Perry Heights Science FlexBook Grade 8 by Ms. Lori Young

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CHAPTER 1 The World of Science

Chapter Outline

1.1 WHAT IS SCIENCE?

1.2 THE SCOPE OF PHYSICAL SCIENCE

1.3 REFERENCES

Have you ever experienced the thrill of an exciting fireworks display like this one? Fireworks were invented about 2000 years ago in China. But it wasn't until much later that people understood the science behind the technology.

Do you know why fireworks explode? Do you know what causes the brilliant bursts of light and the deep rumbling booms? In this FlexBook® digital resource, you'll find out the "hows" and "whys" of many things in the physical world around you—from the chemical reactions that cause fireworks to the waves of energy that travel through space from the sun.

Ghengis Fireworks (www.ghengisfireworks.com). www.flickr.com/photos/ghengisfireworks/9710103655/. CC BY 2.0.

1.1 What Is Science?

Lesson Objectives

- Define science.
- Explain how scientists use induction.
- Distinguish between scientific theories and laws.
- Describe milestones in the history of science.
- Identify contributions of women and minorities to science.

Lesson Vocabulary

- induction
- science
- scientific law
- scientific theory

Introduction

Understanding the "hows" and "whys" of the world is the goal of science. The term science comes from a Latin word that means "having knowledge." But science is as much about adding to knowledge as it is about having knowledge. Science is a way of thinking as well as a set of facts. **Science** can be defined as a way of learning about the natural world that is based on evidence and logic.

Thinking Like a Scientist

Are you like the teen in **Figure** 1.1? Do you ever wonder why things happen? Do you like to find out how things work? If so, then you are already thinking like a scientist. Scientists also wonder how and why things happen. They are curious about the world. To answer their questions, they make many observations. Then they use logic to draw general conclusions.

Induction

Drawing general conclusions from many individual observations is called **induction**. It is a hallmark of scientific thinking. To understand how induction works, think about this simple example. Assume you know nothing about gravity. In fact, pretend you've never even heard of gravity. Perhaps you notice that whenever you let go of an object it falls to the ground. For example, you drop a book, and it crashes to the floor. Your pencil rolls to the edge of the

FIGURE 1.1
Like a scientist, this teen wonders about how and why things happen. What do you wonder about?

desk and down it goes. You throw a ball into the air, and it falls back down. Based on many such observations (**Figure** 1.2), you conclude that all objects fall to the ground.

FIGURE 1.2
From skydivers in the air to kids on a playground slide, whatever goes up always comes back down. Or does it?

Now assume that someone gives you your first-ever helium balloon. You discover that it rises up into the air if you don't hold on to it. Based on this new observation, do you throw out your first idea about falling objects? No; you decide to observe more helium balloons and try to find other objects that fall up instead of down. Eventually, you come to a better understanding based on all your observations. You conclude that objects heavier than air fall to the ground but objects lighter than air do not. Your new conclusion is better because it applies to a wider range of observations. You can learn more about induction, including its limits, by watching the video at this link: http://www.youtube.com/watch?v=E1TpZ_HbK3M (5:39).

MEDIA
Click image to the left for use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5002

How Science Advances

The above example shows how science generally advances. New evidence is usually used to improve earlier ideas rather than entirely replace them. In this way, scientists gradually refine their ideas and increase our understanding of the world. On the other hand, sometimes science advances in big leaps. This has happened when a scientist came up with a completely new way of looking at things. For example, Albert Einstein came up with a new view of gravity. He said it was really just a dent in the fabric of space and time.

Different conclusions can be drawn from the same observations, and it's not possible to tell which one is correct. For example, based on observations of the sun moving across the sky, people in the past couldn't tell whether the sun orbits Earth or Earth orbits the sun. Both models of the solar system are pictured in **Figure** 1.3. It wasn't until strong telescopes were invented that people could make observations that let them choose the correct idea. Not sure which idea is correct? You can learn more by watching the student-created video at this link: http://www.youtube.com/watch?v=JcqdUq16S28 .

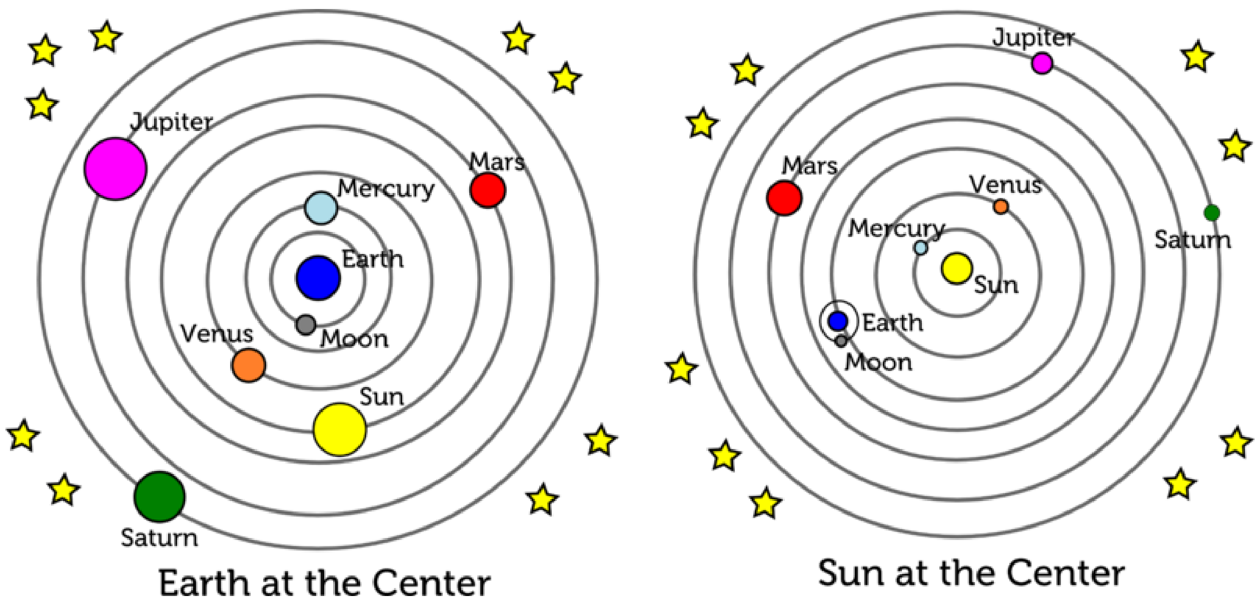


FIGURE 1.3

Both of these models could explain why the sun appears to move across the sky each day. Other observations were needed to decide which model is correct.

Theories and Laws

Some ideas in science gain the status of theories. Scientists use the term "theory" differently than it is used in everyday language. You might say, "I think the dog ate my homework, but it's just a theory." In other words, it's just one of many possible explanations for the missing work. However, in science, a theory is much more than that.

Scientific Theories

A **scientific theory** is a broad explanation that is widely accepted because it is supported by a great deal of evidence. An example is the kinetic theory of matter. According to this theory, all matter consists of tiny particles that are in constant motion. Particles move at different speeds in matter in different states. You can see this in **Figure** 1.4 and at the following URL: http://preparatorychemistry.com/Bishop_KMT_frames.htm . Particles in solids move the least; particles in gases move the most. These differences in particle motion explain why solids, liquids, and gases look and act differently. Think about how ice and water differ, or how water vapor differs from liquid water. The kinetic theory of matter explains the differences. You can learn more about this theory in the chapter *States of Matter*.

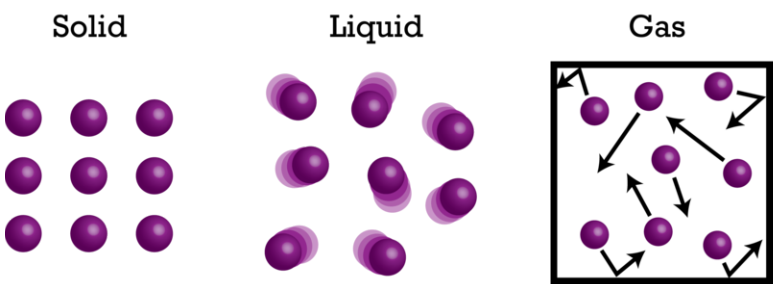


FIGURE 1.4
Why do you think particles move differently in different states of matter? (*Hint*: What causes ice to melt?)

Scientific Laws

Scientific laws are often confused with scientific theories, but they are not the same thing. A **scientific law** is a statement describing what always happens under certain conditions in nature. It answers "how" questions but not "why" questions. An example of a scientific law is Newton's law of gravity. It describes how all objects attract each other. It states that the force of attraction is greater for objects that are closer together or have more mass. However, the law of gravity doesn't explain why objects attract each other in this way. Einstein's theory of general relativity explains why. You can learn more about Newton's law of gravity and Einstein's theory in the chapter *Forces*, and at the following link: http://www.youtube.com/watch?v=O-p8yZYxNGc .

History of Science

People have wondered about the natural world for as long as there have been people. So it's no surprise that modern science has roots that go back thousands of years. The **Table** 1.1 describes just a few milestones in the history of science. A much more detailed timeline is available at the link below. Often, new ideas were not accepted at first because they conflicted with accepted views of the world. A good example is Copernicus' idea that the sun is the center of the solar system. This idea was rejected at first because people firmly believed that Earth was the center of the solar system and the sun moved around it.

http://www.sciencetimeline.net/

TABLE 1.1: Timeline of Scientific Discovery

Date	Scientific Discovery

TABLE 1.1: (continued)

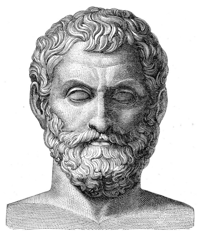
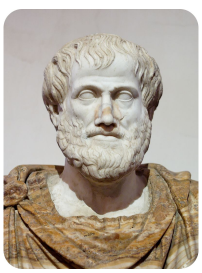
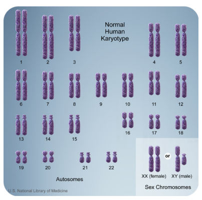
Date	Scientific Discovery
3500 BC  *Mesopotamian calendar*	Several ancient civilizations studied astronomy. They recorded their observations of the movements of stars, the sun, and the moon. We still use the calendar developed by the Mesopotamians about 5500 years ago. It is based on cycles of the moon.
600 BC  *Thales*	The ancient Greek philosopher Thales proposed that natural events, such as lightning and earthquakes, have natural causes. Up until then, people blamed such events on gods or other supernatural causes. Thales has been called the "father of science" for his ideas about the natural world.
350 BC  *Aristotle*	The Greek philosopher Aristotle argued that truth about the natural world can be discovered through observation and induction. This idea is called empiricism. Aristotle's empiricism laid the foundation for the methods of modern science.
400 AD to 1000 AD  *Early Chinese Seismograph*	When Europe went through the Dark Ages, European science withered. However, in other places, science still flourished. For example: • In North Africa, the scientist Alhazen studied light. He used experiments to test competing theories about light. • In China, scientists invented compasses. They also invented seismographs to measure earthquakes. They studied astronomy as well.

TABLE 1.1: (continued)

Date	Scientific Discovery
Mid-1500s to late 1600s  *Galileo*	The Scientific Revolution occurred in Europe. This was the beginning of modern Western science. Many scientific advances were made during this time. • Copernicus proposed that the sun, not Earth, is the center of the solar system. • Galileo improved the telescope and made important discoveries in astronomy. He discovered evidence that supported Copernicus' theory. • Newton proposed the law of gravity.
2001  *Human Chromosomes*	Many scientists around the world worked together to complete the genetic sequence of human chromosomes. This amazing feat will help scientists understand, and perhaps someday cure, genetic diseases.

Women and People of Color in Science

Throughout history, women and people of color have rarely had the same chances as white males for education and careers in science. But they have still made important contributions to science. The **Table** 1.2 gives just a few examples of their contributions to physical science. More contributions are described at these links:

- http://www.inventions.org/culture/science/women/index.html
- http://www1.umn.edu/ships/gender/giese.htm
- https://webfiles.uci.edu/mcbrown/display/faces.html
- http://library.thinkquest.org/20117/

TABLE 1.2: A diversity of people has contributed to physical science.

Contributor	Description
Marie Curie (1867-1934) 	Marie Curie was the first woman to win a Nobel Prize. She won the 1903 Nobel Prize in physics for the discovery of radiation. She won the 1911 Nobel Prize in chemistry for discovering the elements radium and polonium.

TABLE 1.2: (continued)

Contributor	Description
Lise Meitner (1878-1968) 	Lise Meitner was one of the scientists who discovered nuclear fission. This is the process that creates enormous amounts of energy in nuclear power plants.
Irene Joliot-Curie (1897–1956) 	Irene Joliot-Curie, daughter of Marie Curie, won the 1935 Nobel prize in chemistry, along with her husband, for the synthesis of new radioactive elements.
Maria Goeppert-Mayer (1906–1972) 	Maria Goeppert-Mayer was a co-winner of the 1963 Nobel prize in physics for discoveries about the structure of the nucleus of the atom.
Ada E. Yonath (1939–present) 	Ada E. Yonath was a co-winner of the 2009 Nobel prize in chemistry. She made important discoveries about ribosomes, the structures in living cells where proteins are made.

TABLE 1.2: (continued)

Contributor	Description
Shirley Ann Jackson (1946-present) 	Shirley Ann Jackson earned a doctoral degree in physics. She became the chair of the US Nuclear Regulatory Commission.
Ellen Ochoa (1958-present) 	Ellen Ochoa is an inventor, research scientist, and NASA astronaut. She has flown several space missions.

Lesson Summary

- Science is a way of learning about the natural world that is based on evidence and logic. The hallmark of scientific thinking is induction.
- A scientific theory is a broad explanation that is widely accepted because it is supported by a great deal of evidence. A scientific law is a statement describing what always happens under certain conditions in nature.
- Modern science has roots that go back thousands of years. Diverse people from around the world have contributed to the evolution of science.
- Women and minorities have rarely had the same chances in science as white males, but they still have made important contributions.

Lesson Review Questions

Recall

1. Define science.
2. What is induction?
3. State the contributions of Thales and Aristotle to the evolution of science.
4. What was the Scientific Revolution?

Apply Concepts

5. Use induction to draw a logical conclusion based on **Table** 1.3.

TABLE 1.3: Freezing Point of Substances

Substance	Temperature at Freezing (°C)
Pure water (1 cup water)	0
Salt water (1 cup water + 5 grams table salt)	-4
Sugar water (1 cup water + 6 grams sugar)	-5

6. What observation would require you to revise your conclusion in question 5?

Think Critically

7. Compare and contrast scientific theories and scientific laws. Give an example of each.

Points to Consider

Most of the scientists mentioned in this lesson are physical scientists.

- Based on their work, what do you think is the subject matter of physical science?
- What are some questions that physical scientists might investigate?

1.2 The Scope of Physical Science

Lesson Objectives

- Define physical science.
- Explain the relevance of physical science to everyday life.
- Describe examples of careers in physical science.

Lesson Vocabulary

- chemistry
- physical science
- physics

Introduction

Physical science covers a lot of territory. It's easier to describe by what it is not than by what it is. Basically, it's all science that is not life science.

Defining Physical Science

Physical science can be defined as the study of matter and energy. Matter refers to all the "stuff" that exists in the universe. It includes everything you can see and many things that you cannot see, including the air around you. Energy is what gives matter the ability to move and change. Energy can take many forms, such as electricity, heat, and light. Physical science can be divided into chemistry and physics. Chemistry focuses on matter and energy at the scale of atoms and molecules. Physics focuses on matter and energy at all scales, from atoms to outer space.

Chemistry

Chemistry is the study of the structure, properties, and interactions of matter. Important concepts in chemistry include physical changes, such as water freezing, and chemical reactions, such as fireworks exploding. Chemistry concepts can answer all the questions on the left page of the notebook in **Figure** 1.5. Do you know the answers?

Physics

Physics is the study of energy and how it interacts with matter. Important concepts in physics include motion, forces such as magnetism and gravity, and different forms of energy. Physics concepts can answer all the questions on the right page of the notebook in **Figure** 1.5.

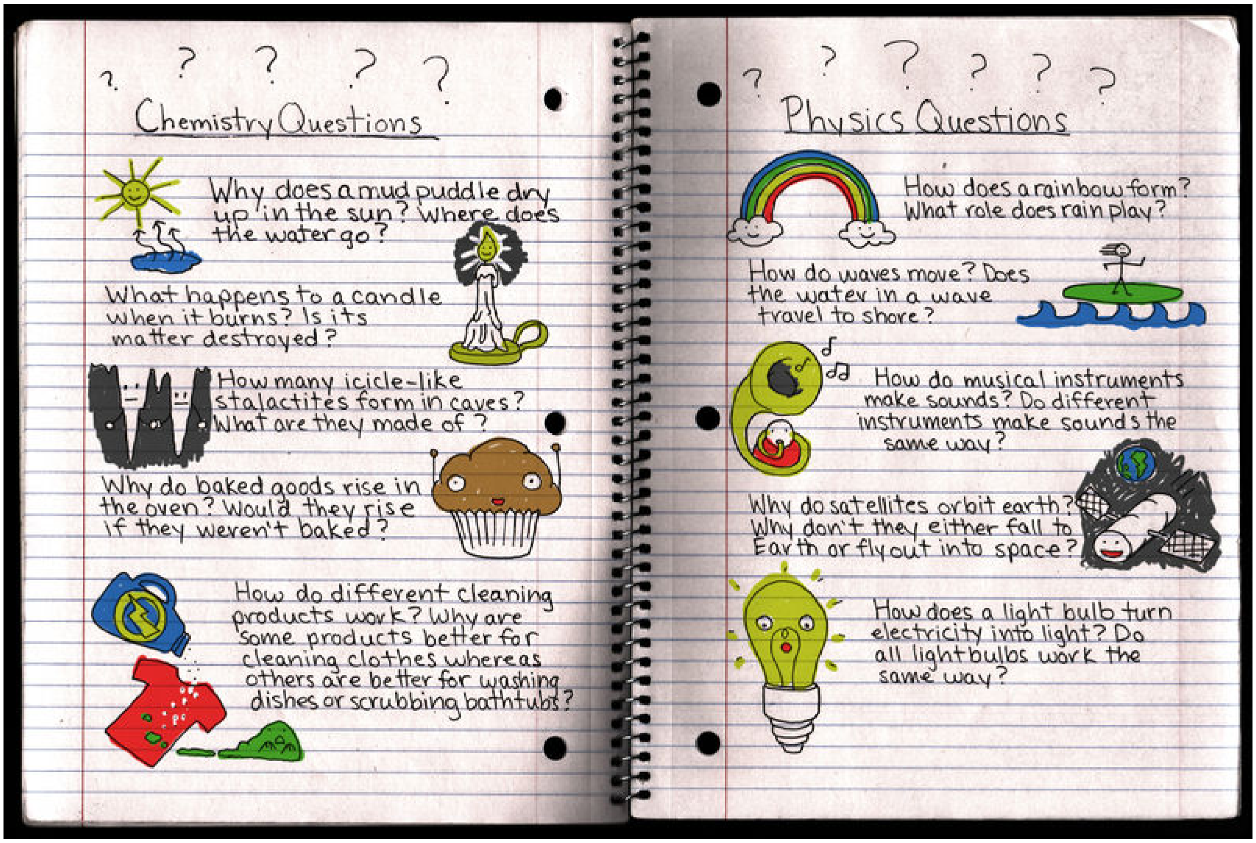


FIGURE 1.5

Using what you already know, try to answer each of these questions. Revisit your answers after you read about the relevant concepts in later chapters.

Physical Science and You

Physical science explains much of what you observe and do in your daily life. In fact, you depend on physical science for almost everything that makes modern life possible. You couldn't drive a car, text message, or send a tweet without decades of advances in chemistry and physics. You wouldn't even be able to turn on a light. **Figure** 1.6 shows some other examples of common activities that depend on advances in physical science. You'll learn the "hows" and "whys" about them as you read the rest of this book.

Careers in Physical Science

People with training in physical science are employed in a variety of places. There are many career options. Just four are described in **Figure** 1.7. Many more are described at the URL below. Do any of these careers interest you?

- http://diplomaguide.com/article_directory/sh/page/Physical%20Science/sh/Job_Titles_and_Careers_List.html
.

FIGURE 1.6
All these activities involve matter and energy. Can you explain how or why?

Lesson Summary

- Physical science is the study of matter and energy. It includes chemistry, which focuses on matter, and physics, which focuses on energy.
- Physical science explains everyday observations and actions. Its advances make modern life possible.
- There are many career options in physical science. Examples include pharmacist and surveyor.

Lesson Review Questions

Recall

1. Define physical science.
2. What is the focus of chemistry?
3. Describe an example of a career in physical science.

FIGURE 1.7

How might chemistry or physics be involved in each of these careers?

Apply Concepts

4. What practical question might be answered with physics concepts?

Think Critically

5. Energy is needed to make matter move. Explain how you use energy to ride a bike uphill. What force allows you to coast downhill without peddling?

Points to Consider

Figure 1.7 describes several careers in physical science. Other careers in physical science include research scientist and engineer.

- What do you think research scientists do?
- How do you think the work of engineers differs from that of research scientists?

For **Table** 1.1, from top to bottom:

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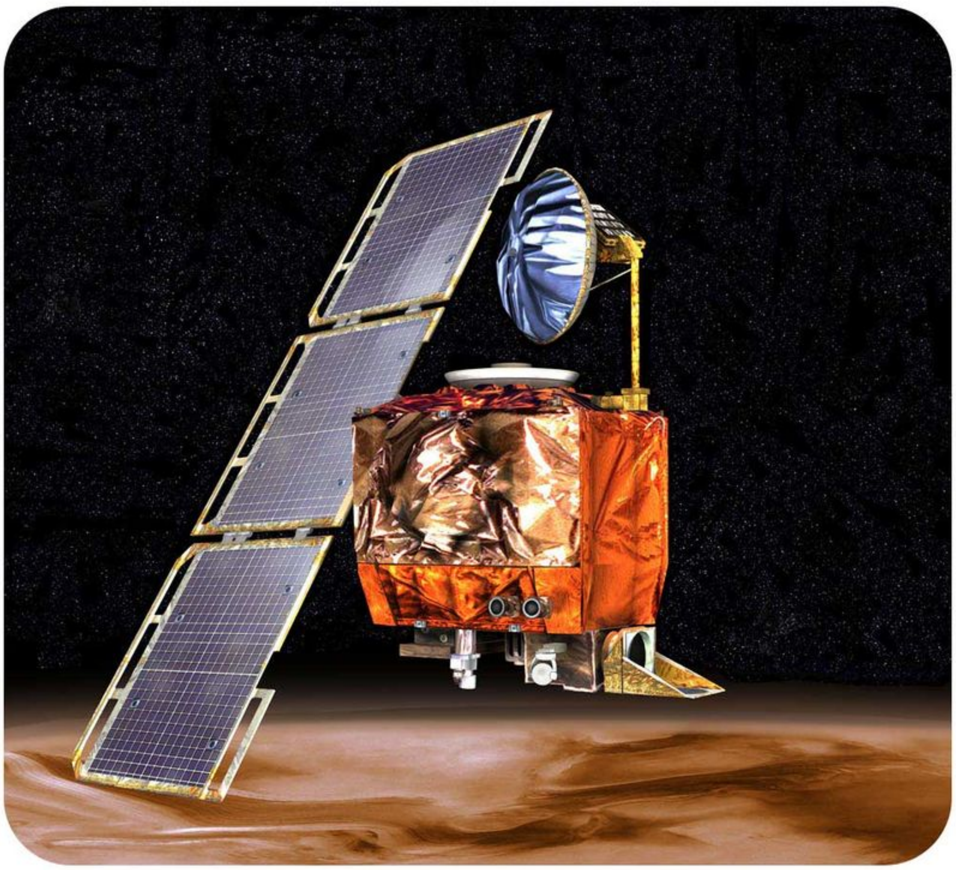
CHAPTER 2 Scientific Research and Technology

Chapter Outline

2.1 SCIENTIFIC INVESTIGATION
2.2 SCIENCE SKILLS
2.3 TECHNOLOGY
2.4 REFERENCES



In 1999, NASA's Mars Climate Orbiter, pictured here, burned up as it passed through Mars' atmosphere. The satellite was programmed to orbit Mars at high altitude and gather climate data. Instead, the Orbiter flew too low and was lost almost as soon as it reached the red planet. What happened to the Orbiter? The answer is human error. The flight system software on the Orbiter was written using scientific units of measurement. The ground crew was entering data using the common English system of units.

The example of the Mars Climate Orbiter shows the importance of using a standard system of measurement in science and technology. Measurement is just one of the basic skills needed in these fields. What other skills are needed? In this chapter, you'll find out.

