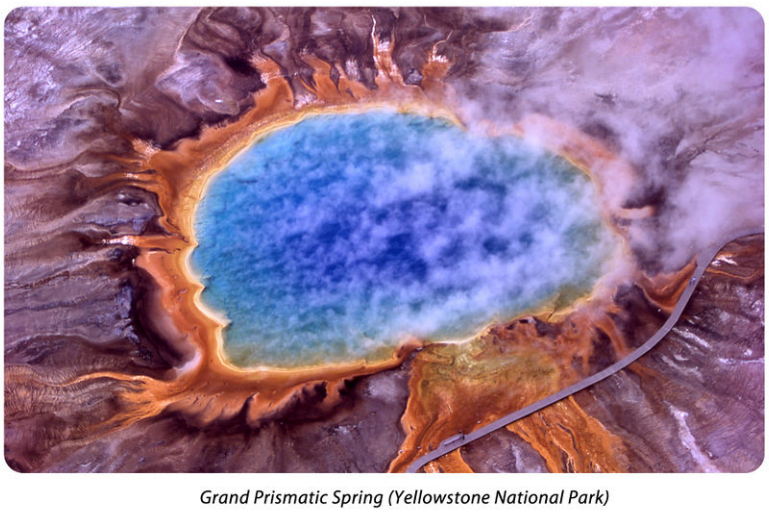


FIGURE 19.16
Grand Prismatic Spring in the Yellowstone National Park is the largest hot spring in the U.S. How can you tell from the photo that the water in this spring is hot?

Geysers

Heated groundwater may become trapped in spaces within rocks. Pressure builds up as more water seeps into the spaces. When the pressure becomes great enough, the water bursts out of the ground at a crack or weak spot. This is called a **geyser**. When the water erupts from the ground, the pressure is released. Then more water collects and the pressure builds up again. This leads to another eruption.

Old Faithful is the best-known geyser in the world. You can see a picture of it in **Figure** 19.17. The geyser erupts faithfully every 90 minutes, day after day. During each eruption, it may release as much as 30,000 liters of water!

FIGURE 19.17
Old Faithful in Yellowstone National Park is a geyser named for its regular cycle of eruptions.

Wells

Most groundwater does not flow out of an aquifer as a spring or geyser. So to use the water that's stored in an aquifer people must go after it. How? They dig a well. A **well** is a hole that is dug or drilled through the ground down to an aquifer. This is illustrated in **Figure** 19.18.

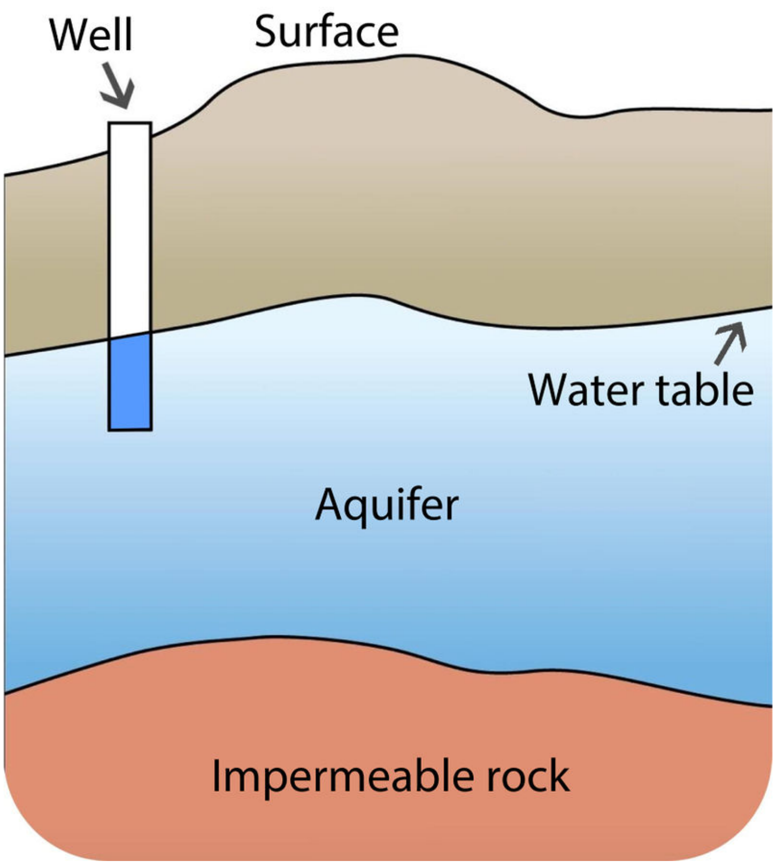


FIGURE 19.18
A well runs from the surface to a point below the water table. Why must a well go lower than the water table?

People have depended on water from wells for thousands of years. To bring water to the surface takes energy because the force of gravity must be overcome. Today, many wells use electricity to pump water to the surface. However, in some places, water is still brought to the surface the old-fashioned way — with human labor. The well pictured in **Figure** 19.19 is an example of this type of well. A hand-cranked pulley is used to lift the bucket of water to the surface.

Lesson Summary

- Groundwater is freshwater below Earth's surface. It seeps down from the surface through pores in soil and rock. It keeps seeping downward until it reaches a layer of impermeable rock.
- An aquifer is an underground layer of rock that is saturated with groundwater. One of the biggest aquifers in the world is the Ogallala aquifer in the American Midwest.

FIGURE 19.19
This old water well uses human muscle power to bring water to the surface.

- Water that flows out of the ground where an aquifer meets the surface is called a spring. Spring water may contain dissolved minerals. It may also be heated by magma in the crust. Heated groundwater that erupts from the ground under pressure is called a geyser.
- Many people get their freshwater from an aquifer. They obtain the water through a well. A well is a hole that is dug or drilled through the ground down to an aquifer.

Lesson Review Questions

Recall

1. Define groundwater.
2. Describe how water enters the ground.
3. What is the water table? What might cause it to rise or fall?
4. Define aquifer. Where does an aquifer get its water?
5. What is the purpose of a well?

Apply Concepts

6. Assume you live in a town that gets its water from an aquifer. The aquifer lies beneath the town. Apply lesson concepts to predict what may happen if water is pumped out of the aquifer faster than it is recharged. Then, write a letter to the editor of the town's newspaper. State what you think may happen. Argue for the need to use water wisely.

Think Critically

7. Compare and contrast springs and geysers.

8. LaShawna and her family went to Yellowstone National Park. They saw a spring called Green Dragon Spring. Steam was rising off the water. When LaShawna saw the steam, she said that the water must contain a lot of minerals. Do you agree with LaShawna's statement? Why or why not?

Points to Consider

Freshwater is needed by many living things on Earth. However, most of Earth's water is not fresh. Instead, it is salt water in the oceans.

- What do you know about Earth's oceans? For example, how deep are they? And why is their water salty?
- Ocean water moves in waves, tides, and currents. Do you know what causes these ocean water movements?

19.4 References

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