Image courtesy of NASA. commons.wikimedia.org/wiki/File:Mars_Climate_Orbiter_2.jpg. Public Domain.

2.1 Scientific Investigation

Lesson Objectives

- List the steps of a scientific investigation.
- Describe the relationship of ethics to scientific research.

Lesson Vocabulary

- control
- ethics
- experiment
- field study
- hypothesis
- manipulated variable
- observation
- replication
- responding variable

Introduction

Investigation is at the heart of science. It is how scientists do research. Scientific investigations produce evidence that helps answer questions and solve problems. If the evidence cannot provide answers or solutions, it may still be useful. It may lead to new questions or problems for investigation. As more knowledge is discovered, science advances.

Steps of a Scientific Investigation

Scientists investigate the world in many ways. In different fields of science, researchers may use different methods and be guided by different theories and hypotheses. However, most scientists, including physical scientists, usually follow the general approach shown in **Figure** 2.1. This approach typically includes the following steps:

- Identify a research question or problem.
- Form a hypothesis.
- Gather evidence, or data, to test the hypothesis.
- Analyze the evidence.
- Decide whether the evidence supports the hypothesis
- Draw conclusions.
- Communicate the results.

Scientists may follow these steps in a different sequence. Or they may skip or repeat some of the steps. Which steps are repeated in **Figure** 2.1?

Asking Questions

A scientific investigation begins with a question or problem. Often, the question arises because a scientist is curious about something she has observed. An **observation** is any information that is gathered with the senses. People often have questions about things they see, hear, or observe in other ways. For example, a teen named Tara has a bracelet with a magnetic clasp, like the one shown in **Figure** 2.2. Tara has noticed that the two magnets in the clasp feel harder to pull apart on cold days than on warm days. She wonders whether temperature affects the strength of a magnet.

Forming Hypotheses and Making Predictions

Tara is curious. She decides to investigate. She begins by forming a hypothesis. A **hypothesis** is a potential answer to a question that can be tested by gathering information. If it isn't possible to gather evidence to test an answer, then it cannot be used as a scientific hypothesis. In fact, the question it addresses may not even be answerable by science. For example, in the children's television show *Sesame Street*, there was a large Snuffalufagus (kind of like an elephant). But Snuffy would disappear whenever people came around. So if someone said "Is there a Snuffy on Sesame Street?," that question would be unanswerable by science, since there isn't any test that can be performed –because Snuffy would disappear as soon as a scientist showed up. Can you think of other examples of questions outside the realm of science?

This important distinction, that evidence taken in by observation is experimented on by a scientist, is what separates legitimate science from other things which may pretend to be science. Fields which claim to be scientific but don't use the scientific method are called "pseudoscience." If a person can't gather data through some sort of instrument or sense information, they can't form a scientific conclusion. If there is no way to prove the hypothesis false, there is no scientific claim either. For example, if a friend told you that Snuffy visited him every day, but he was invisible whenever anyone walked into the room, this claim is not scientific, *since there is no way to prove him false*.

Developing a hypothesis may require creativity as well as reason. However, in Tara's case, the hypothesis is simple. She hypothesizes that a magnet is stronger at lower temperatures. Based on her hypothesis, Tara makes a prediction. If she cools a magnet, then it will pick up more metal objects, such as paper clips. Predictions are often phrased as "if-then" statements like this one. Is Tara's prediction correct? She decides to do an experiment.

Doing Experiments

An **experiment** is a controlled scientific study of specific variables. A variable is a factor that can take on different values. There must be at least two variables in an experiment. They are called the manipulated variable and the responding variable.

- The **manipulated variable** (also called the "independent variable") is a factor that is changed by the researcher. For example, Tara will change the temperature of a magnet. Temperature is the manipulated variable in her experiment.
- The **responding variable** (also called the "dependent variable") is a factor that the researcher predicts will change if the manipulated variable changes. Tara predicts the number of paper clips attracted by the magnet will be greater at lower temperatures. Number of paper clips is the responding variable in her experiment.

Tara wonders what other variables might affect the strength of a magnet. She thinks that the size and shape of a magnet might affect its strength. These are variables that must be controlled. A **control** is a variable that is held constant so it won't influence the outcome of an experiment. By using the same magnet at different temperatures,

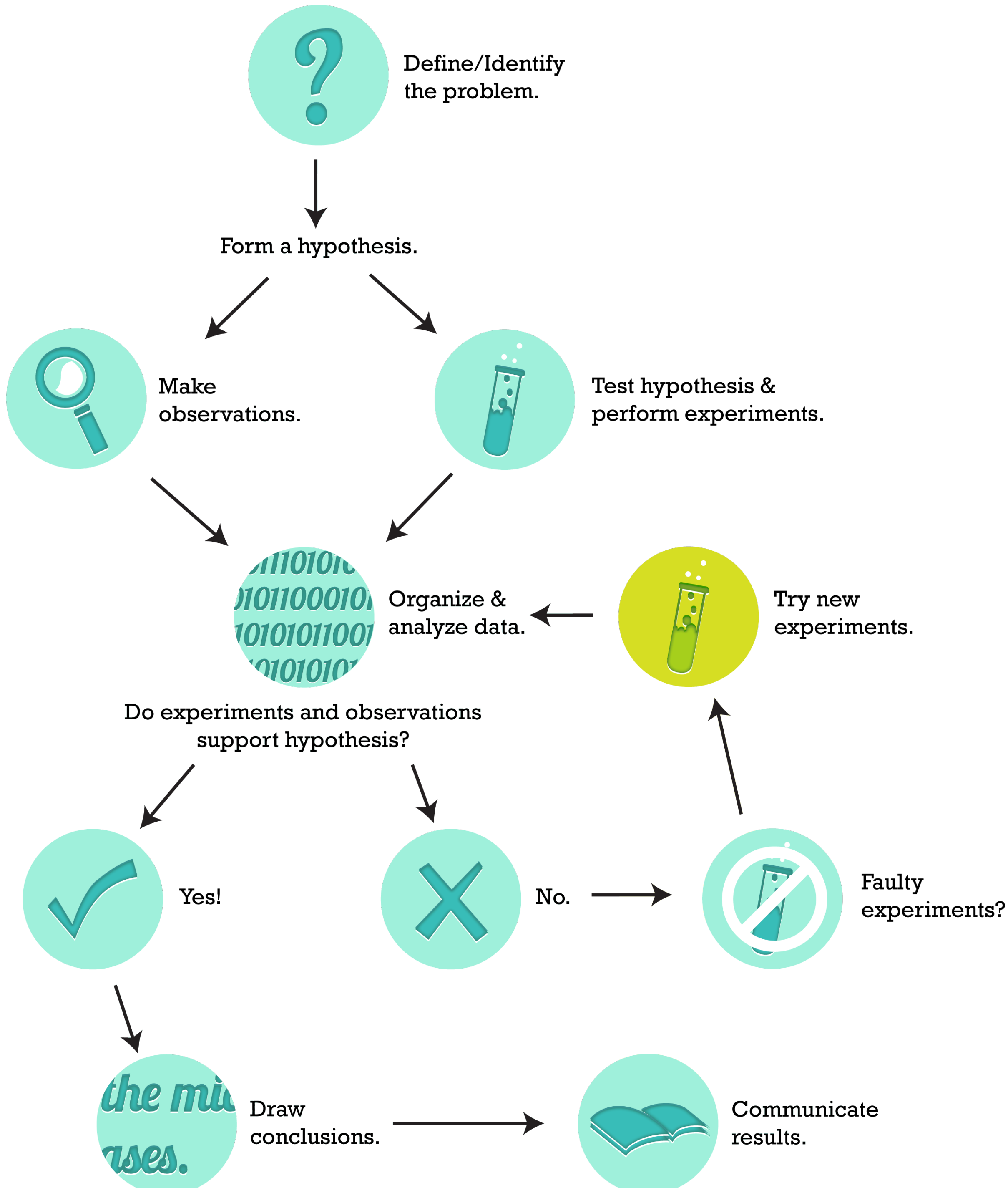


FIGURE 2.1

This diagram shows the steps of a scientific investigation. Other arrows could be added to the diagram. Can you think of one? (*Hint*: Sometimes evidence that does not support one hypothesis may lead to a new hypothesis to investigate.)

FIGURE 2.2
Each end of this bracelet contains a small magnet. The magnets attract each other and hold together the two ends.

Tara is controlling for any magnet variables that might affect the results. What other variables should Tara control? (*Hint*: What about the paper clips?)

Doing Other Types of Studies

Not everything in physical science is as easy to study as magnets and paper clips. Sometimes it's not possible or desirable to do experiments. There are some things with which a person simply cannot experiment. A distant star is a good example. Scientists study stars by making observations with telescopes and other devices. Often, it's important to investigate a problem in the real world instead of in a lab. Scientists do **field studies** to gather real-world evidence. You can see an example of a field study in **Figure** 2.3.

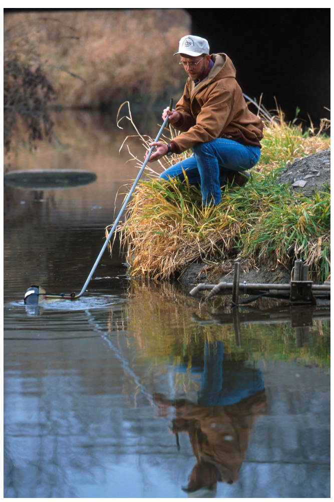


FIGURE 2.3
This scientist is investigating the effects farming practices have on the water quality. He is collecting and analyzing samples of river water. How might the evidence he gathers in the field help him solve the problem?

Communicating Results

Researchers should always communicate their results. By sharing their results, they may be able to get helpful feedback from other scientists. Reporting on research also lets other scientists repeat the investigation to see whether they get the same results. Getting the same results when an experiment is repeated is called **replication**. If results can be replicated, it means they are more likely to be correct. Replication of investigations is one way that a hypothesis may eventually become a theory.

Scientists can share their results in various ways. For example, they can write articles for peer-reviewed science journals. Peer review means that the work is analyzed by peers, in this case other scientists. This is the best way to ensure that the results are accurate and reported honestly. Another way to share results with other scientists is with presentations at scientific meetings (see **Figure** 2.4). Creating websites and writing articles for newspapers and magazines are ways to share research with the public. Why might this be important?

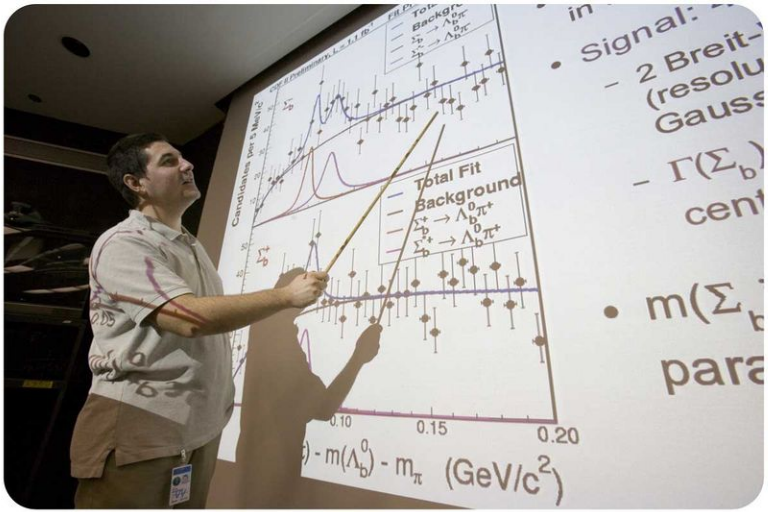


FIGURE 2.4
This researcher is presenting his results to a group of other scientists in his field.

Ethics and Scientific Research

Ethics refers to rules for deciding between right and wrong. Ethics is an important issue in science. Scientific research must be guided by ethical rules, including those listed below. The rules help ensure that the research is done safely and the results are reliable. Following the rules furthers both science and society. You can learn more about the role of ethics in science by following the links at this URL: http://www.files.chem.vt.edu/chem-ed/ethics/index.html#resources .

Ethical Rules for Scientific Research

- Scientific research must be reported honestly. It is wrong and misleading to make up or change research results.
- Scientific researchers must try to see things as they really are. They should avoid being biased by the results they expect or want to get.
- Researchers must be careful. They should take pains to avoid errors in their data.
- Researchers studying human subjects must tell their subjects about any potential risks of the research. Subjects also must be told that they can refuse to participate in the research.
- Researchers must inform coworkers, students, and members of the community about any risks of the research. They should proceed with the research only if they have the consent of these groups.
- Researchers studying living animals must treat them humanely. They should provide for their needs and do what they can to avoid harming them (see **Figure** 2.5).

Sometimes, science can help people make ethical decisions in their own lives, although science is unlikely to be the only factor involved. For example, scientific evidence shows that human actions are affecting Earth's climate. Actions such as driving cars are causing Earth to get warmer. Does this mean that it is unethical to drive a car to work or school? What if driving is the only way to get there? As this example shows, ethical decisions are likely to be influenced by many factors, not just science. Can you think of other factors that might affect ethical decisions such as this one?

FIGURE 2.5

This scientist is studying lab rats. He keeps them in comfortable cages and provides them with plenty of food and water.

Lesson Summary

- Steps of a scientific investigation include identifying a research question or problem, forming a hypothesis, gathering evidence, analyzing evidence, deciding whether the evidence supports the hypothesis, drawing conclusions, and communicating the results.
- Scientific research must be guided by ethical rules. They help ensure that the research is done safely and the results are reliable.

Lesson Review Questions

Recall

1. List the steps of a typical scientific investigation.
2. State why communication is important in scientific research.
3. Identify three ethical rules for scientific research.

Apply Concepts

4. Write a hypothesis based on this question: Do vinegar and water freeze at the same temperature? Make a prediction based on your hypothesis.
5. Describe an experiment you could do to test your prediction in question 4. Identify the variables and controls in your experiment. Include a list of materials. With your teacher's approval, conduct your investigation.

Think Critically

6. In Tara's experiment with the magnet, she measured and recorded the data in the **Table** 2.1.

TABLE 2.1: Tara's Data Table

Magnet Temperature (°C)	Number of Paper Clips Picked up by Magnet
24	8
4	6
3	6

Based on these data, Tara wrote this conclusion:

Magnets get stronger at cooler temperatures, but only down to 4°C. Below 4°C, the strength of magnets does not change.

Do you agree with Tara's conclusion? Why or why not? Suggest an alternative explanation for the data.

7. Describe a better experiment to test Tara's original hypothesis. (*Hint*: You might include more measurements, a wider range of temperatures, and more than one magnet.)

Points to Consider

Scientific investigations often involve measuring. For example, Tara measured the temperature of a magnet with a thermometer. Thermometers may have different scales. You may be most familiar with the Fahrenheit and Celsius scales.

- Do you know how the Fahrenheit and Celsius scales differ? For example, what are the freezing and boiling points of water on each scale?
- Do you know how to convert a temperature from one scale to the other?

2.2 Science Skills

Lesson Objectives

- Explain how measurements are made in scientific research.
- Describe how to keep good records in scientific investigations.
- Demonstrate how to use significant figures and scientific notation.
- Calculate descriptive statistics and use data graphs.
- Identify the role of models in science.
- Describe how to stay safe when doing scientific research.

Lesson Vocabulary

- accuracy
- Kelvin scale
- mean
- model
- precision
- range
- scientific notation
- SI
- significant figures

Introduction

Measuring is an important science skill. Other skills needed to do science include keeping records, doing calculations, organizing data, and making models. Knowing how to stay safe while doing scientific investigations may be the most important skill of all. You will read about all these science skills in this lesson.

Measuring

One of the most important aspects of measuring is the system of units used for measurement. Remember the Mars Climate Orbiter that opened this chapter? It shows clearly why a single system of measurement units is needed in science.

Using SI Units

The measurement system used by most scientists is the International System of Units, or **SI**. **Table** 2.2 lists common units in this system. SI is easy to use because everything is based on the number 10. Basic units are multiplied or divided by powers of ten to arrive at bigger or smaller units. Prefixes are added to the names of the basic units to indicate the powers of ten. For example, the meter is the basic unit of length. The prefix *kilo-* means 1000, so a kilometer is 1000 meters. Can you infer what the other prefixes in the table mean? If not, you can find out at this URL: http://physics.nist.gov/cuu/Units/prefixes.html .

TABLE 2.2: Common SI Units

Variable	Basic SI Unit (English Equivalent)	Related SI Units	Equivalent Units
Length	meter (m) (1 m = 39.37 in)	kilometer (km) decimeter (dm) centimeter (cm) millimeter (mm) micrometer (μm) nanometer (nm)	= 1000 m = 0.1 m = 0.01 m = 0.001 m = 0.000001 m = 0.000000001 m
Volume	cubic meter (m^3) (1 m^3 = 1.3 yd^3)	liter (L) milliliter (mL)	= 1 dm^3 = 1 cm^3
Mass	gram (g) (1 g = 0.04 oz)	kilogram (kg) milligram (mg)	= 1000 g = 0.001 g

The SI system has units for other variables in addition to the three shown here in **Table** 2.2. Some of these other units are introduced in later chapters.

Problem Solving

Problem: Use information in **Table** 2.2 to convert 3 meters to inches.

Solution: 3 m = 3 $\times$ 39.37 in = 118.11 in

You Try It!

Problem: Rod needs to buy 1 m of wire for a science experiment. The wire is sold by the yard, not the meter. If he buys 1 yd of wire, will he have enough? (*Hint*: How many inches are there in 1 yd? In 1 m?)

Measuring Temperature

The SI scale for measuring temperature is the **Kelvin scale**. However, some scientists use the Celsius scale instead. If you live in the U.S., you are probably more familiar with the Fahrenheit scale. **Table** 2.3 compares all three temperature scales. What is the difference between the boiling and freezing points of water on each of these scales?

TABLE 2.3: Temperature Scales

Scale	Freezing Point of Water	Boiling Point of Water
Kelvin	273 K	373 K
Celsius	0°C	100°C
Fahrenheit	32°F	212°F

Each 1-degree change on the Kelvin scale is equal to a 1-degree change on the Celsius scale. This makes it easy to convert measurements between Kelvin and Celsius. For example, to go from Celsius to Kelvin, just add 273. How would you convert a temperature from Kelvin to Celsius?

Converting between Celsius and Fahrenheit is more complicated. The following conversion factors are used:

- Celsius $\rightarrow$ Fahrenheit : $(°C \times 1.8) + 32 = \ °F$
- Fahrenheit $\rightarrow$ Celsius : $(°F - 32) \div 1.8 = \ °C$

Problem Solving

Problem: Convert 10°C to Fahrenheit.

Solution: (10°C × 1.8) + 32 = 50°F

You Try It!

Problem: The weather forecaster predicts a high temperature today of 86°F. What will the temperature be in Celsius?

Using Measuring Devices

Measuring devices must be used correctly to get accurate measurements. **Figure** 2.6 shows the correct way to use a graduated cylinder to measure the volume of a liquid.

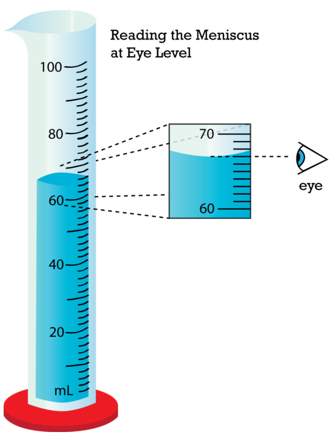


FIGURE 2.6

This cylinder contains about 66 mL of liquid. What would the measurement be if you read the top of the meniscus by mistake?

Follow these steps when using a graduated cylinder to measure liquids:

- Place the cylinder on a level surface before adding liquid.
- Move so your eyes are at the same level as the top of the liquid in the cylinder.
- Read the mark on the glass that is at the lowest point of the curved surface of the liquid. This is called the meniscus.

At the URLs below, you can see the correct way to use a metric ruler to measure length and a beam balance to measure mass.

- http://www.wsd1.org/waec/math/Consumer%20Math%20Advanced/Unit%202%20Design%20and%20Measurement/Ruler%20Meas/measmain.htm (metric ruler)
- http://www.youtube.com/watch?v=C9howXG7LUY (beam balance) (5:14)

MEDIA

Click image to the left for use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5036

Accuracy and Precision

Measurements should be both accurate and precise.

- **Accuracy** is how close a measurement is to the true value. For example, 66 mL is a fairly accurate measurement of the liquid in **Figure** 2.6.
- **Precision** is how exact a measurement is. A measurement of 65.5 mL is more precise than a measurement of 66 mL. But in **Figure** 2.6, it is not as accurate.

You can think of accuracy and precision in terms of a game like darts. If you are aiming for the bull's-eye and get all of the darts close to it, you are being both accurate and precise. If you get the darts all close to each other somewhere else on the board, you are precise, but not accurate. And finally, if you get the darts spread out all over the board, you are neither accurate nor precise.

Keeping Records

Record keeping is very important in scientific investigations. Follow the tips below to keep good science records.

- Use a bound laboratory notebook so pages will not be lost. Write in ink for a permanent record.
- Record the steps of all procedures.
- Record all measurements and observations.
- Use drawings as needed.
- Date all entries, including drawings.

Calculating

Doing science often requires calculations. Converting units is just one example. Calculations are also needed to find derived quantities.

Calculating Derived Quantities

Derived quantities are quantities that are calculated from two or more different measurements. Examples include area and volume. It's easy to calculate these quantities for a simple shape. For a rectangular solid, like the one in **Figure** 2.7, the formulas are:

$$\text{Area (of each side)} = \text{length} \times \text{ width } (l \times w)$$
$$\text{Volume} = \text{length} \times \text{width} \times \text{height } (l \times w \times h)$$

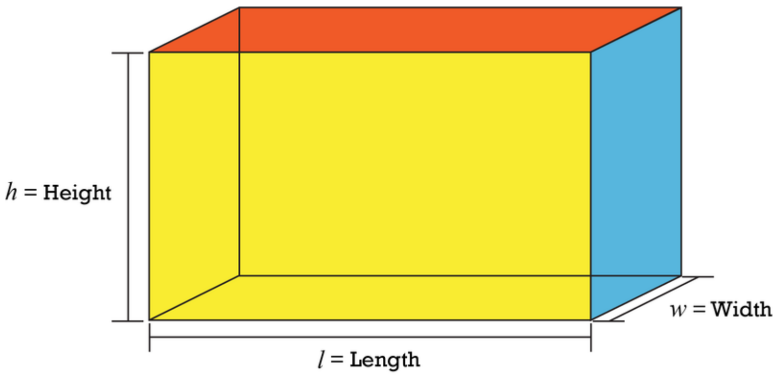


FIGURE 2.7
Dimensions of a rectangular solid include length (l), width (w), and height (h). The solid has six sides. How would you calculate the total surface area of the solid?

Helpful Hints

When calculating area and volume, make sure that:

- all the measurements have the same units.
- answers have the correct units. Area should be in squared units, such as cm^2; volume should be in cubed units, such as cm^3. Can you explain why?

Naturally, not all derived quantities will have the same types of units. In the examples above, the only fundamental unit used was meters for the length of one of the sides of the box. However, if you had a quantity like speed (a derived quantity), it would be equal to distance traveled (which is meters) divided by the amount of time you spent traveling that distance (which is in seconds). Therefore your speed would be measured in meters per second.

Using Significant Figures

Assume you are finding the area of a rectangle with a length of 6.8 m and a width of 6.9 m. When you multiply the length by the width on your calculator, the answer you get is 46.92 m^2. Is this the correct answer? No; the correct answer is 46.9 m^2. The correct answer must be rounded down so there is just one digit to the right of the decimal point. That's because the answer cannot have more digits to the right of the decimal point than any of the original measurements. Using extra digits implies a greater degree of precision than actually exists. The correct number of digits is called the number of **significant figures**. To learn more about significant figures and rounding, you can watch the videos at the URLs below.

- http://www.youtube.com/watch?v=ZbTxK6-1fDg (3:20)
- http://www.youtube.com/watch?v=MuVyoqz5lxM (8:30)

Using Scientific Notation

Quantities in science may be very large or very small. This usually requires many zeroes to the left or right of the decimal point. Such numbers can be hard to read and write accurately. That's where scientific notation comes in. **Scientific notation** is a way of writing very large or small numbers that uses exponents. Numbers are written in this format:

$$a \times 10^b$$

The letter *a* stands for a decimal number. The letter *b* stands for an exponent, or power, of 10. For example, the number 300 is written as 3.0×10^2. The number 0.03 is written as 3.0×10^{-2}. **Figure** 2.8 explains how to convert numbers to and from scientific notation. For a review of exponents, watch: http://www.youtube.com/watch?v=8htcZca0JIA .

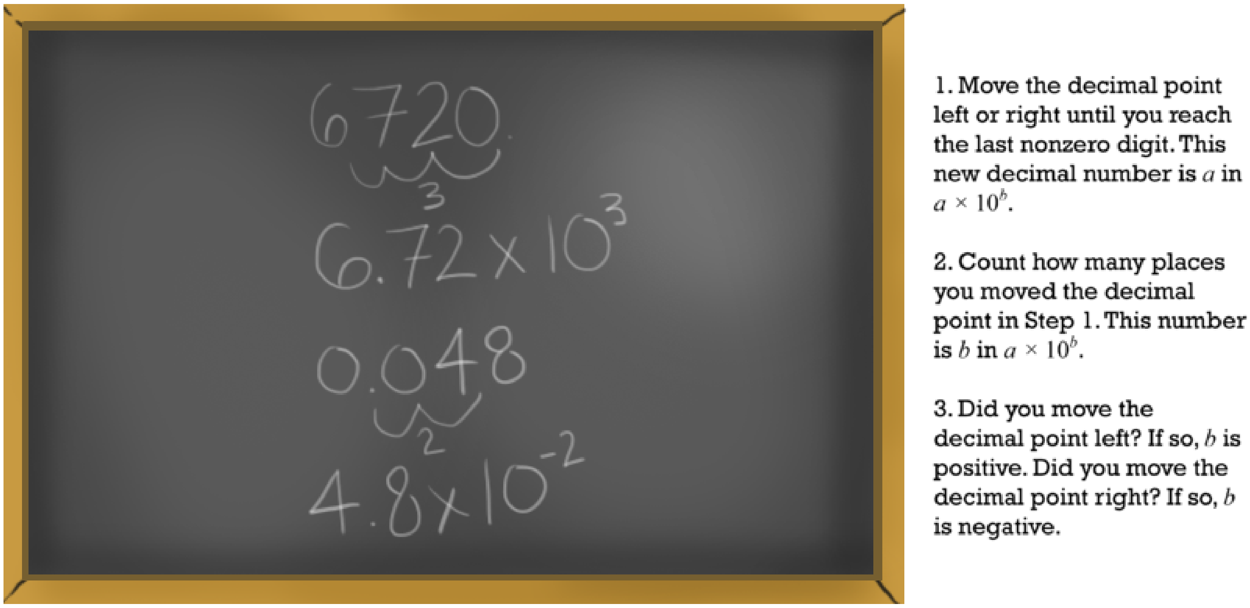


FIGURE 2.8
Follow the steps in reverse to convert numbers from scientific notation.

You Try It!

Problem: Write the number 46,000,000 in scientific notation.

Organizing Data

In a scientific investigation, a researcher may make and record many measurements. These may be compiled in spreadsheets or data tables. In this form, it may be hard to see patterns or trends in the data. Descriptive statistics and graphs can help organize the data so patterns and trends are easier to spot.

Example: A vehicle checkpoint was set up on a busy street. The number of vehicles of each type that passed by the checkpoint in one hour was counted and recorded in **Table** 2.4. These are the only types of vehicles that passed the checkpoint during this period.

TABLE 2.4: Data Table

Type of Vehicle	Number
4-door cars	150
2-door cars	50
SUVs	80

TABLE 2.4: (continued)

Type of Vehicle	Number
vans	50
pick-up trucks	70

Descriptive Statistics

A descriptive statistic sums up a set of data in a single number. Examples include the mean and range.

- The **mean** is the average value. It gives you an idea of the typical measurement. The mean is calculated by summing the individual measurements and dividing the total by the number of measurements. For the data in **Table** 2.4, the mean number of vehicles by type is: (150 + 50 + 80 + 50 + 70) ÷ 5 = 80. (There are two other words people can sometimes use when they use the word "average." They might be referring to a quantity called the "median" or the "mode." You'll see these quantities in later courses, but for now, we'll just say the average is the same thing as the mean.)
- The **range** is the total spread of values. It gives you an idea of the variation in the measurements. The range is calculated by subtracting the smallest value from the largest value. For the data in **Table** 2.4, the range in numbers of vehicles by type is: 150 - 50 = 100.

Graphs

Graphs can help you visualize a set of data. Three commonly used types of graphs are bar graphs, circle graphs, and line graphs. **Figure** 2.9 shows an example of each type of graph. The bar and circle graphs are based on the data in **Table** 2.4, while the line graph is based on unrelated data. You can see more examples at this URL: http://www.beaconlearningcenter.com/weblessons/kindsofgraphs/default.htm .

- Bar graphs are especially useful for comparing values for different types of things. The bar graph in **Figure** 2.9 shows the number of vehicles of each type that passed the checkpoint.
- Circle graphs are especially useful for showing percents of a whole. The circle graph in **Figure** 2.9 shows the percent of all vehicles counted that were of each type.
- Line graphs are especially useful for showing changes over time. The line graph in **Figure** 2.9 shows how distance from school changed over time when some students went on a class trip.

Helpful Hints

Circle graphs show percents of a whole. What are percents?

- Percents are fractions in which the denominator is 100. *Example:* 30% = 30/100
- Percents can also be expressed as decimal numbers. *Example:* 30% = 0.30

You Try It!

Problem: Show how to calculate the percents in the circle graph in **Figure** 2.9.

Need a refresher on percents, fractions, and decimals? Go to this URL: http://www.mathsisfun.com/decimal-fraction-percentage.html .

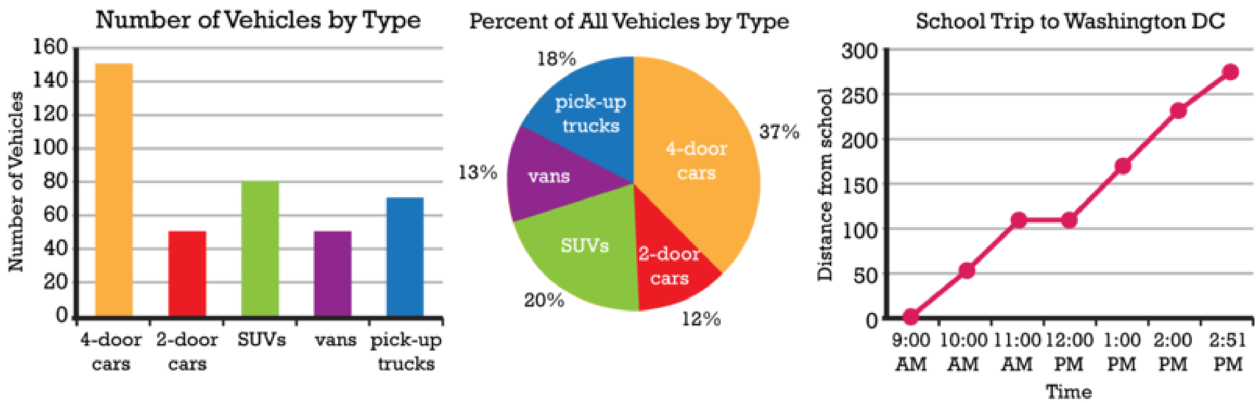


FIGURE 2.9

These are three commonly used types of graphs. When would you want to use a bar graph? What about a line graph?

Using Models

Did you ever read a road map, sketch an object, or play with toy trucks or dolls? No doubt, the answer is yes. What do all these activities have in common? They all involve models. A **model** is a representation of an object, system, or process. For example, a road map is a representation of an actual system of roads on the ground.

Models are very useful in science. They provide a way to investigate things that are too small, large, complex, or distant to investigate directly. **Figure** 2.10 shows an example of a model in chemistry. To be useful, a model must closely represent the real thing in important ways, but it must be simpler and easier to manipulate than the real thing. Do you think the model in **Figure** 2.10 meets these criteria?

Staying Safe in Science

Research in physical science can be exciting, but it also has potential dangers. Whether in the lab or in the field, knowing how to stay safe is important.

Safety Symbols

Lab procedures and equipment may be labeled with safety symbols. These symbols warn of specific hazards, such as flames or broken glass. Learn the symbols so you will recognize the dangers. A list of common safety symbols is shown in **Figure** 2.11. Do you know how to avoid each hazard? You can learn more at this URL: http://www.angelfire.com/va3/chemclass/safety.html .

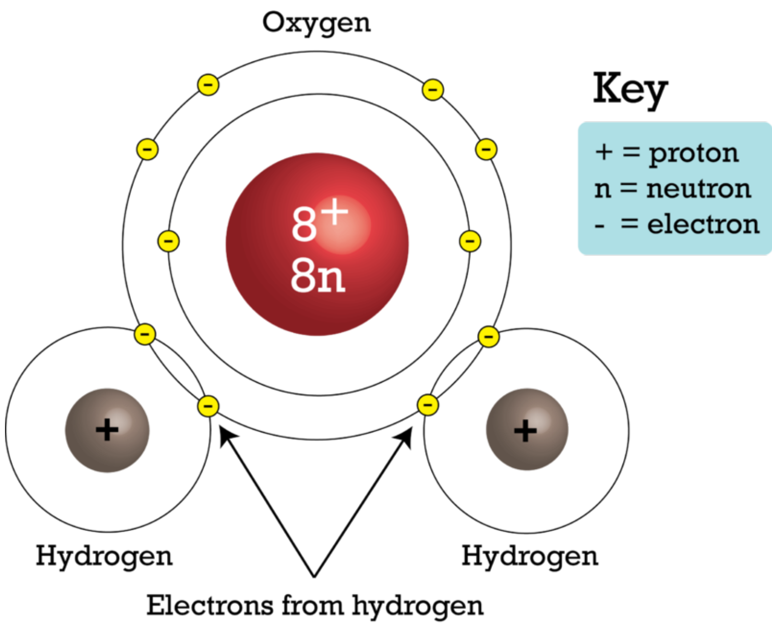


FIGURE 2.10
This model represents a water molecule. It shows that a water molecule consists of an atom of oxygen and two atoms of hydrogen. What else does the model show?

FIGURE 2.11
Why does glassware pose a hazard?

Safety Rules

Following basic safety rules is the best way to stay safe in science. Safe practices help prevent accidents. Several lab safety rules are listed below. Different rules may apply when you work in the field. But in all cases, you should always follow your teacher's instructions.

Lab Safety Rules

- Wear safety gear, including goggles, an apron, and gloves.
- Wear a long-sleeved shirt and shoes that completely cover your feet.
- Tie back your hair if it is long.
- Do not eat or drink in the lab.
- Never work alone.
- Never perform unauthorized experiments.
- Never point the open end of a test tube at yourself or another person.
- Always add acid to water —never water to acid —and add the acid slowly.
- To smell a substance, use your hand to fan vapors toward your nose rather than smell it directly. This is demonstrated in **Figure** 2.12.
- When disposing of liquids in the sink, flush them down the drain with lots of water.
- Wash glassware and counters when you finish your lab work.
- Thoroughly wash your hands with soap and water before leaving the lab.

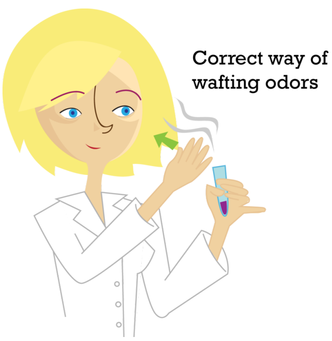


FIGURE 2.12
This is the correct way to smell a chemical in science lab. This helps prevent possible injury from toxic fumes.

Even when you follow the rules, accidents can happen. Immediately alert your teacher if an accident occurs. Report all accidents, even if you don't think they are serious.

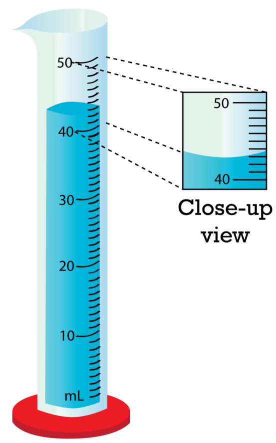
Lesson Summary

- Most scientists use the SI system of units. It includes the Kelvin scale for temperature. Measurements should be both accurate and precise.
- Good record keeping is very important in scientific research.
- Doing science often requires calculations, such as finding derived quantities. Calculations may involve significant figures or scientific notation.
- Descriptive statistics and graphs help organize data so patterns and trends are more apparent. Descriptive statistics include the mean and range. Types of graphs include bar, circle, and line graphs.
- A model is a representation of an object, system, or process. Models help scientists investigate things that are too small, large, complex, or distant to study directly.
- Staying safe while doing scientific research means recognizing safety symbols and following safety rules.

Lesson Review Questions

Recall

1. What are the basic SI units for length, volume, and mass?
2. How much liquid does this graduated cylinder contain?



3. Define the mean and range of a data set. How are they calculated?
4. What is a model? How are models used in science?
5. What hazard does each of these symbols represent?

Apply Concepts

6. Do the following calculations:
   a. Write the number 0.0000087 in scientific notation.
   b. Convert 50°C to °F.
   c. Find the volume of a cube that measures 5 cm on each dimension (length, width, and height).
7. Make a safety poster to convey one of the lab safety rules in this lesson.

Think Critically

8. Compare and contrast accuracy and precision of measurements in science.

Points to Consider

Most of the skills described in this lesson are important in technology as well as science.

- What is technology?
- How do you think technology differs from science?

2.3 Technology

Lesson Objectives

- Define technology.
- Outline the technological design process.
- Explain how science and technology are related.
- Describe how technology and society influence each other.

Lesson Vocabulary

- engineer
- technological design
- technology

Introduction

What do you think of when you hear the word technology? Do devices like computers and solar-powered cars come to mind? Devices such as these are just one meaning of the term "technology." As a field of study, technology is much broader than that.

What Is Technology?

Technology is the application of knowledge to real-world problems. It includes methods and processes as well as devices like computers and cars. An example is the Bessemer process. It is a cheap method of making steel that was invented in the 1850s. It is just one of many technological advances that have occurred in manufacturing. Technology is also responsible for most of the major advances in agriculture, transportation, communications, and medicine. Clearly, technology has had a huge impact on people and society. It is hard to imagine what life would be like without it.

Professionals in technology are generally called **engineers**. Most engineers have a strong background in physical science. There are many different careers in engineering. You can learn about some of them at the URLs below.

- http://www.sciencebuddies.org/science-fair-projects/science_careers.shtml?gclid=CMbjl5HB4qgCFcW8Kgod7HdmGQ
- http://www.careertoolkits.com/engineering/

Technological Design

The development of new technology is called **technological design**. It is similar to scientific investigation. Both processes use evidence and logic to solve problems.

Technological Design Process

Figure 2.13 shows the steps of the technological design process. Consider the problem of developing a solar-powered car. Many questions would have to be researched in the design process. For example, what is the best shape for gathering the sun's rays? How will the energy from the sun be stored? Will a back-up energy source be needed? After researching the answers, possible designs are developed. This takes imagination as well as reason. Then a model is made of the best design, and the model is tested. This allows any problems with the design to be worked out before a final design is selected.

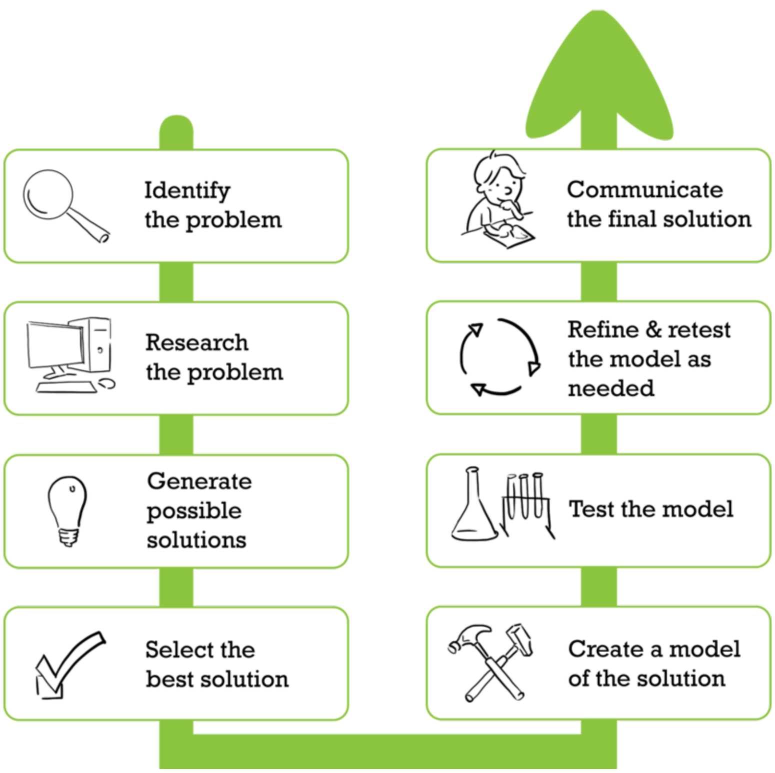


FIGURE 2.13
This flowchart represents the process of technological design. How does the technological design process resemble a scientific investigation?

Constraints on Technological Design

Technological design always has constraints. Constraints are limits on the design. Common constraints include:

- laws of nature, such as the law of gravity.
- properties of the materials used.
- cost of producing a technology.

Ethical concerns are also constraints on many technological designs. Like scientists, engineers must follow ethical rules. For example, the technologies they design must be as safe as possible for people and the environment.

Engineers must weigh the benefits and risks of new technologies, and the benefits should outweigh the risks.

Advances in Technology

Technology advances as new materials and processes are invented. Computers are a good example. **Table** 2.5 and the videos below show some of the milestones in their evolution. The evolution of modern computers began in the 1930s. Computers are still evolving today. How have computers changed during your lifetime?

- http://www.youtube.com/watch?v=ETVAlcMXitk (4:11)

MEDIA
Click image to the left for use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5039

- http://www.youtube.com/watch?v=gas2Xi0rW6A (5:36)

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TABLE 2.5: **Evolution of Computers**

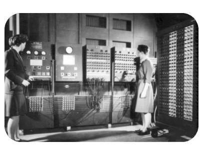
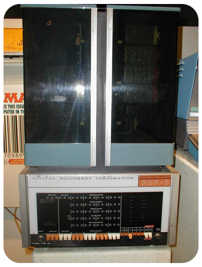
Computer (Year)	Description
ENIAC (1946)  *US Army Photo*	Like other early computers, the huge ENIAC computer used vacuum tubes for electrical signals. This made it very large and expensive. It could do just one task at a time. It had to be rewired to change programs. That's what the women in this photo are doing.
ERMA (1955)	The ERMA computer represented a new computer technology. It used transistors instead of vacuum tubes. This allowed computers to be smaller, cheaper, and more energy efficient.

TABLE 2.5: (continued)

Computer (Year)	Description
PDP-8 (1968) 	By the late 1960s, tiny transistors on silicon chips were invented. They increased the speed and efficiency of computers. They also allowed computers to be much smaller. The PDP-8 computer pictured here was the first "mini" computer.
Macintosh 128K (1984) 	The next major advance in computers was the development of microprocessors. A microprocessor consisted of thousands of integrated circuits placed on a tiny silicon chip. This allowed computers to be more powerful and even smaller. The computer pictured here is the first Macintosh personal computer.
MacBook Air (2010) 	The computers of the 21st century are tiny compared with the lumbering giants of the mid-1900s. Their problem-solving abilities are also immense compared with early computers. The diversity of software programs available today allows users to undertake an immense variety of tasks —and no rewiring is needed!

Technology and Science

Technology is sometimes referred to as applied science, but it has a different goal than science. The goal of science is to increase knowledge. The goal of technology is to use knowledge for practical purposes.

Although they have different goals, technology and science work hand in hand. Each helps the other advance. Scientific knowledge is needed to create new technologies. New technologies are used to further science. The microscope is a good example. Scientific knowledge of light allowed 17^{th} century lens makers to make the first microscopes. This new technology let scientists view a world of tiny objects they had never before seen. **Figure** 2.14 describes other examples.

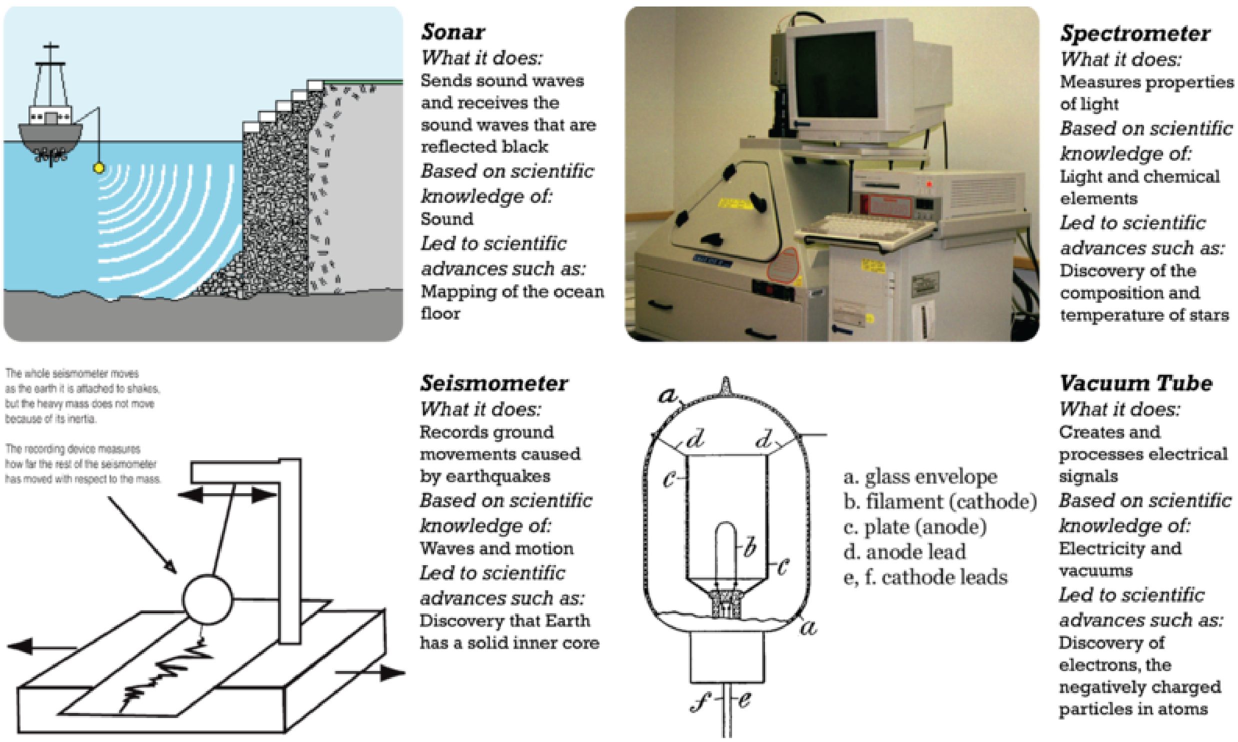


FIGURE 2.14
Each of the technologies pictured here is based on scientific knowledge. Each also led to important scientific advances.

Technology and Society

The goal of technology is to solve people's problems. Therefore, the problems of society generally set the direction that technology takes. Technology, in turn, affects society. It may make people's lives easier or healthier. Two examples are described in **Figure** 2.15.

You can read about other examples at these URLs:

- http://mezocore.wordpress.com/
- http://www.makingthemodernworld.org.uk/everyday_life/

Lesson Summary

- Technology is the application of knowledge to real-world problems. Engineers are professionals in technology.
- Technological design is the development of new technology. The design process is based on evidence and logic.
- Technology and science have different goals, but each helps the other advance.
- The problems of society generally set the direction of technology. New technologies, in turn, may make

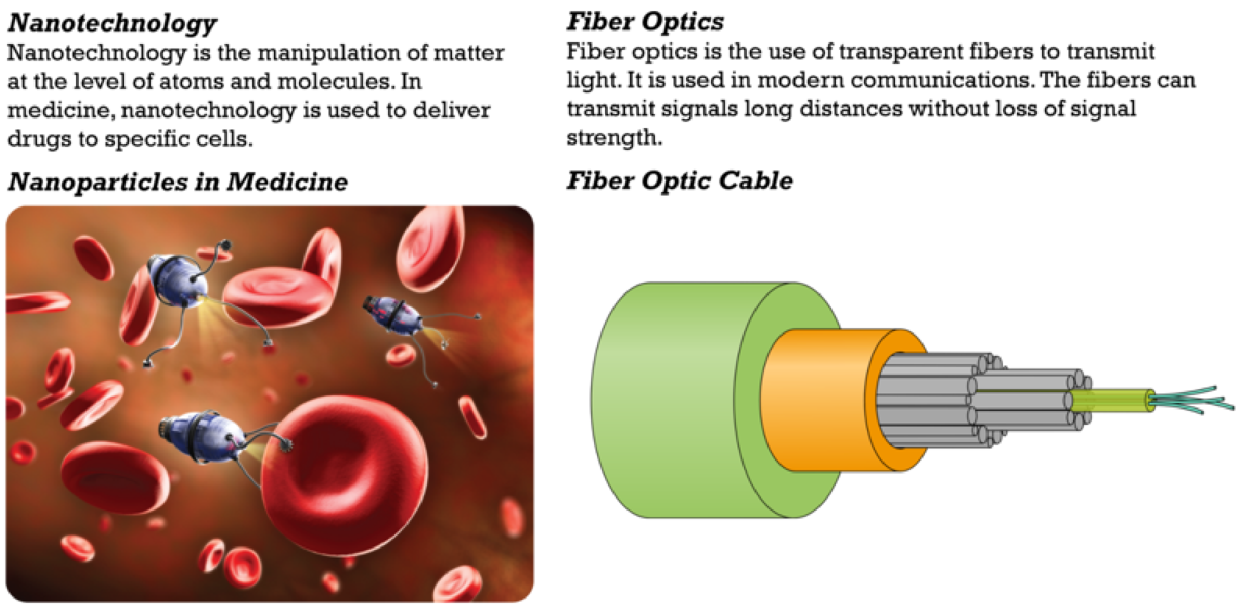


FIGURE 2.15

Technologies that help people may be as simple as forks and knives. Or they may be as complex as the two examples described here. How does technology help you?

people's lives easier or healthier.

Lesson Review Questions

Recall

1. Define technology.
2. What do engineers do?
3. List the steps of the technological design process.

Apply Concepts

4. A team of engineers is designing a new type of car. What are likely to be some of the constraints on the design?

Think Critically

5. Compare and contrast science and technology.
6. Relate technology and society.

Points to Consider

Nanotechnology manipulates atoms and molecules of matter.

- What is matter? What are its characteristics?
- Do you think all matter consists of atoms and molecules?

For **Table** 2.5, from top to bottom,

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CONCEPT 3 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** 3.1. 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.

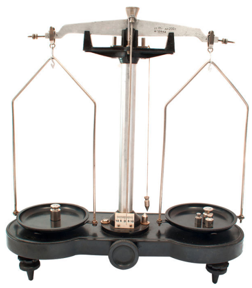

FIGURE 3.1
This balance shows one way of measuring mass. When both sides of the balance are at the same level, it means that objects in the two pans have the same mass.

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** 3.2. 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 3.2
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 $(10 \times 9.8 \text{ N}) = 98$ 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** 3.3. 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 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).

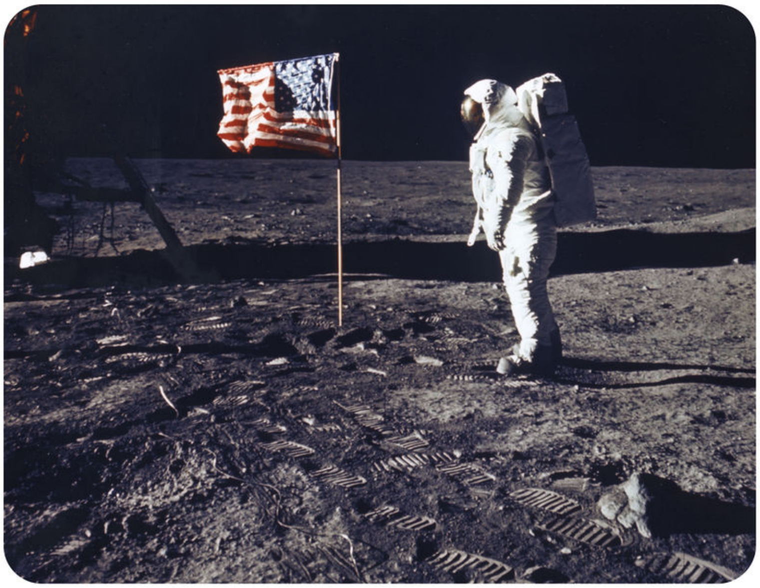

FIGURE 3.3
If the astronaut weighed 175 pounds on Earth, he would have weighed only 29 pounds on the moon. If his mass on Earth was 80 kg, what would his mass have been on the moon?

- 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 ($l \times w \times h$). For solids that have irregular shapes, the displacement method is used to measure volume. You can see how it works in **Figure** 3.4 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&feature=related

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** 3.5. Can you think of other physical properties?

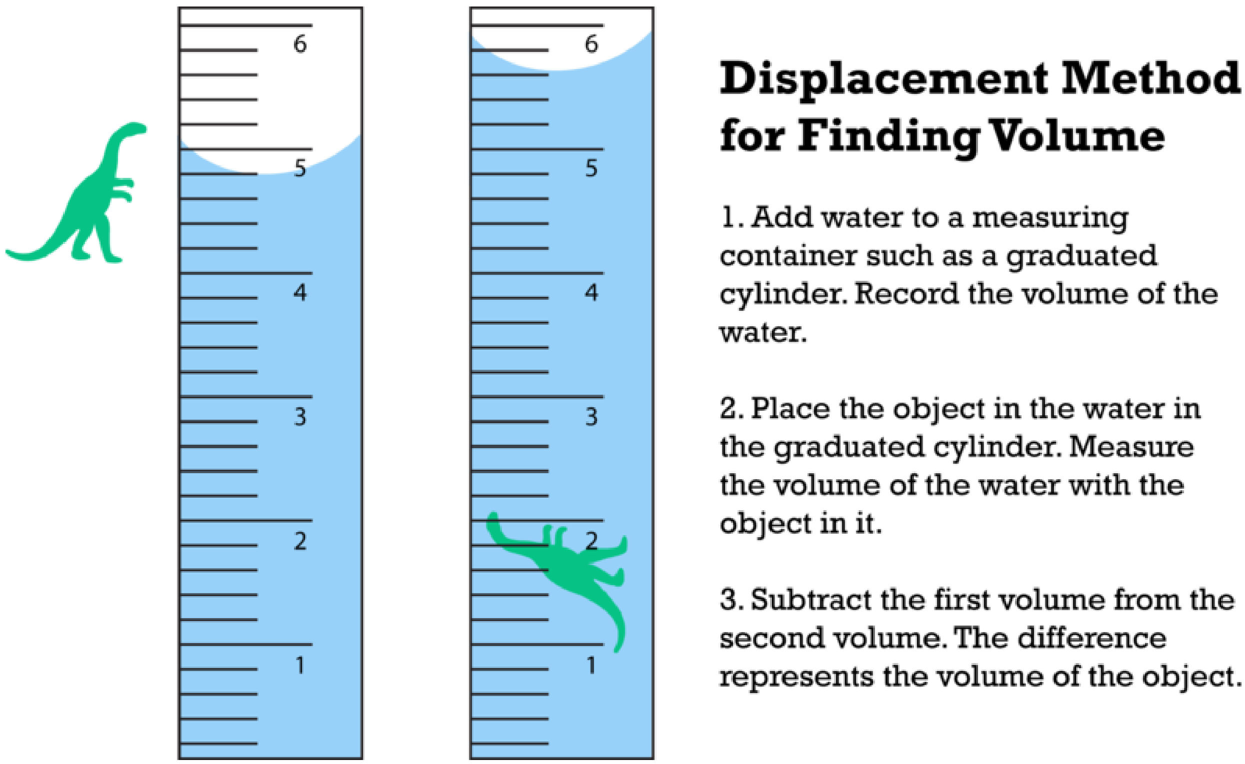

FIGURE 3.4
The displacement method is used to find the volume of an irregularly shaped solid object. It measures the amount of water that the object displaces, or moves out of the way. What is the volume of the toy dinosaur in mL?

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 3.5

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

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** 3.6). Rust is not iron but an entirely different substance that consists of both iron and oxygen.

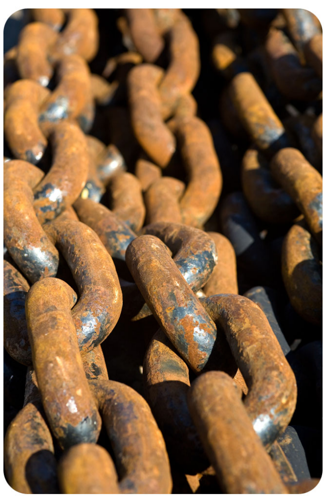

FIGURE 3.6
The iron in this steel chain has started to rust.

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?

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CONCEPT 4 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** 4.1). 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 4.1
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** 4.2 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.

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

FIGURE 4.2
In each of these changes, only the physical properties of matter change. The chemical properties remain the same.

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Click image to the left for use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5068

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** 4.3, 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** 4.4 and the video below show other examples of chemical changes.

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

FIGURE 4.3
This girl is pouring vinegar on baking soda. This causes a bubbling "volcano."

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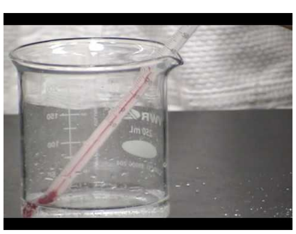
Signs of Chemical Change

How can you tell whether a chemical change has occurred? Often, there are clues. Several are demonstrated in **Figures** 4.3 and 4.4 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 4.4
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** 4.5, 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

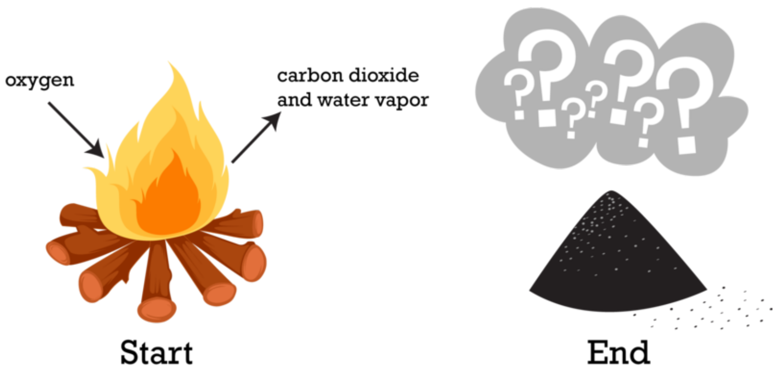

FIGURE 4.5
Burning is a chemical process. Is mass destroyed when wood burns?

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?

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CONCEPT 5 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

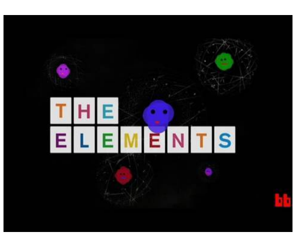
Introduction

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** 5.1 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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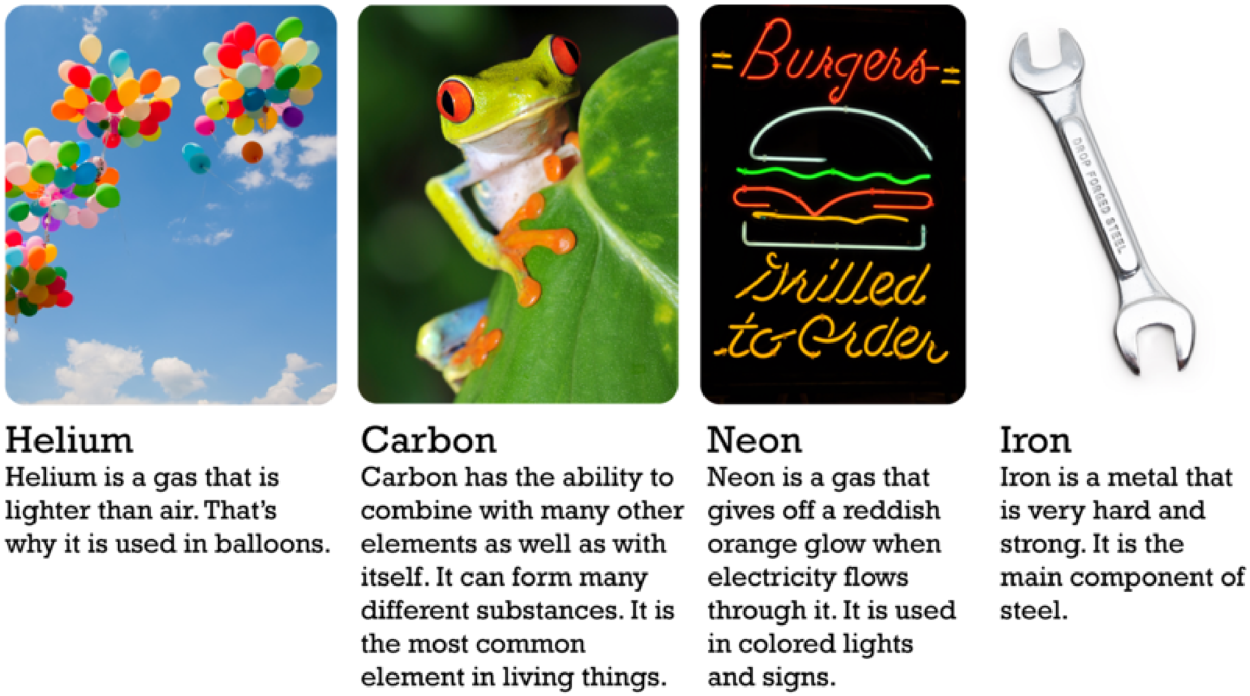

FIGURE 5.1
Each of the elements described here has different uses because of its properties.

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** 5.2). All gold atoms have the same structure and properties.

FIGURE 5.2
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&feature=related (3:53).

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URL: http://www.ck12.org/flx/render/embeddedobject/195

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** 5.3). But together, sodium and chlorine form a harmless, unreactive compound that you can safely sprinkle on food.

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** 5.4). You can learn more about molecules at this link: http://www.nyhallsci.org/marvelousmolecules/marveloussub.html .

FIGURE 5.3
Table salt is much different than its components. What are some of its properties?

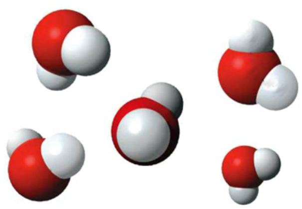


FIGURE 5.4
Water is a compound that forms molecules. Each water molecule consists of two atoms of hydrogen (white) and one atom of oxygen (red).

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** 5.5). 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&feature=related .

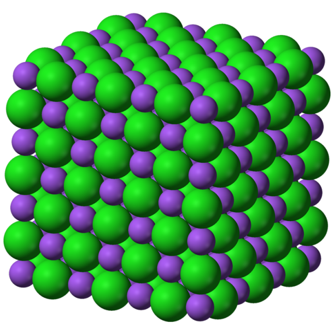


FIGURE 5.5
A crystal of table salt has a regular, repeating pattern of ions.

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** 5.6.

FIGURE 5.6
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.

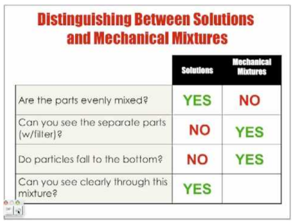
Particle Size in Mixtures

Mixtures have different properties depending on the size of their particles. Three types of mixtures based on particle size are described below. **Figure** 5.7 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)

MEDIA
Click image to the left for use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5065

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



Distinguishing Between Solutions and Mechanical Mixtures

	Solutions	Mechanical Mixtures
Are the parts evenly mixed?	YES	NO
Can you see the separate parts (w/filter)?	NO	YES
Do particles fall to the bottom?	NO	YES
Can you see clearly through this mixture?	YES	

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Click image to the left for use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5066

- 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 5.7
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** 5.8 and in the videos below.

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

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Click image to the left for use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/653

- http://www.youtube.com/watch?v=UsouAlL-YZU&NR=1 (2:41)

MEDIA

Click image to the left for use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5067

FIGURE 5.8

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?

References

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Concept 6 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** 6.1. 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 6.1
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** 6.2. Each is described in detail below.

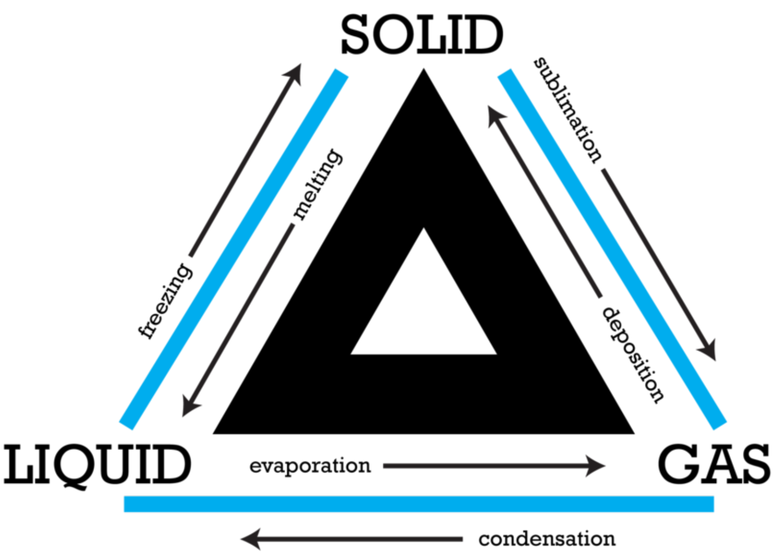

FIGURE 6.2
Which process changes a solid to a gas? Which process changes a gas to a solid?

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** 6.3.

FIGURE 6.3
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** 6.4?

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

FIGURE 6.4
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.

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** 6.5. 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.

FIGURE 6.5
Evaporation of water occurs even at relatively low temperatures. The water trapped in this pothole will evaporate sooner or later.

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** 6.6. A gas condenses when it is cooled below its boiling point. At what temperature does water vapor condense?

FIGURE 6.6
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** 6.7 shows chunks of dry ice in water 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 6.7
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** 6.8.

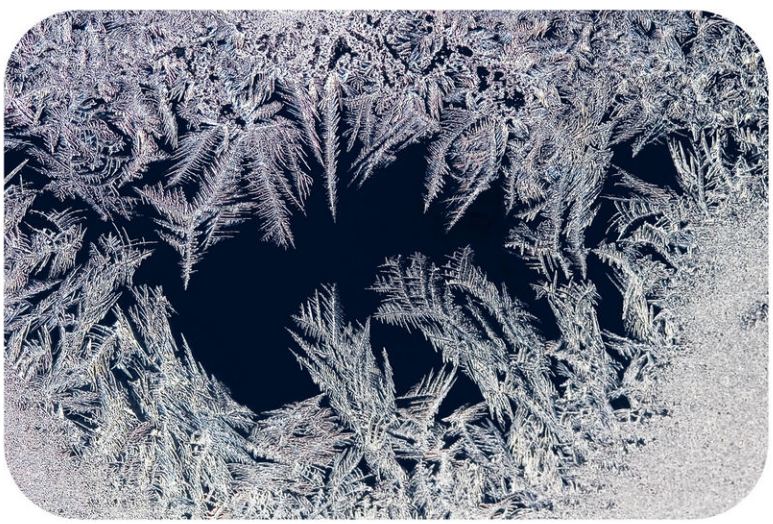

FIGURE 6.8
Frost is solid water that forms when water vapor undergoes deposition.

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.
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?

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CONCEPT 7 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

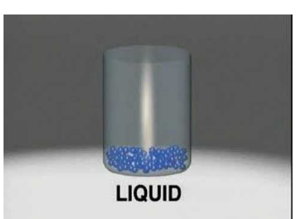
- energy
- gas
- kinetic energy
- kinetic theory of matter
- liquid
- plasma
- solid
- states of matter

Introduction

States of matter are the different forms in which matter can exist. Look at **Figure** 7.1. 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** 7.2 and described below. You can also watch videos about the three states at these URLs:

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



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Click image to the left for use the URL below.

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

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

FIGURE 7.1
This photo represents solid, liquid, and gaseous water. Where is the gaseous water in the picture?

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URL: http://www.ck12.org/flx/render/embeddedobject/5071

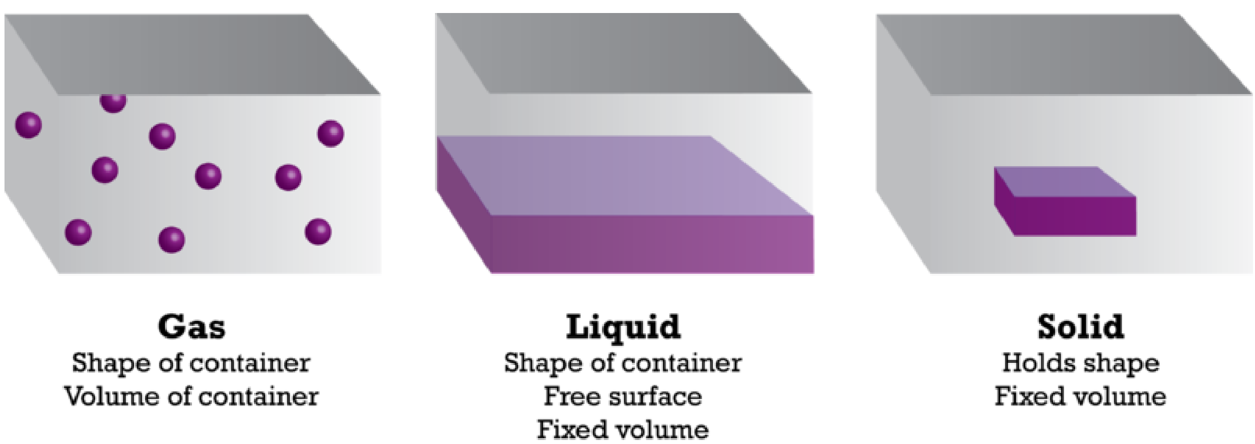

FIGURE 7.2
These three states of matter are common on Earth. What are some substances that usually exist in each of these states?

Solids

Ice is an example of solid matter. A **solid** is matter that has a fixed volume and a fixed shape. **Figure** 7.3 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 7.3

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** 7.4.

FIGURE 7.4

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

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** 7.5.
- Viscosity is a liquid's resistance to flowing. Thicker liquids are more viscous than thinner liquids. For example, the honey in **Figure** 7.5 is more viscous than the vinegar.

FIGURE 7.5
These images illustrate surface tension and viscosity of liquids.

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

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Click image to the left for use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5072

Gases

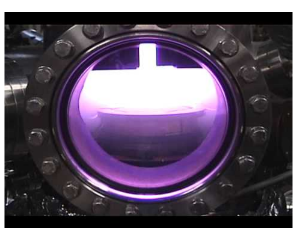
Water vapor is an example of a gas. A **gas** is matter that has neither a fixed volume nor a fixed shape. Instead, a gas takes both the volume and the shape of its container. It spreads out to take up all available space. You can see an example in **Figure** 7.6.

FIGURE 7.6
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** 7.7. 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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URL: http://www.ck12.org/flx/render/embeddedobject/5073

FIGURE 7.7
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 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.

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** 7.8 and in the animation at this URL: http://www.tutorvista.com/content/physics/physics-i/heat/kinetic-molecular-theory.php .

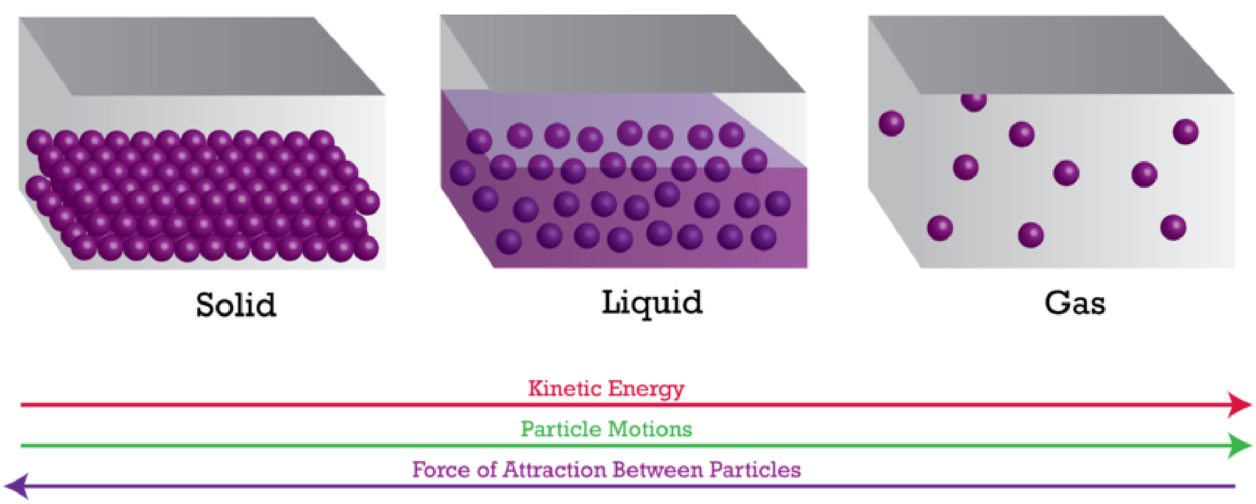

FIGURE 7.8
Kinetic energy is needed to overcome the force of attraction between particles of the same substance.

- 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 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** 7.9 is curved upward. Why doesn't the water overflow the glass?

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?

FIGURE 7.9
The surface of water in the glass is curved upward. How does surface tension explain this phenomenon?

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CONCEPT 8 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 8.1 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 .

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** 8.1 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.

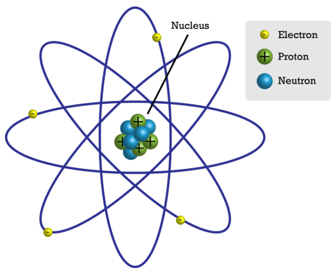


FIGURE 8.1
This simple atomic model shows the particles inside the atom.

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** 8.2. 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** 8.2.

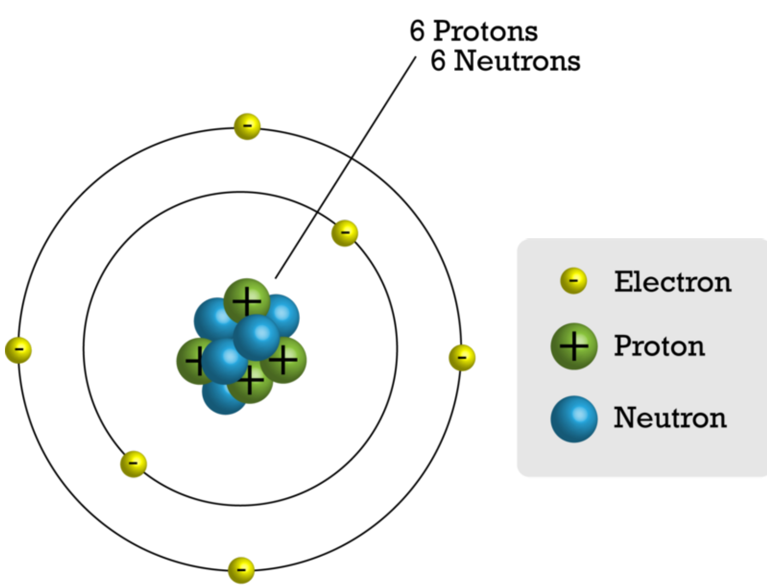


FIGURE 8.2
This model shows the particles that make up a carbon atom.

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.

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** 8.3). 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/ .

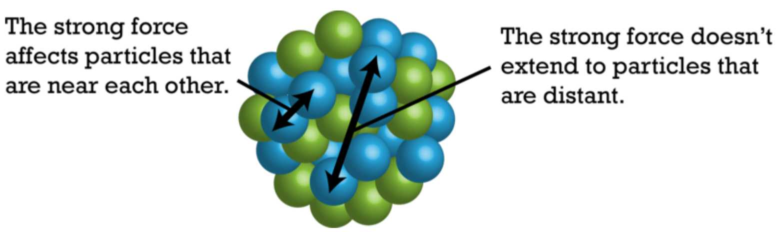


FIGURE 8.3
The strong force is effective only between particles that are very close together in the nucleus.

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** 8.4 shows how these numbers are usually written.

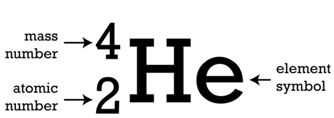


FIGURE 8.4
The symbol He stands for the element helium. Can you infer how many electrons a helium atom has?

- 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** 8.5. 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.

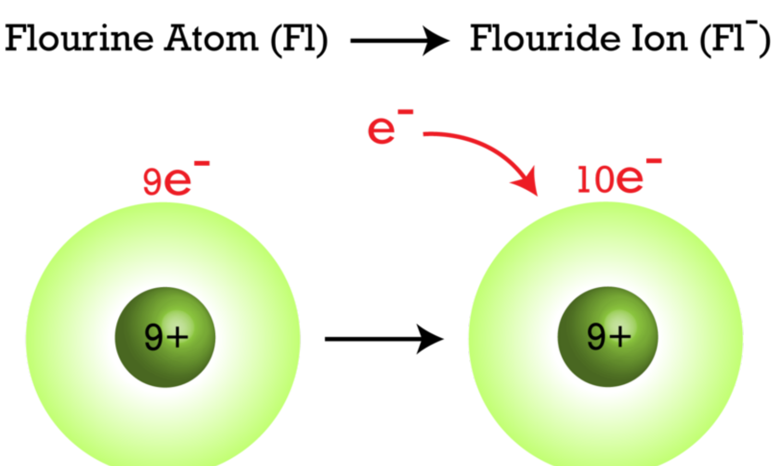
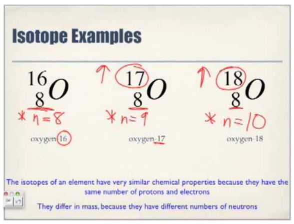


FIGURE 8.5
When a fluorine atom gains an electron, it becomes a negative fluoride ion.

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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Click image to the left for use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5074

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** 8.6. 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.

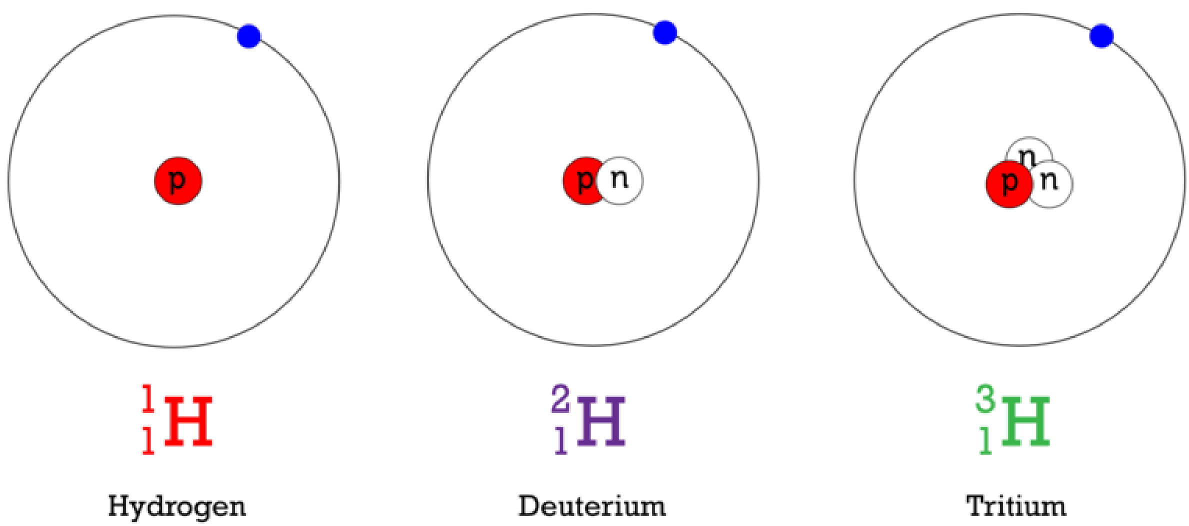


FIGURE 8.6

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?

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

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

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.

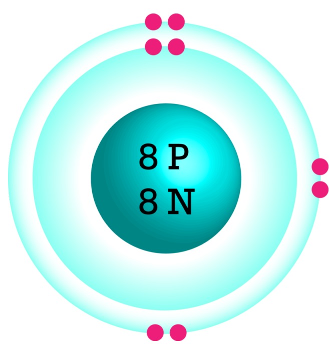
Lesson Review Questions

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?

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation. . CC-BY-NC-SA 3.0
3. CK-12 Foundation. . CC-BY-NC-SA 3.0
4. CK-12 Foundation. . CC-BY-NC-SA 3.0
5. CK-12 Foundation. . CC-BY-NC-SA 3.0
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CONCEPT 9 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** 9.1. 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 .

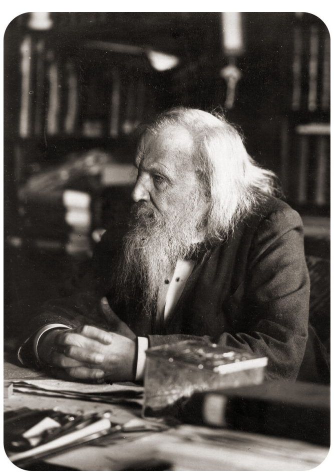

FIGURE 9.1
Dmitri Mendeleev developed the first periodic table of the elements in 1869.

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** 9.2. 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 9.2

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** 9.2)? 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** 9.3 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** 9.3. 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** 9.4 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

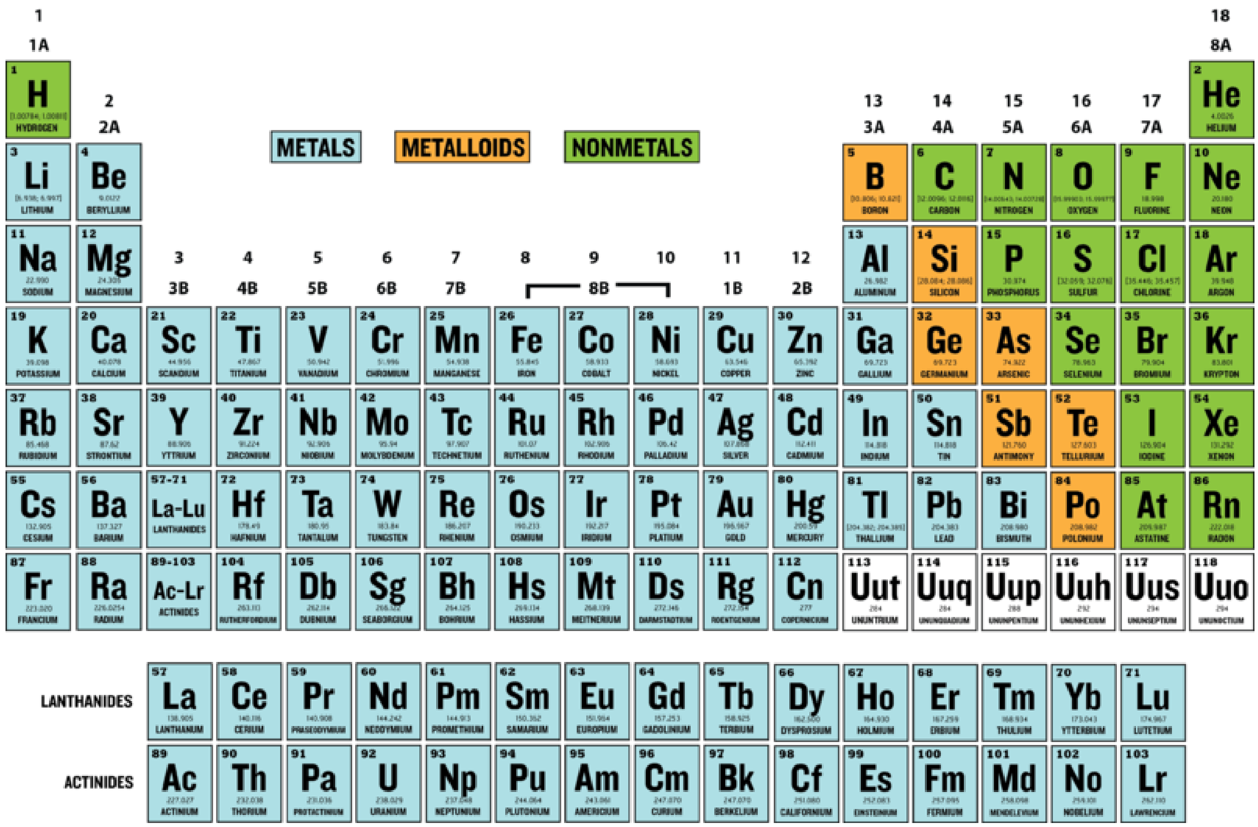

FIGURE 9.3

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

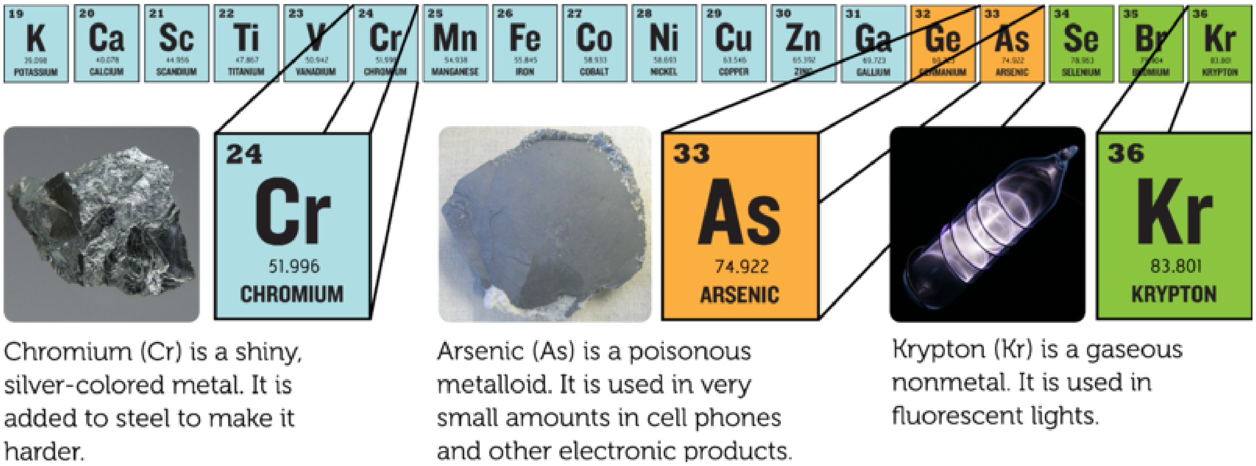

FIGURE 9.4

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?

References

1. . http://en.wikipedia.org/wiki/File:DIMendeleevCab.jpg . Public Domain
2. Dmitri Mendeleev. http://authors.ck12.org/wiki/index.php/File:Mendelejevs_periodiska_system_1871.png . Public Domain
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4. (Chromium and krypton) Jurii; (Arsenic) Aram Dulyan (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

Concept 10 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** 10.1. 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=m55kgyApYrY (3:17).

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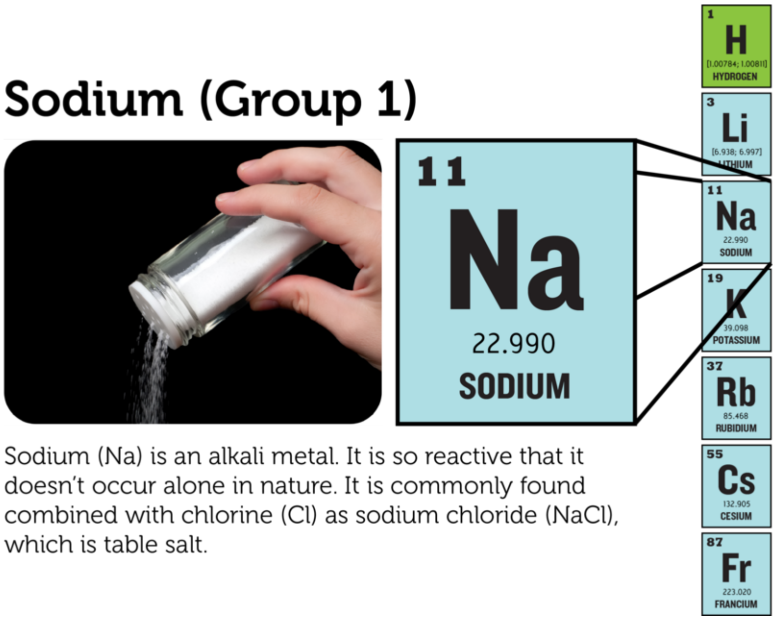

FIGURE 10.1

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** 10.2). 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** 10.3). 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.

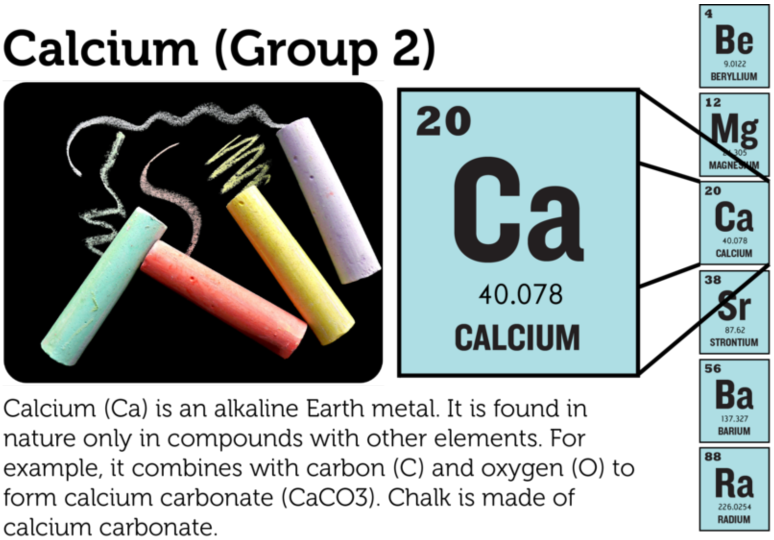

FIGURE 10.2
The alkaline Earth metals make up group 2 of the periodic table.

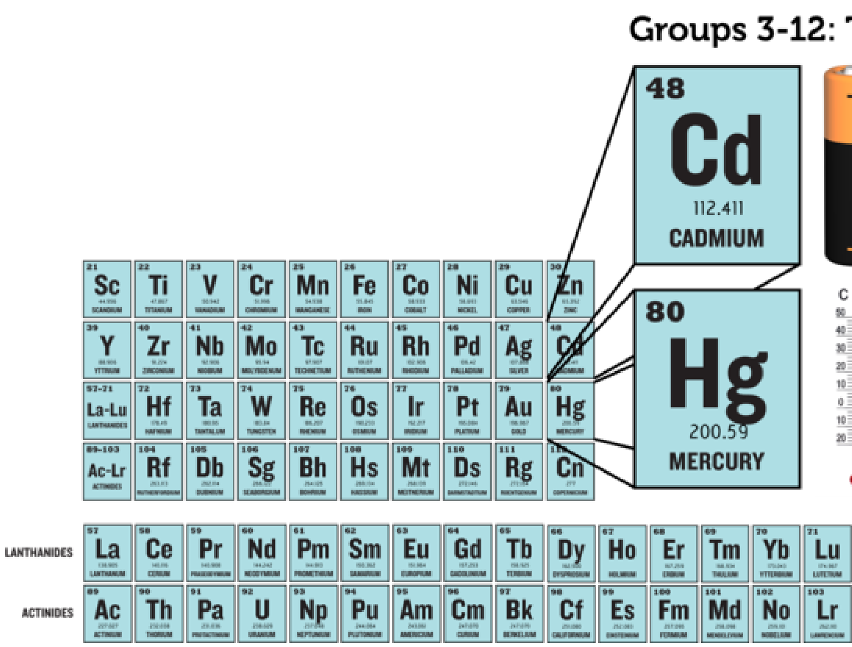

FIGURE 10.3
All the elements in groups 3–12 are transition metals.

Groups 13-16: Groups Containing Metalloids

Groups 13–16 each contain one or more metalloids. These groups are shown in **Figure** 10.4.

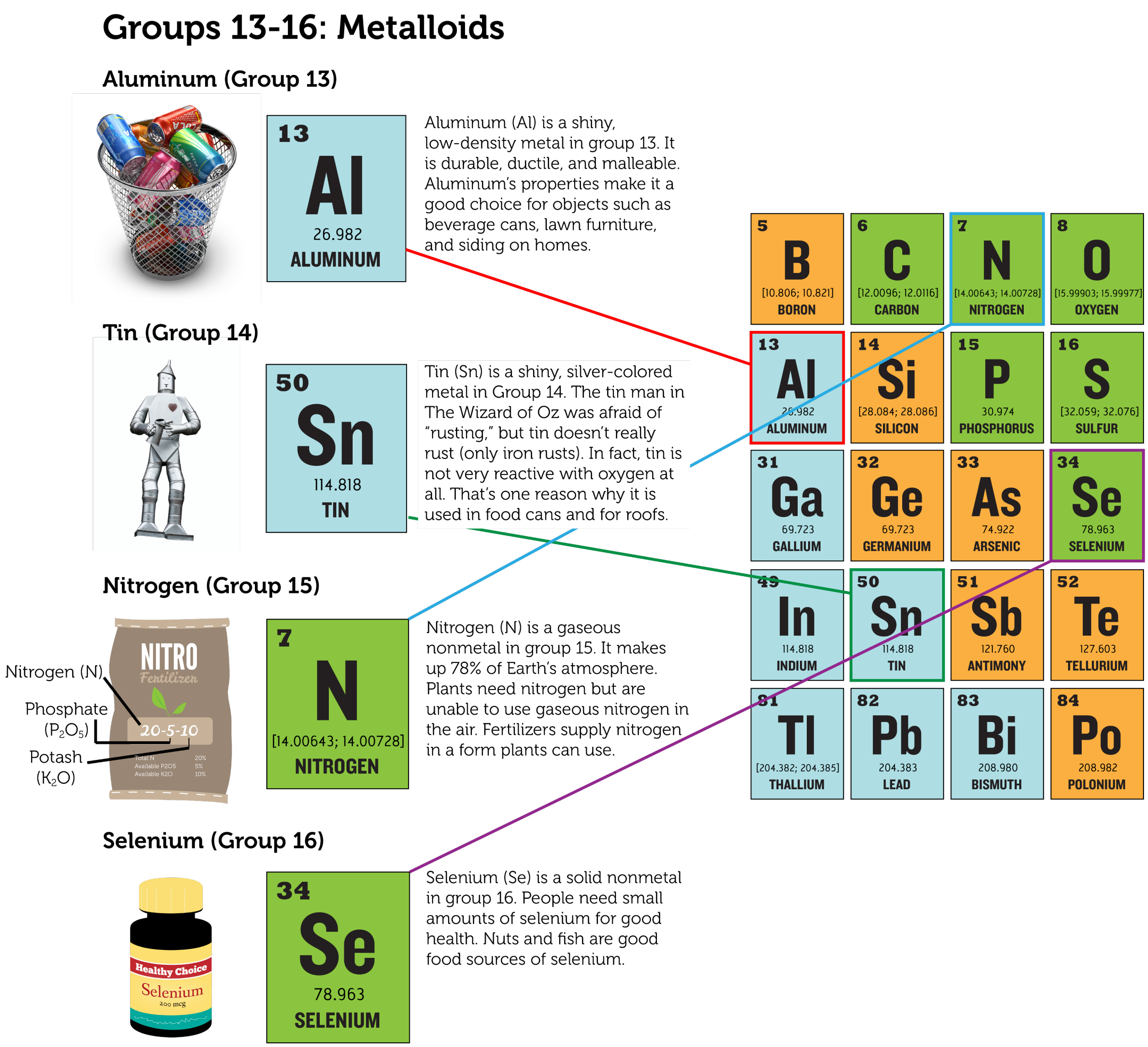

FIGURE 10.4

These groups each contain one or more metalloids.

- 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 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** 10.5). 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 .

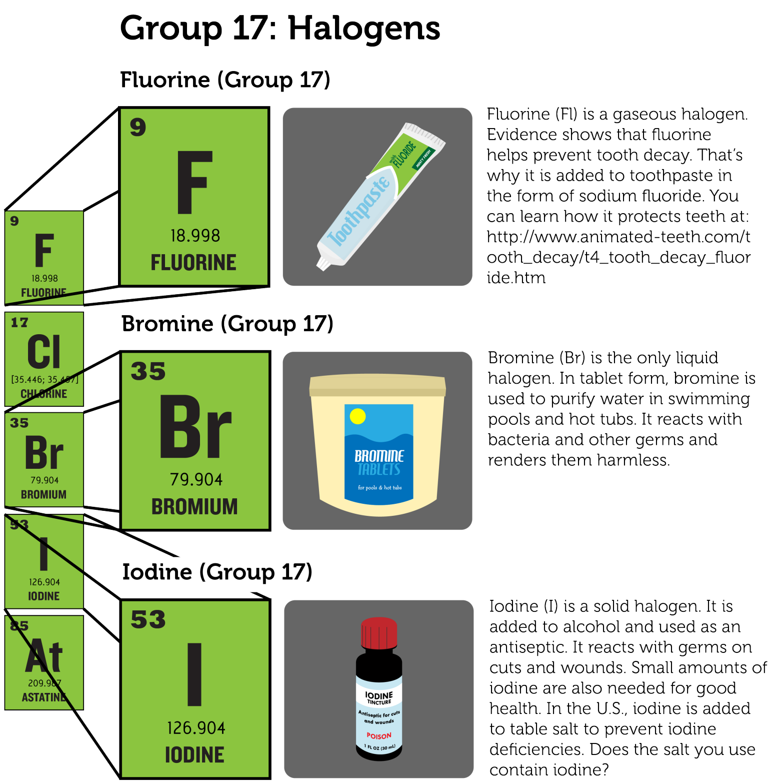

FIGURE 10.5
Group 17 consists of the nonmetals called halogens.

Group 18: Noble Gases

Group 18 elements are nonmetals called **noble gases** (see **Figure** 10.6). 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).

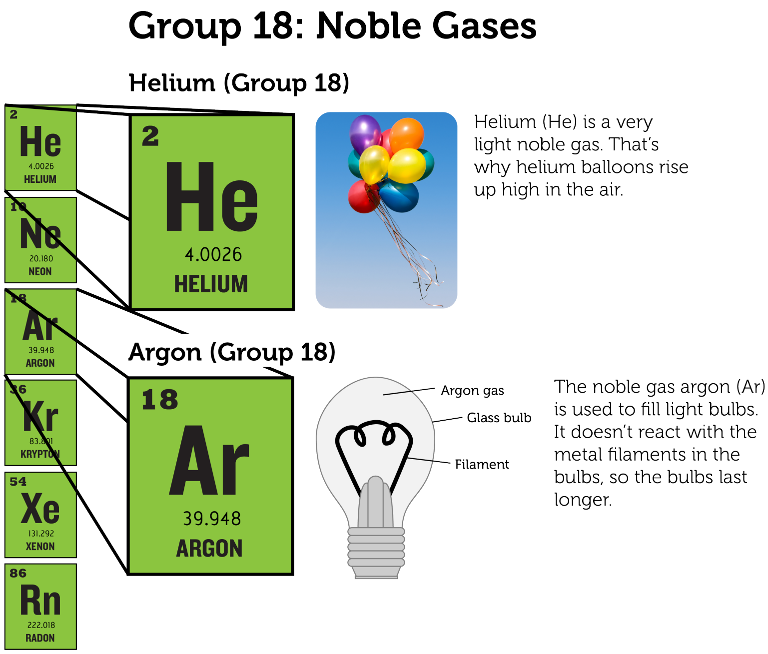

FIGURE 10.6
Noble gases include helium and argon.

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.

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?

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?

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CONCEPT 11 Classes of Elements

Lesson Objectives

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

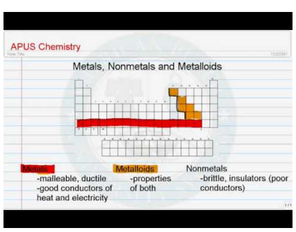
Vocabulary

- 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)



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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** above) 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).

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

Most metals are shiny. That's because they reflect a lot of light. This tray is made mainly of the metal silver (Ag).

Most metals are ductile. This means they can be pulled into long thin shapes, like these wires made of the metal copper (Cu).

Most metals are malleable. This means they can be formed into thin sheets without breaking, like this foil made of the metal aluminum (Al).

FIGURE 11.1

The three properties described here characterize most metals.

pots and stovetops. Metals have other characteristic properties as well. Most are shiny, ductile, and malleable. These properties are illustrated in **Figure** 11.1. 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** above. 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** 11.2. 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 11.2

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** above, 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** 11.3. 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** 11.4 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.

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** 11.1 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.

FIGURE 11.3
Metalloids share properties with both metals and nonmetals.

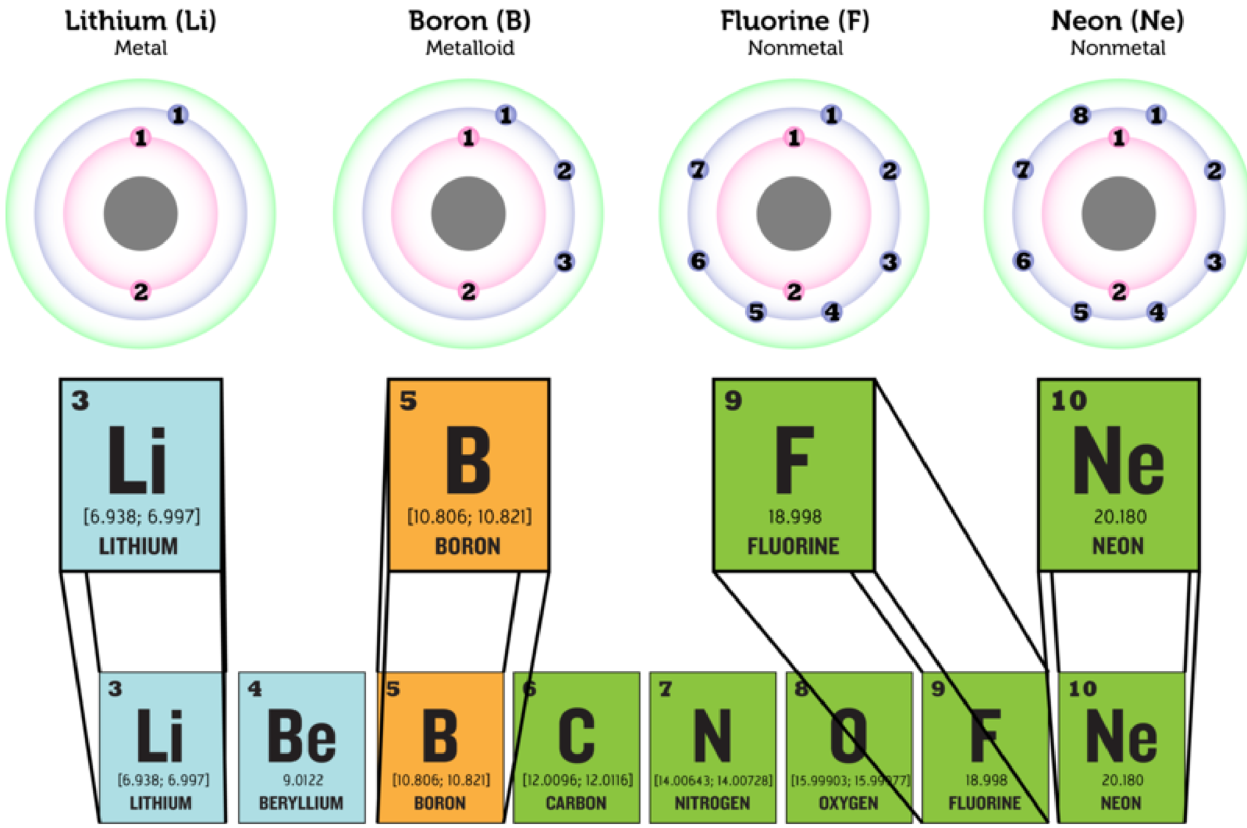
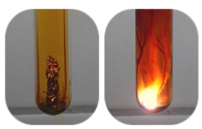


FIGURE 11.4
The number of electrons increases from left to right across each period in the periodic table. In period 2, lithium (Li) has the fewest electrons and neon (Ne) has the most. How do the numbers of electrons in their outer energy levels compare?

TABLE 11.1: These examples show the relative reactivity of elements in the three classes.

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.

TABLE 11.1: (continued)

Element	Description
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. This picture shows it reacting with aluminum foil in a test tube. The aluminum starts burning within a couple of minutes of the bromine contacting it.
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

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

1. 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

1. 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.
2. 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?

References

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CONCEPT 12 Chromosomes

- Define gene and chromosome.
- Distinguish between chromosomes and chromatin.
- Explain the significance of sister chromatids.
- Describe homologous chromosomes.

How is it assured that every cell in your body has the same DNA?

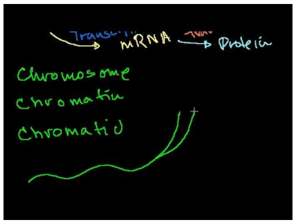
Chromosomes, like those shown here, must form prior to cell division, to ensure that each daughter cell receives a complete set of genetic material. Essentially, each new cell receives half of each "X-shaped" chromosome.

Chromosomes

In eukaryotic cells, the nucleus divides before the cell itself divides. The process in which the nucleus divides is called mitosis. Before mitosis occurs, a cell's DNA is replicated. This is necessary so that each daughter cell will have a complete copy of the genetic material from the parent cell. How is the replicated DNA sorted and separated so that each daughter cell gets a complete set of the genetic material? To understand how this happens, you need to know more about chromosomes.

Chromosomes are coiled structures made of DNA and proteins. Chromosomes are the form of the genetic material of a cell during cell division. It is this coiled structure that ensures proper segregation of the chromosomes during cell division. During other phases of the cell cycle, DNA is not coiled into chromosomes. Instead, it exists as a grainy material called **chromatin**.

The vocabulary of DNA: chromosomes, chromatids, chromatin, transcription, translation, and replication is discussed at http://www.youtube.com/watch?v=s9HPNwXd9fk (18:23).



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Chromatids and the Centromere

DNA condenses and coils into the familiar X-shaped form of a chromosome, shown in **Figure** 12.1, only after it has replicated. (You can watch DNA coiling into a chromosome at the link below.) Because DNA has already replicated, each chromosome actually consists of two identical copies. The two copies are called sister **chromatids**. They are attached to one another at a region called the **centromere**. A remarkable animation can be viewed at http://www.hhmi.org/biointeractive/media/DNAi_packaging_vo2-sm.mov .

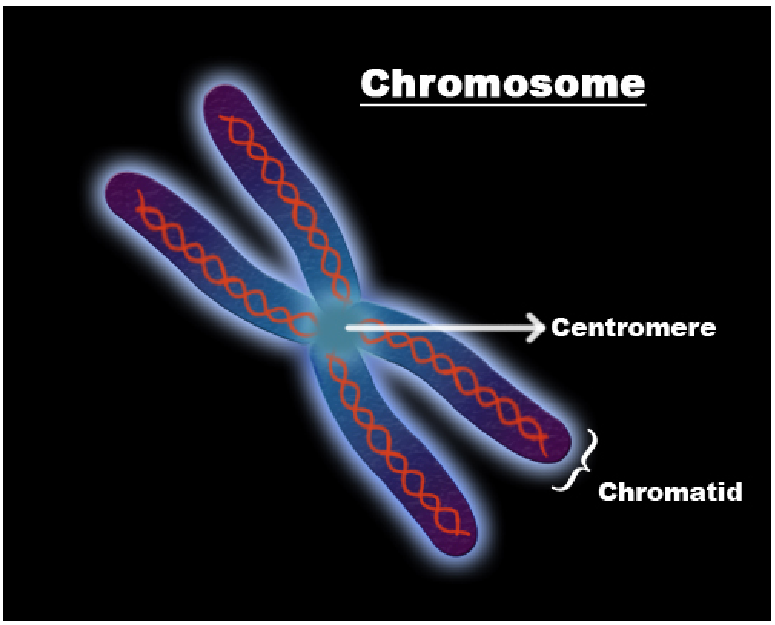


FIGURE 12.1

Chromosome. After DNA replicates, it forms chromosomes like the one shown here.

Chromosomes and Genes

The DNA of a chromosome is encoded with genetic instructions for making proteins. These instructions are organized into units called **genes**. Most genes contain the instructions for a single protein. There may be hundreds or even thousands of genes on a single chromosome.

Human Chromosomes

Human cells normally have two sets of chromosomes, one set inherited from each parent. There are 23 chromosomes in each set, for a total of 46 chromosomes per cell. Each chromosome in one set is matched by a chromosome of the same type in the other set, so there are actually 23 pairs of chromosomes per cell. Each pair consists of chromosomes of the same size and shape that also contain the same genes. The chromosomes in a pair are known as **homologous chromosomes**.

Summary

- Chromosomes are coiled structures made of DNA and proteins.
- Chromosomes form after DNA replicates; prior to replication, DNA exists as chromatin.
- Chromosomes contain genes, which code for proteins.
- Human cells normally have 46 chromosomes, made up of two sets of chromosomes, one set inherited from each parent.

Practice

Use this resource to answer the questions that follow.

- **Chromosomes** at http://johnkyrk.com/chromosomestructure.html .

1. What is a chromosome?
2. What is chromatin?
3. What is a histone?

Review

1. What are chromosomes? When do they form?
2. Identify the chromatids and the centromere of a chromosome.
3. Explain how chromosomes are related to chromatin. Why are chromosomes important for mitosis?
4. How many chromosomes are in a normal human cell?

References

1. Zappy's. Diagram of a chromosome. CC BY-NC 3.0

CONCEPT 13 Asexual vs. Sexual Reproduction

- Distinguish cell division from asexual reproduction.
- Compare and contrast asexual and sexual reproduction.
- Distinguish binary fission, fragmentation, and budding.
- Define zygote.
- Differentiate between haploid and diploid.

One parent or two?

That is the main difference between sexual and asexual reproduction. Sexual reproduction just means combining genetic material from two parents. Asexual reproduction produces offspring genetically identical to the one parent.

Reproduction: Asexual vs. Sexual

Cell division is how organisms grow and repair themselves. It is also how many organisms produce offspring. For many single-celled organisms, reproduction is a similar process. The parent cell simply divides to form two daughter cells that are identical to the parent. In many other organisms, two parents are involved, and the offspring are not identical to the parents. In fact, each offspring is unique. Look at the family in **Figure** 13.1. The children resemble their parents, but they are not identical to them. Instead, each has a unique combination of characteristics inherited from both parents.

Reproduction is the process by which organisms give rise to offspring. It is one of the defining characteristics of living things. There are two basic types of reproduction: asexual reproduction and sexual reproduction.

FIGURE 13.1
Family Portrait: Mother, Daughter, Father, and Son. Children resemble their parents, but they are never identical to them. Do you know why this is the case?

Asexual Reproduction

Asexual reproduction involves a single parent. It results in offspring that are genetically identical to each other and to the parent. All prokaryotes and some eukaryotes reproduce this way. There are several different methods of asexual reproduction. They include binary fission, fragmentation, and budding.

- **Binary fission** occurs when a parent cell splits into two identical daughter cells of the same size.
- **Fragmentation** occurs when a parent organism breaks into fragments, or pieces, and each fragment develops into a new organism. Starfish, like the one in **Figure** 13.3, reproduce this way. A new starfish can develop from a single ray, or arm. Starfish, however, are also capable of sexual reproduction.
- **Budding** occurs when a parent cell forms a bubble-like bud. The bud stays attached to the parent cell while it grows and develops. When the bud is fully developed, it breaks away from the parent cell and forms a new organism. Budding in yeast is shown in **Figure** 13.3.

Asexual reproduction can be very rapid. This is an advantage for many organisms. It allows them to crowd out other organisms that reproduce more slowly. Bacteria, for example, may divide several times per hour. Under ideal conditions, 100 bacteria can divide to produce millions of bacterial cells in just a few hours! However, most bacteria do not live under ideal conditions. If they did, the entire surface of the planet would soon be covered with them. Instead, their reproduction is kept in check by limited resources, predators, and their own wastes. This is true of most other organisms as well.

Sexual Reproduction

Sexual reproduction involves two parents. As you can see from **Figure** 13.4, in sexual reproduction, parents produce reproductive cells—called **gametes**—that unite to form an offspring. Gametes are **haploid** cells. This means they contain only half the number of chromosomes found in other cells of the organism. Gametes are produced by a type of cell division called **meiosis**, which is described in detail in a subsequent concept. The process in which two gametes unite is called **fertilization**. The fertilized cell that results is referred to as a **zygote**. A zygote is **diploid** cell, which means that it has twice the number of chromosomes as a gamete.

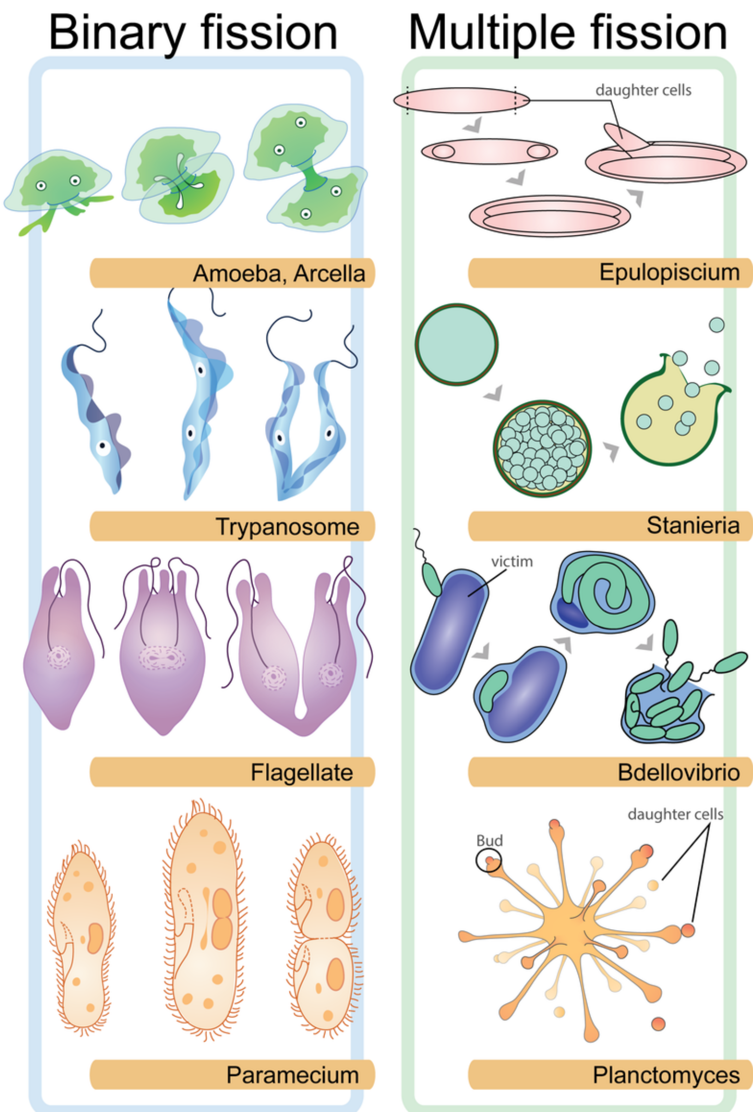
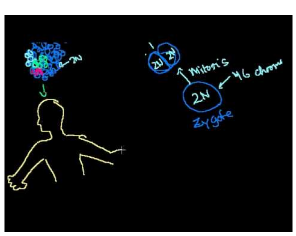


FIGURE 13.2

Binary Fission in various single-celled organisms (left). Cell division is a relatively simple process in many single-celled organisms. Eventually the parent cell will pinch apart to form two identical daughter cells. In multiple fission (right), a multinucleated cell can divide to form more than one daughter cell. Multiple fission is more often observed among protists.

Mitosis, Meiosis and Sexual Reproduction is discussed at http://www.youtube.com/watch?v=kaSIjIzAtYA .



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Summary

- Asexual reproduction involves one parent and produces offspring that are genetically identical to each other and to the parent.
- Sexual reproduction involves two parents and produces offspring that are genetically unique.

FIGURE 13.3
Starfish reproduce by fragmentation and yeasts reproduce by budding. Both are types of asexual reproduction.

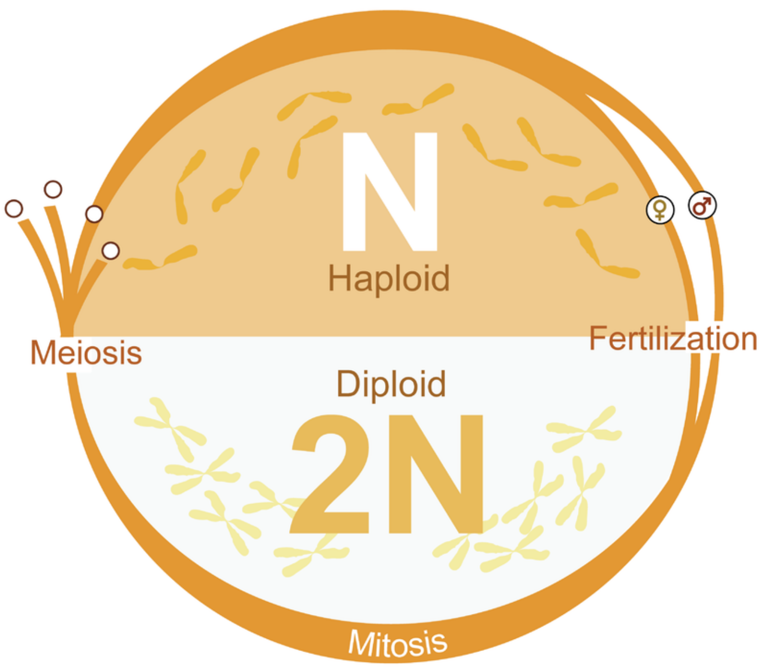

FIGURE 13.4
Cycle of Sexual Reproduction. Sexual reproduction involves the production of haploid gametes by meiosis. This is followed by fertilization and the formation of a diploid zygote. The number of chromosomes in a gamete is represented by the letter n. Why does the zygote have 2n, or twice as many, chromosomes?

- During sexual reproduction, two haploid gametes join in the process of fertilization to produce a diploid zygote.
- Meiosis is the type of cell division that produces gametes.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Life Cycles**

1. Define parthenogenesis.
2. What type of organisms can benefit from asexual reproduction?
3. What are the four major types of asexual reproduction?
4. Give two examples of organisms that reproduce by binary fission.
5. What is the difference between budding and fragmentation?
6. What is sexual reproduction?
7. How many chromosomes are in a human gamete?
8. What is meiosis?

Review

1. What are three types of asexual reproduction?
2. Define gamete and zygote. What number of chromosomes does each have (in humans)?
3. What happens during fertilization?
4. Compare and contrast asexual and sexual reproduction.

References

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2. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Illustrates binary fission in single-celled organisms and multiple fission in multinucleated cells. CC BY-NC 3.0
3. Starfish: Flickr:amanderson2; Yeast: Zappy's. Starfish and yeasts are examples of organisms that reproduce asexually. Starfish: CC BY 2.0; Yeast: CC BY-NC 3.0
4. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. An illustrative overview of the sexual reproduction process. CC BY-NC 3.0

CONCEPT 14 Mendel's Discoveries

Lesson Objectives

- Identify Mendel, and explain why peas were good plants for him to study.
- Outline Mendel's experiments, and state his laws of heredity.
- Summarize Mendel's scientific legacy.

Lesson Vocabulary

- dominant
- genetics
- law of independent assortment
- law of segregation
- Mendel
- pollination
- recessive

Introduction

People have long known that offspring are similar to their parents. Whether it's puppies or people, offspring and parents usually share many traits. However, before Gregor Mendel's research, people didn't know how parents pass traits to their offspring.

A Monk and His Peas

Mendel was an Austrian Monk who lived in the 1800s. You can see his picture in **Figure** 14.1.

Mendel the Scientist

Mendel didn't call himself a scientist. But he had all the traits of good scientist. He was observant and curious, and he asked a lot of questions. He also tried to find answers to his questions by doing experiments. Working alone in his garden in the mid-1800s, he grew thousands of pea plants over many years. He carefully crossed plants with different traits. Then he observed what traits showed up in their offspring. He repeated each experiment many times.

Why Study Peas?

Pea plants were a good choice to study for several reasons. One reason is that they are easy to grow. They also grow quickly. In addition, peas have many traits that are easy to observe, and each trait exists in two different forms.

FIGURE 14.1
Gregor Mendel

Figure 14.2 shows the traits that Mendel studied in pea plants. For example, one trait is flower color. Flowers may be either white or violet. Another trait is stem length. Plants may be either tall or short.

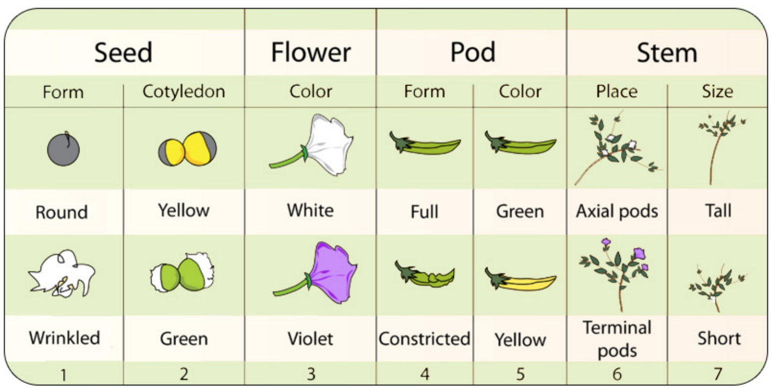


FIGURE 14.2
Traits Mendel studied in peas

Pea plants reproduce sexually. The male gametes are released by tiny grains of pollen. The female gametes lie deep within the flowers. Fertilization occurs when pollen from one flower reaches the female gametes in the same or a different flower. This is called **pollination**. Mendel was able to control which plants pollinated each other. He transferred pollen by hand from flower to flower.

Mendel's Experiments and Laws of Heredity

At first, Mendel studied one trait at a time. This was his first set of experiments. These experiments led to his first law, the law of segregation. Then Mendel studied two traits at a time. This was his second set of experiments. These experiments led to his second law, the law of independent assortment.

Mendel's First Set of Experiments

An example of Mendel's first set of experiments is his research on flower color. He transferred pollen from a plant with white flowers to a plant with violet flowers. This is called cross-pollination. Then Mendel observed flower color in their offspring. The offspring formed the first generation (F1). You can see the outcome of this experiment in **Figure** 14.3.

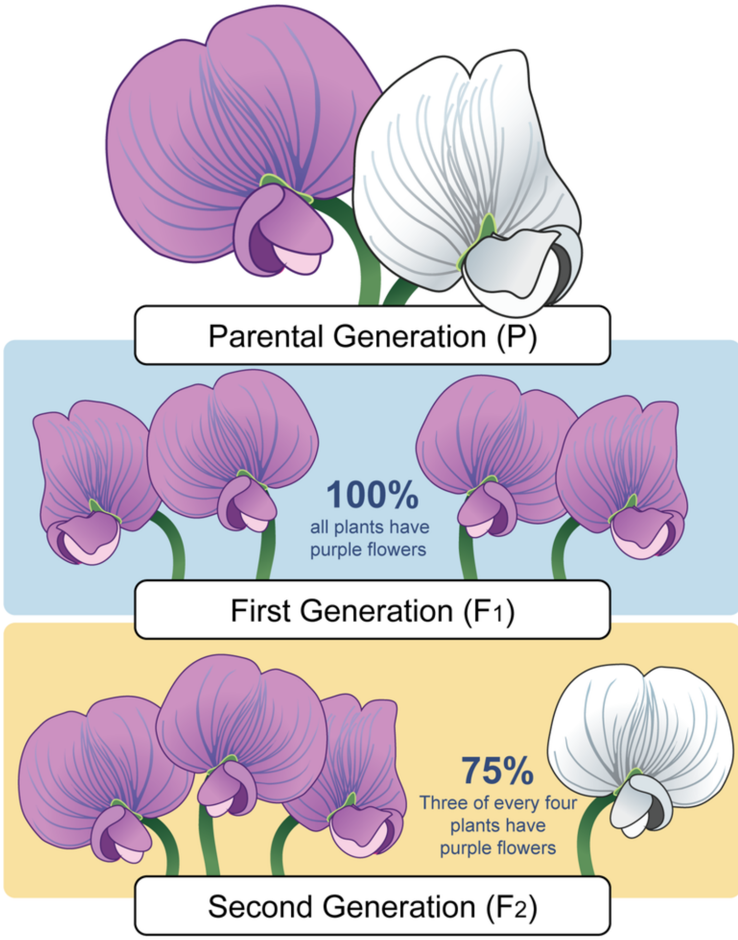


FIGURE 14.3
Mendel's flower color experiment

All of the F1 plants had violet flowers. Mendel wondered, "What happened to the white form of the trait?" "Did it disappear?" If so, the F1 plants should have only violet-flowered offspring. Mendel let the FI plants pollinate themselves. This is called self-pollination. Then he observed flower color in their offspring. These offspring formed the second generation (F2). Surprisingly, the trait of white flowers showed up in the F2 plants. One out of every four F2 plants had white flowers. The other three out of four had violet flowers. In other words, F2 plants with violet flowers and F2 plants with white flowers had a 3:1 ratio.

Mendel repeated this experiment with each of the other traits. For each trait, he got the same results. One form of the trait seemed to disappear in the F1 plants. Then it showed up again in the F2 plants. Moreover, the two forms of the trait always showed up in the F2 plants in the same 3:1 ratio.

Law of Segregation

Based on these results, Mendel concluded that each trait is controlled by two factors. He also concluded that one of the factors for each trait dominates the other. He described the dominating factor as **dominant**. He used the term **recessive** to describe the other factor. If both factors are present in an individual, only the dominant factor is expressed. This explains why one form of a trait always seems to disappear in the F1 plants. These plants inherit both factors for the trait, but only the dominant factor shows up. The recessive factor is hidden.

When F1 plants reproduce, the two factors separate and go to different gametes. This is Mendel's first law, the **law of segregation**. It explains why both forms of the trait show up again in the F2 plants. One out of four F2 plants inherits two of the recessive factors for the trait. In these plants, the recessive form of the trait is expressed.

Second Set of Experiments

Mendel wondered whether different traits are inherited together. For example, are seed form and seed color passed together from parents to offspring? Or do the two traits split up in the offspring? To answer these questions, Mendel studied two traits at a time. For example, he crossed plants that had round, yellow seeds with plants that had wrinkled, green seeds. Then he observed how the two traits showed up in their offspring (F1). You can see the results of this cross in **Figure** 14.4. All of the F1 plants had round, yellow seeds. The wrinkled and green forms of the traits seemed to disappear in the F1 plants.

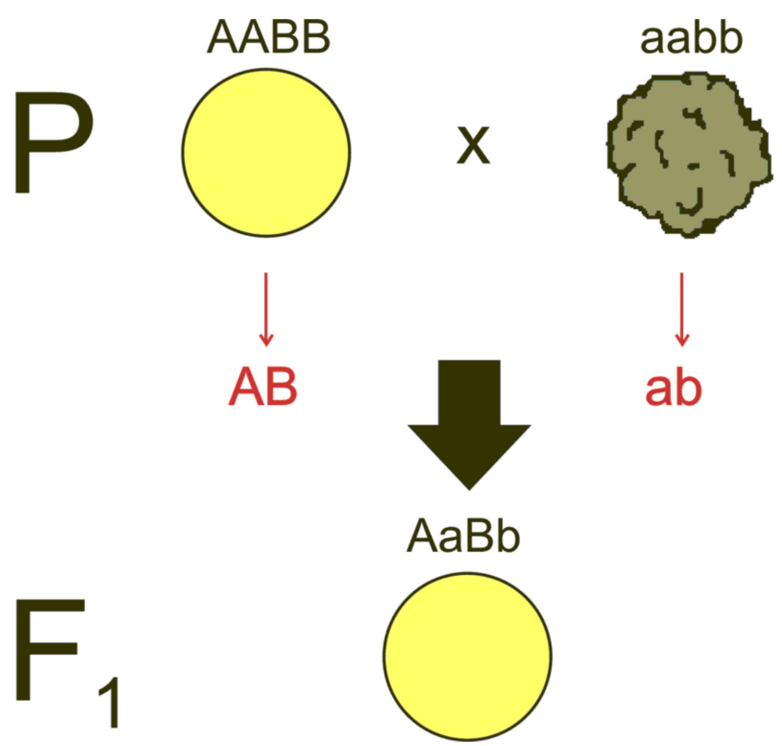


FIGURE 14.4
Seed color: B = yellow (dominant); b = green (recessive)

Then Mendel let the F1 plants self-pollinate. Their offspring, the F2 plants, had all possible combinations of the two traits. You can see this in **Figure** 14.5. For example there were plants that had round, green seeds, as well as plants that had wrinkled, yellow seeds. In this case the ratios were 9:3:3:1. The ratios are shown across the bottom of **Figure** 14.5.

Mendel repeated this experiment with other combinations of two traits. In each case, he got the same results. One form of each trait seemed to disappear in the F1 plants. Then these forms reappeared in the F2 plants in all possible combinations. Moreover, the different combinations of traits always occurred in the same 9:3:3:1 ratio.

Law of Independent Assortment

The results of Mendel's two-trait experiments led to the **law of independent assortment**. This law states that factors controlling different traits go to gametes independently of each other. This explains why F2 plants have all possible combinations of the two traits.

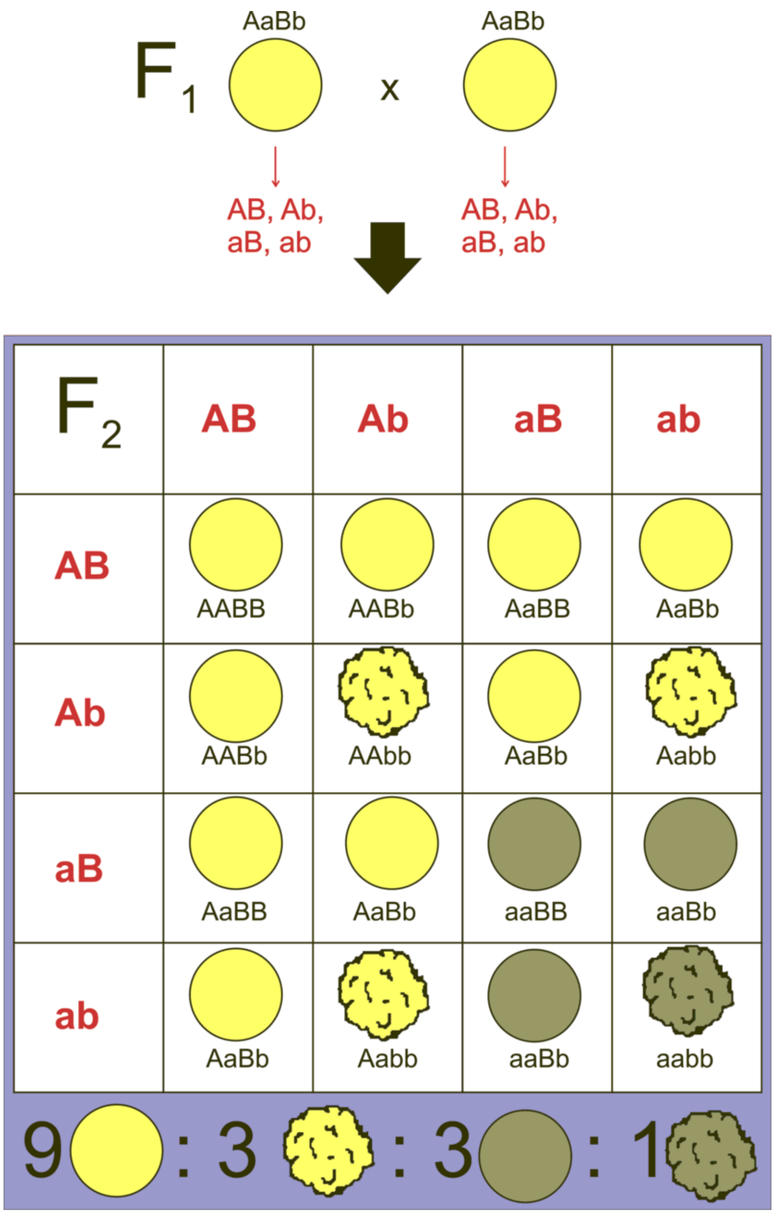


FIGURE 14.5

F2 plants produced when F1 plants self-pollinate

Mendel's Legacy

You might think that Mendel's discoveries would have made him an instant science rock star. He'd found the answers to age-old questions about heredity. In fact, Mendel's work was largely ignored until 1900. That's when three other scientists independently arrived at Mendel's laws. Only then did people appreciate what a great contribution to science Mendel had made. Mendel's discoveries form the basis of the modern science of genetics. **Genetics** is the science of heredity. For his discoveries, Mendel is now called the "father of genetics."

Watch this entertaining, upbeat video for an excellent review of Mendel's life and work. It's also a good introduction to the next lesson, "Introduction to Genetics."

http://www.youtube.com/watch?v=GTiOETaZg4w

Lesson Summary

- Gregor Mendel was an Austrian monk who studied heredity in pea plants in the mid-1800s. Peas were a good choice for this purpose for several reasons.
- Mendel first experimented with one trait at a time. This led to his law of segregation. According to this law, the two factors that control a trait separate and go to different gametes.
- Mendel then experimented with two traits at a time. This led to his law of independent assortment. According to this law, the factors that control different traits go to gametes independently of each other.
- Mendel's discoveries were not appreciated until 1900. Now Mendel is called the "father of genetics." Genetics is the science of heredity.

Lesson Review Questions

Recall

1. Who was Gregor Mendel?
2. Why were peas a good choice of plants for Mendel to study?
3. State Mendel's laws.

Apply Concepts

4. Some plants reproduce asexually. What results would Mendel have obtained if he had chosen to study these plants instead of peas?

Think Critically

5. Why did Mendel need to grow two offspring generations (F1 and F2) to develop his law of segregation?
6. Explain how the results of Mendel's second set of experiments led to his law of independent assortment.

Points to Consider

Mendel's research revealed that traits are controlled by "factors" that parents pass to their offspring. Today, we know that Mendel's "factors" are genes.

1. What are genes?
2. How do genes control traits?

References

1. Erik Nordenskiöld. Gregor Mendel . Public Domain
2. Jodi So and Rupali Raju. Traits studied by Mendel . CC BY-NC 3.0
3. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0

4. Miguelferig. F1 generation . public domain
5. Miguelferig. F1 generation . public domain

CONCEPT 15 Meiosis

- Give an overview of sexual reproduction.
- Summarize meiosis.
- Outline the stages of meiosis.
- Describe how chromosomes separate in meiosis I and meiosis II.

How do you make a cell with half the DNA?

Meiosis. This allows cells to have half the number of chromosomes, so two of these cells can come back together to form a new organism with the complete number of chromosomes. This process not only helps produce gametes, it also ensures genetic variation.

Meiosis

The process that produces haploid gametes is meiosis. **Meiosis** is a type of cell division in which the number of chromosomes is reduced by half. It occurs only in certain special cells of the organisms. During meiosis, homologous chromosomes separate, and **haploid** cells form that have only one chromosome from each pair. Two cell divisions occur during meiosis, and a total of four haploid cells are produced. The two cell divisions are called meiosis I and meiosis II. The overall process of meiosis is summarized in **Figure** 15.1. You can watch an animation of meiosis at this link: http://www.youtube.com/watch?v=D1_-mQS_FZ0 .

Phases of Meiosis

Meiosis I begins after DNA replicates during interphase of the cell cycle. In both meiosis I and meiosis II, cells go through the same four phases as mitosis - prophase, metaphase, anaphase and telophase. However, there are

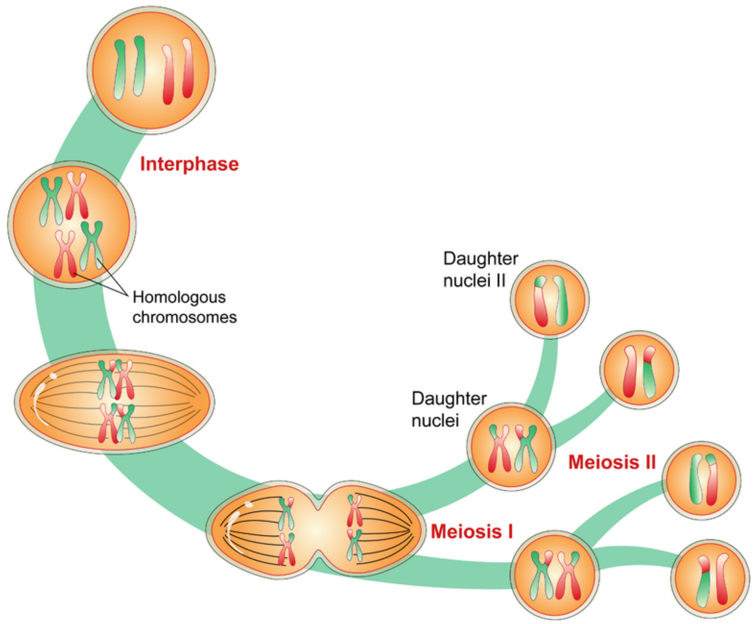


FIGURE 15.1

Overview of Meiosis. During meiosis, homologous chromosomes separate and go to different daughter cells. This diagram shows just the nuclei of the cells. Notice the exchange of genetic material that occurs prior to the first cell division.

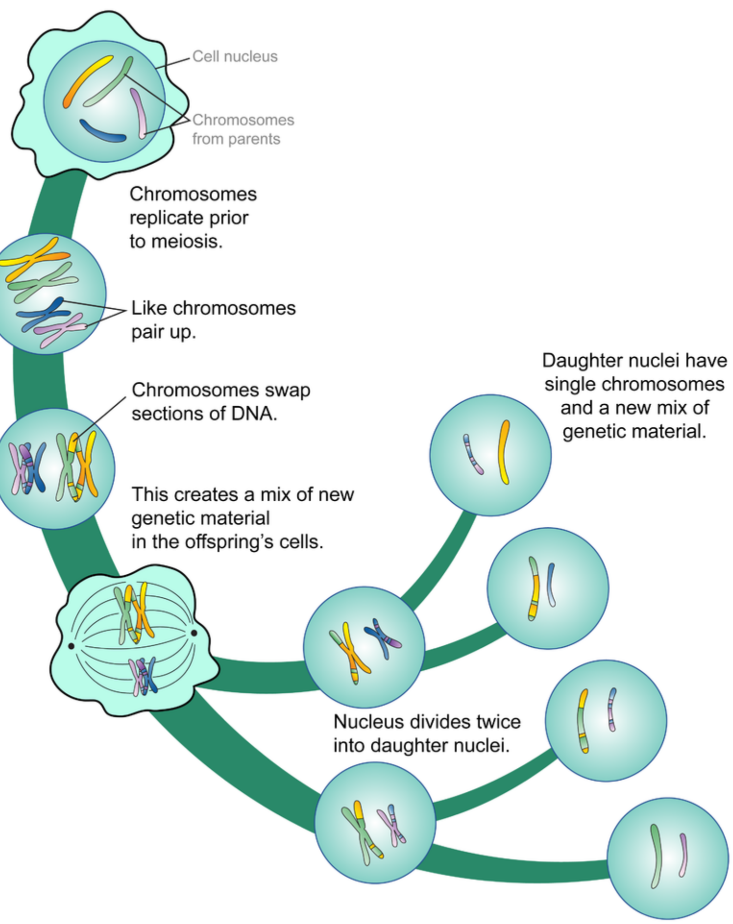


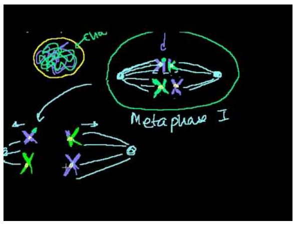
FIGURE 15.2

Phases of Meiosis. This flowchart of meiosis shows meiosis I in greater detail than meiosis II. Meiosis I—but not meiosis II—differs somewhat from mitosis. Compare meiosis I in this flowchart with the earlier figure featuring mitosis. How does meiosis I differ from mitosis?

important differences between meiosis I and mitosis. The flowchart in **Figure** 15.2 shows what happens in both meiosis I and II.

Compare meiosis I in this flowchart with the figure from the *Mitosis and Cytokinesis* concept. How does meiosis I differ from mitosis? Notice at the beginning of meiosis (prophase I), homologous chromosomes exchange segments of DNA. This is known as **crossing-over**, and is unique to this phase of meiosis.

The phases of meiosis are discussed at http://www.youtube.com/watch?v=ijLc52LmFQg (27:23).



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Click image to the left for use the URL below.

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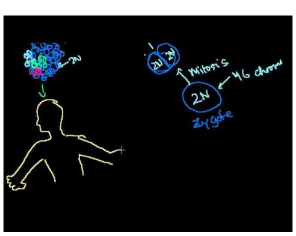
Meiosis I

1. Prophase I: The nuclear envelope begins to break down, and the chromosomes condense. Centrioles start moving to opposite poles of the cell, and a spindle begins to form. Importantly, **homologous chromosomes** pair up, which is unique to prophase I. In prophase of mitosis and meiosis II, homologous chromosomes do not form pairs in this way. Crossing-over occurs during this phase (see the *Genetic Variation* concept).
2. Metaphase I: Spindle fibers attach to the paired homologous chromosomes. The paired chromosomes line up along the equator (middle) of the cell. This occurs only in metaphase I. In metaphase of mitosis and meiosis II, it is sister chromatids that line up along the equator of the cell.
3. Anaphase I: Spindle fibers shorten, and the chromosomes of each homologous pair start to separate from each other. One chromosome of each pair moves toward one pole of the cell, and the other chromosome moves toward the opposite pole.
4. Telophase I and Cytokinesis: The spindle breaks down, and new nuclear membranes form. The cytoplasm of the cell divides, and two haploid daughter cells result. The daughter cells each have a random assortment of chromosomes, with one from each homologous pair. Both daughter cells go on to meiosis II. The DNA does not replicate between meiosis I and meiosis II.

Meiosis II

1. Prophase II: The nuclear envelope breaks down and the spindle begins to form in each haploid daughter cell from meiosis I. The centrioles also start to separate.
2. Metaphase II: Spindle fibers line up the sister chromatids of each chromosome along the equator of the cell.
3. Anaphase II: Sister chromatids separate and move to opposite poles.
4. Telophase II and Cytokinesis: The spindle breaks down, and new nuclear membranes form. The cytoplasm of each cell divides, and four haploid cells result. Each cell has a unique combination of chromosomes.

Mitosis, Meiosis and Sexual Reproduction is discussed at http://www.youtube.com/watch?v=kaSIjIzAtYA (18:23).



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You can watch an animation of meiosis at this link: http://www.youtube.com/watch?v=D1_-mQS_FZ0 .

Summary

- Meiosis is the type of cell division that produces gametes.
- Meiosis involves two cell divisions and produces four haploid cells.
- Sexual reproduction has the potential to produce tremendous genetic variation in offspring. This is due in part to crossing-over during meiosis.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Stages of Meiosis**

1. What is a fundamental goal of meiosis?
2. What does *2n* refer to?
3. Describe synapsis, crossing-over, and chiasmata.
4. What is the metaphase plate?
5. How does meiosis ensure independent assortment?
6. What does NOT occur during interkinesis?
7. Describe the main difference between metaphase I and metaphase II. (*Hint*: DNA alignment)
8. Describe the products of meiosis I and meiosis II.
9. List four differences between meiosis and mitosis.

Practice II

- **Meiosis** at http://www.concord.org/activities/meiosis .
- **Meiosis** at http://johnkyrk.com/meiosis.html .

Review

1. What is meiosis?
2. Compare the events of metaphase I to metaphase II?
3. Create a diagram to show how crossing-over occurs and how it creates new gene combinations on each chromosome.
4. Explain why sexual reproduction results in genetically unique offspring.
5. Explain how meiosis I differs from mitosis.

References

1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. An illustrated overview of meiosis. CC BY-NC 3.0
2. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. A more detailed illustration of the phases of meiosis. CC BY-NC 3.0

CONCEPT 16 Introduction to Genetics

Lesson Objectives

- Define gene and allele.
- Describe the relationship between genotype and phenotype.
- Show how to predict genotype and phenotype ratios in offspring for simple traits.
- Identify ways traits may be more complex than those studied by Mendel.
- Explain how sex-linked traits are inherited.

Lesson Vocabulary

- allele
- autosome
- genotype
- heterozygote
- homozygote
- phenotype
- Punnett square
- sex chromosome
- sex-linked trait

Introduction

When Mendel's laws were rediscovered in 1900, scientists were starting to learn about the molecules of heredity. They had already observed chromosomes and seen cells undergoing meiosis. Within a few decades they would learn the structure of DNA and how proteins are made. They would also learn that Mendel's "factors" consist of DNA. We now call these factors genes. For a great review of Mendel's work and an excellent introduction to this lesson, watch this entertaining video:

https://www.youtube.com/watch?v=CBezq1fFUEA

Genes and Alleles

Today we know that the traits of organisms are controlled by genes on chromosomes. A gene can be defined as a section of a chromosome that contains the genetic code for a particular protein. The position of a gene on a chromosome is called its locus. Each gene may have different versions. The different versions are called **alleles**. **Figure** 16.1 shows an example in pea plants. It shows the gene for flower color. The gene has two alleles. There is a purple-flower allele and a white-flower allele. Different alleles account for most of the variation in the traits of organisms within a species.

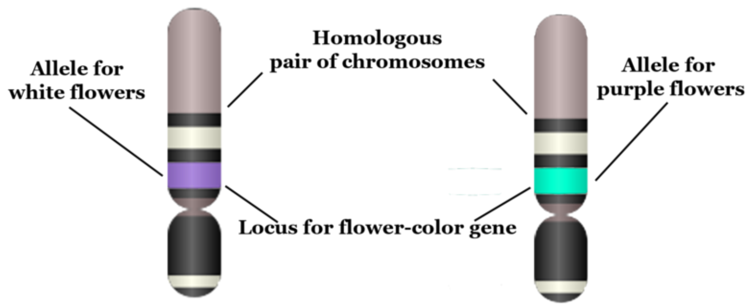

FIGURE 16.1
This diagram shows how genes and alleles are related.

In sexually reproducing species, chromosomes are present in cells in pairs. Chromosomes in the same pair are called homologous chromosomes. They have the same genes at the same loci. These may be the same or different alleles. During meiosis, when gametes are produced, homologous chromosomes separate. They go to different gametes. Thus, the alleles for each gene also go to different gametes.

Genotype and Phenotype

When gametes unite during fertilization, the resulting zygote inherits two alleles for each gene. One allele comes from each parent.

Genotype

The two alleles that an individual inherits make up the individual's **genotype**. The two alleles may be the same or different. Look at **Table** 16.1. It shows alleles for the flower-color gene in peas. The alleles are represented by the letters B (purple flowers) and b (white flowers). A plant with two alleles of the same type (BB or bb) is called a **homozygote**. A plant with two different alleles (Bb) is called a **heterozygote**.

TABLE 16.1: **Genotypes and phenotypes for alleles B and b, with B dominant to b**

Genotypes	Phenotypes
BB (homozygote)	purple flowers
Bb (heterozygote)	purple flowers
bb (homozygote)	white flowers

Phenotype

The expression of an organism's genotype is called its **phenotype**. The phenotype refers to the organism's traits, such as purple or white flowers. Different genotypes may produce the same phenotype. This will be the case if one allele is dominant to the other. Both BB and Bb genotypes in Table 6.1 have purple flowers. That's because the B allele is dominant to the b allele, which is recessive. The terms *dominant* and *recessive* are the terms Mendel used to describe his "factors." Today we use them to describe alleles. In a Bb heterozygote, only the dominant B allele is expressed. The recessive b allele is expressed only in the bb genotype.

Mendelian Inheritance

Each trait Mendel studied was controlled by one gene with two alleles. In each case, one of the alleles was dominant to the other. This resulted in just two possible phenotypes for each trait. Each trait Mendel studied was also controlled by a gene on a different chromosome. As a result, each trait was inherited independently of the others. With traits any gamete from this parent will have the B allele. There is also a 50 percent chance that any gamete will have the b allele.

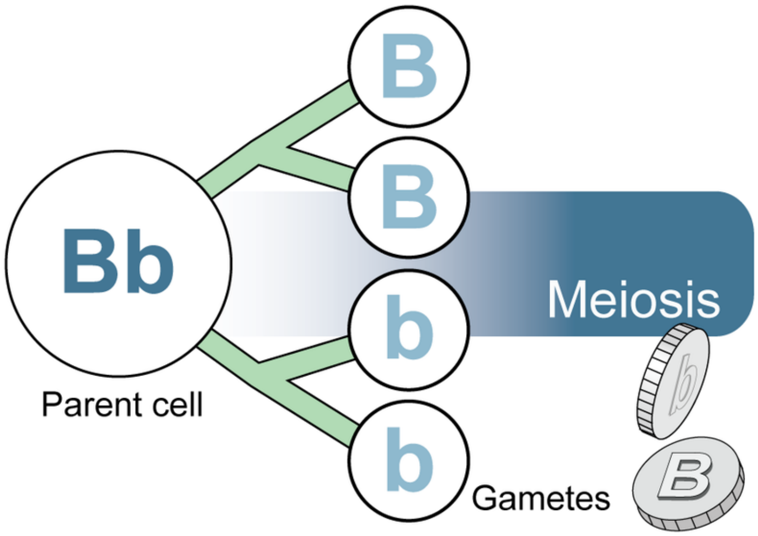

FIGURE 16.2
Gametes from a heterozygote parent (Bb)

Predicting Genotype Ratios

Now let's see what happens if two parent pea plants have the Bb genotype. What genotypes are possible for their offspring? And what ratio of genotypes would you expect? The easiest way to find the answer to these questions is with a Punnett square.

A **Punnett square** is a chart that makes it easy to find the possible genotypes in offspring of two parents. **Figure** 16.3 shows a Punnett square for the two parent pea plants. The gametes produced by the male parent are at the top of the chart. The gametes produced by the female parent are along the left side of the chart. The different possible combinations of alleles in their offspring can be found by filling in the cells of the chart.

If the parents had four offspring, their most likely genotypes would be one BB, two Bb, and one bb. But the genotype ratios of their actual offspring may differ. That's because which gametes happen to unite is a matter of chance, like a coin toss. The Punnett square just shows the possible genotypes and their most likely ratios.

Predicting Phenotype Ratios

You know that the B allele is dominant to the b allele. Therefore, you can also use the Punnett square in **Figure** 16.3 to predict the most likely offspring phonotypes. If the parents had four offspring, their most likely phenotypes would be three with purple flowers (1 BB + 2 Bb) and one with white flowers (1 bb).

Non-Mendelian Inheritance

Inheritance is often more complex than it is for traits like those Mendel studied. Several factors can complicate it.

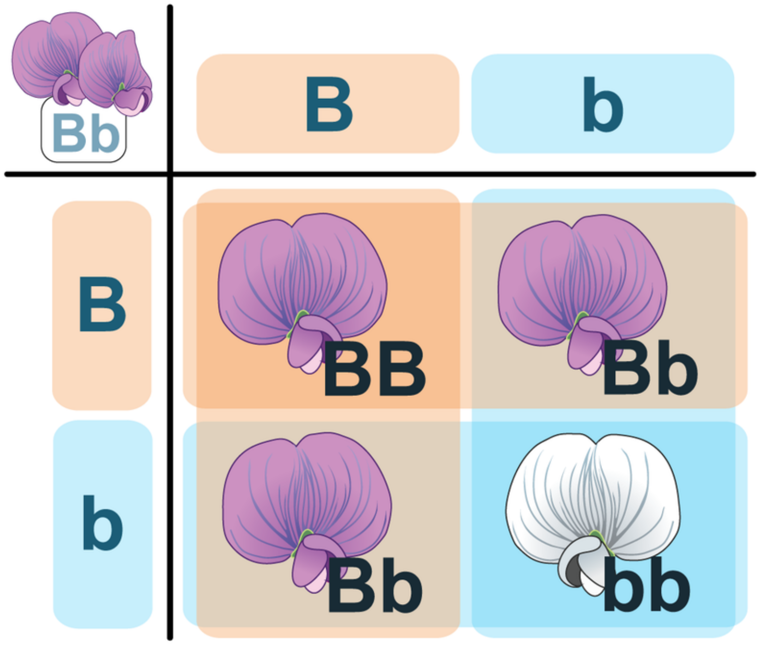

FIGURE 16.3
Punnett square for two Bb parents

Codominance and Incomplete Dominance

If a gene has two alleles, one may not be dominant to the other. There are other possibilities. One possibility is called codominance. Another is called incomplete dominance.

- With codominance, both alleles are expressed equally in heterozygotes. The red and white flower in **Figure** 16.4 has codominant alleles for red petals and white petals.
- With incomplete dominance, a dominant allele is not completely dominant. Instead, it is influenced by the recessive allele in heterozygotes. The pink flower in **Figure** 16.4 is an example. It has an incompletely dominant allele for red petals. It also has a recessive allele for white petals. This results in a flower with pink petals.

FIGURE 16.4
Codominance (left) and incomplete dominance (right)

Multiple Alleles

Many genes have more than two alleles. An example is ABO blood type in people. There are three common alleles for the gene that controls this trait. The allele for type A is codominant with the allele for type B. Both of these alleles are dominant to the allele for type O. The possible genotypes and phenotypes for this trait are shown in **Table** below

TABLE 16.2: ABO genotypes and phenotypes

Genotype	Phenotype
AA	Type A
AO	Type A
BB	Type B
BO	Type B
AB	Type AB
OO	Type O

Polygenic Traits

Some traits are controlled by more than one gene. They are called polygenic traits. Each gene for a polygenic trait may have two or more alleles. The genes may be on the same or different chromosomes. Polygenic traits may have many possible phenotypes. Skin color and adult height are examples of polygenic traits in humans. Think about all the variation in the heights of adults you know. Normal adults may range from less than 5 feet tall to more than 7 feet tall. There are people at every gradation of height in between these extremes.

Environmental Influences

Genes play an important role in determining an organism's traits. However, for many traits, phenotype is influenced by the environment as well. For example, skin color is controlled by genes but also influenced by exposure to sunlight. You can see the effect of sunlight on skin in **Figure** 16.5.

FIGURE 16.5
Skin color darkens when exposed to the sun.

Sex Chromosomes and Sex-Linked Traits

Animals and most plants have two special chromosomes. They are called **sex chromosomes**. These are chromosomes that determine the sex of the organism. All of the other chromosomes are called **autosomes**. Genes on sex chromosomes may be inherited differently than genes on autosomes.

Human Sex Chromosomes

In people, the sex chromosomes are called X and Y chromosomes. Individuals with two X chromosomes are normally females. Individuals with one X and one Y chromosome are normally males. As you can see in **Figure** 16.6, mothers pass an X chromosome to each of their children. Fathers pass an X to their daughters and a Y to their sons.

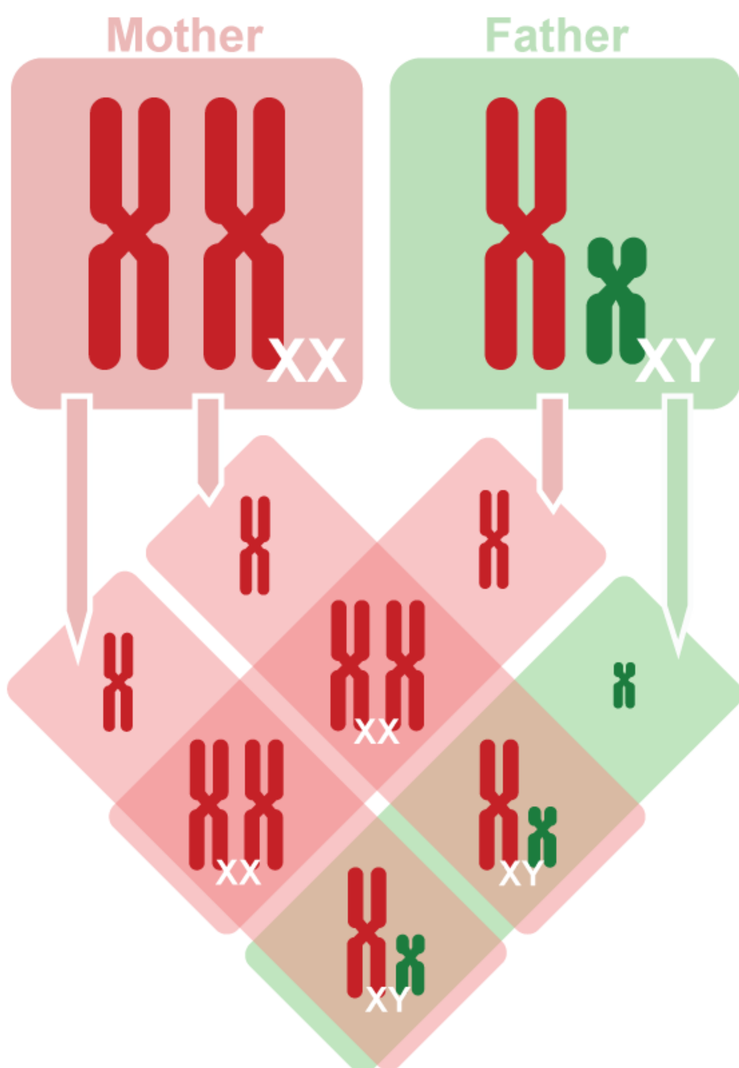

FIGURE 16.6

Inheritance of sex chromosomes

Sex-Linked Traits

Traits controlled by genes on the sex chromosomes are called **sex-linked traits**. One gene on the Y chromosome determines male sex. There are very few other genes on the Y chromosome, which is the smallest human chromosome. There are hundreds of genes on the much larger X chromosome. None is related to sex. Traits controlled by genes on the X chromosome are called X-linked traits.

X-linked traits have a different pattern of inheritance than traits controlled by genes on autosomes. With just one X chromosome, males have only one allele for any X-linked trait. Therefore, a recessive X-linked allele is always expressed in males. With two X chromosomes, females have two alleles for any X-linked trait, just as they do for autosomal traits. Therefore, a recessive X-linked allele is expressed in females only when they inherit two copies of it. This explains why X-linked recessive traits show up less often in females than males.

Inheritance of Color Blindness

An example of a recessive X-linked trait is red-green color blindness. People with this trait can't see red or green colors. This trait is fairly common in males but rare in females. **Figure** 16.7 is a pedigree for this trait. A pedigree is a chart that shows how a trait is inherited in a family. The mother has one allele for color blindness. She doesn't have color blindness because she also has a dominant normal allele for the gene. Instead, she is called a carrier for the trait. She passes the allele to half of her children. One daughter is a carrier, and one son has the color blindness trait. No matter how many children this couple has, none of the daughters will have color blindness, but half of the sons, on average, will have the trait. Can you explain why?

Lesson Summary

- Traits are controlled by genes on chromosomes. A gene may have different versions called alleles.
- The two alleles for a gene that an individual inherits make up the individual's genotype. The expression of the genotype as a trait is the individual's phenotype.
- Mendel studied simple traits controlled by one gene with two alleles and dominance. For traits like these, Punnett squares can be used to predict possible genotypes and phenotypes and their likely ratios in offspring.
- Inheritance is more complex for traits in which there is codominance or incomplete dominance. Traits may also be controlled by multiple alleles or multiple genes. Many traits are influenced by the environment as well.
- Sex chromosomes determine sex in animals and many plants. Other chromosomes are called autosomes. Sex-linked traits are controlled by genes on sex chromosomes. They may be inherited differently than autosomal traits.

Lesson Review Questions

Recall

1. Write a short paragraph in which you correctly use the concepts chromosome, gene, allele, locus, and trait.
2. What are codominance and incomplete dominance? Give an example of each.
3. What is the difference between a multiple allele trait and a polygenic trait?

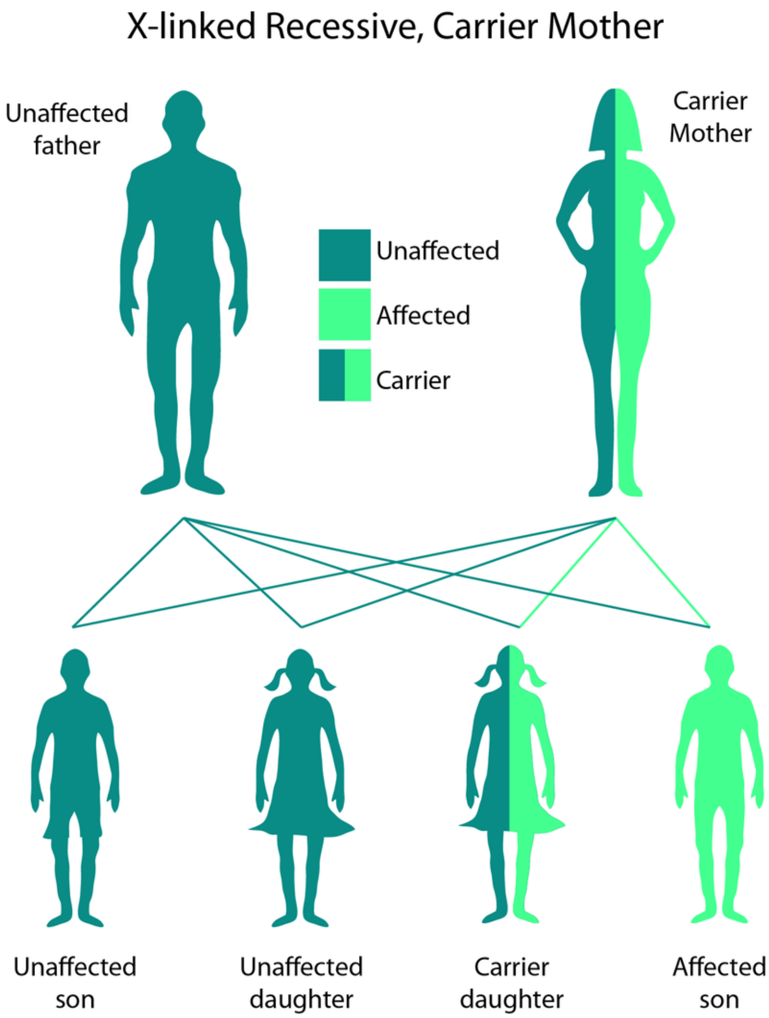

FIGURE 16.7
Pedigree for color blindness

Apply Concepts

4. Use a Punnett square to determine the possible offspring genotypes of parents with the genotypes Bb and bb. Assume that B is the dominant allele for violet flower color in peas and b is the recessive allele for white flower color. What is the expected ratio of violet-flowered to white-flowered offspring based on your Punnett square?

Think Critically

5. Compare and contrast genotype and phenotype.
6. Explain why it is the father rather than the mother who determines the sex of their offspring.

Points to Consider

Genetics began with the rediscovery of Mendel's laws in 1900. There have been many advances in genetics since then.

1. What are some recent advances in genetics?
2. What do we now know about human genes?

References

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4. Darwin Cruz, Sandy Schultz. Contrasts codominance and incomplete dominance . CC-BY 2.0 (both)
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6. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Inheritance of sex chromosomes . CC BY-NC 3.0
7. Jodi So. Color blindness inheritance . CC-BY-NC 3.0

CONCEPT 17 Advances in Genetics

Lesson Objectives

- Explain the significance of the Human Genome Project.
- Describe human genetic disorders.
- Identify methods and uses of biotechnology.

Lesson Vocabulary

- biotechnology
- gene therapy
- genetically modified organism (GMO)
- genetic disorder
- genome
- Human Genome Project

Introduction

The science of genetics has come a long way since Mendel's laws were rediscovered in 1900. There have been many advances in genetics. One of the most impressive advances was sequencing the human genome.

Sequencing the Human Genome

A species' **genome** consists of all of its genetic information. The human genome consists of the complete set of genes in the human organism. It's all the DNA of a human being.

The Human Genome Project

The **Human Genome Project** was launched in 1990. It was an international effort to sequence all 3 billion bases in human DNA. Another aim of the project was to identify the more than 20,000 human genes and map their locations on chromosomes. The logo of the Human Genome Project in **Figure** 17.1 shows that the project brought together experts in many fields.

The Human Genome Project was completed in 2003. It was one of the greatest feats of modern science. It provides a complete blueprint for a human being. It's like having a very detailed manual for making a human organism.

Applications of the Sequence

Knowing the sequence of the human genome is very useful. For example, it helps us understand how humans evolved. Another use is in medicine. It is helping researchers identify and understand genetic disorders. You can

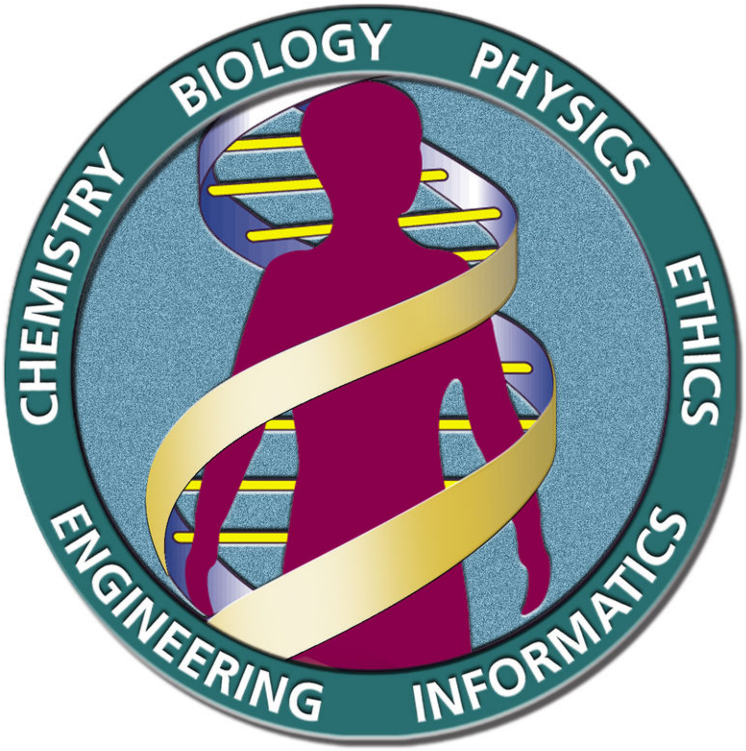

FIGURE 17.1
Human Genome Project logo

learn more about the Human Genome Project and its applications by watching this funny, fast-paced video:

http://www.youtube.com/watch?v=F5LzKupeHtw

Human Genetic Disorders

Sequencing the human genome has increased our knowledge of genetic disorders. **Genetic disorders** are diseases caused by mutations. Many genetic disorders are caused by mutations in a single gene. Others are caused by abnormal numbers of chromosomes.

Disorders Caused by Single Gene Mutations

Table 17.1 lists some genetic disorders caused by mutations in just one gene. It include autosomal and X-linked disorders. It also includes dominant and recessive disorders.

TABLE 17.1: Examples of human genetic disorders caused by single gene mutations

Genetic Disorder	Effect of Mutation	Signs of the Disorder	Type of Trait
Marfan syndrome	Defective protein in tissues such as cartilage and bone	Heart and bone defects; unusually long limbs	Autosomal dominant
Cystic fibrosis	Defective protein needed to make mucus	Unusually thick mucus that clogs airways in lungs and ducts in other organs	Autosomal recessive

TABLE 17.1: (continued)

Genetic Disorder	Effect of Mutation	Signs of the Disorder	Type of Trait
Sickle Cell Anemia	Defective hemoglobin protein that is needed to transport oxygen in red blood cells	Sickle-shaped red blood cells that block blood vessels and interrupt blood flow	Autosomal recessive
Hemophilia A	Reduced activity of a protein needed for blood to clot	Excessive bleeding that is difficult to control	X-linked recessive

Relatively few genetic disorders are caused by dominant alleles. A dominant allele is expressed in everybody who inherits even one copy of it. If it causes a serious disorder, affected people may die young and fail to reproduce. They won't pass the allele to the next generation. As a result, the allele may die out of the population. One of the exceptions is Marfan syndrome. It is thought to have affected Abraham Lincoln. He's pictured in **Figure** 17.2. His very long limbs are one reason for the suspicion of Marfan syndrome in this former U.S. president.

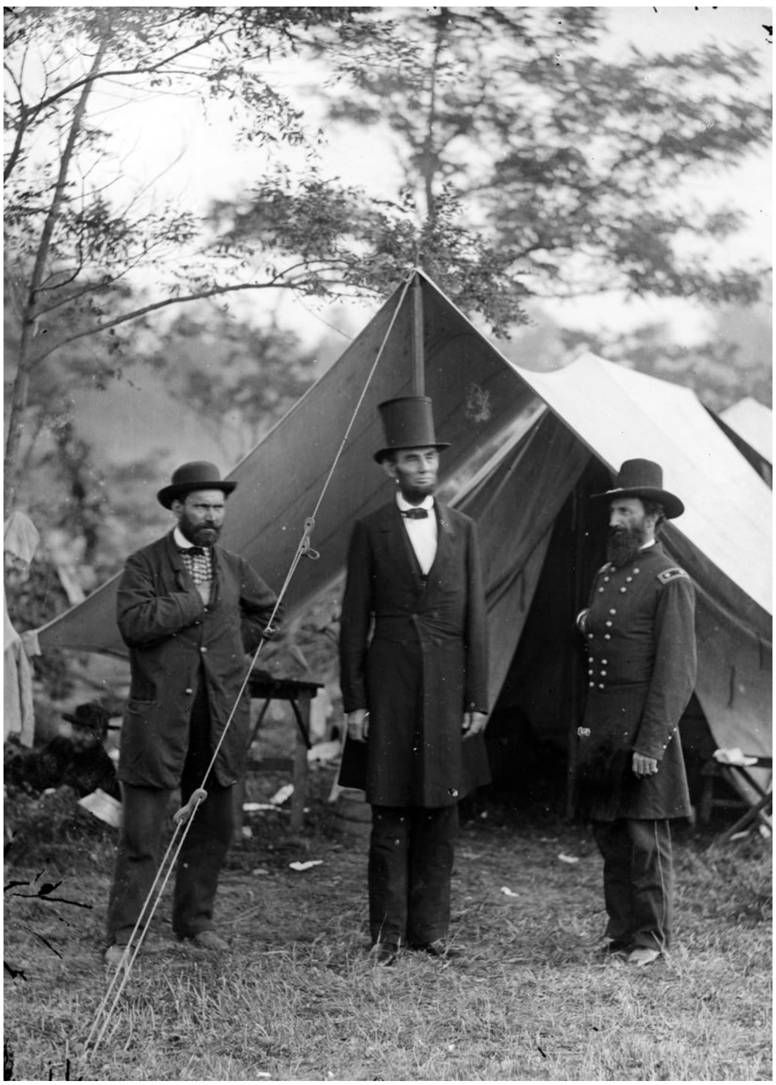

FIGURE 17.2
Abraham Lincoln (center) may have had the genetic disorder Marfan syndrome

Recessive disorders are more common than dominant ones. Why? A recessive allele is not expressed in heterozygotes. These people are called carriers. They don't have the genetic disorder but they carry the recessive allele. They can also pass this allele to their offspring. A recessive allele is more likely than a dominant allele to pass to the next generation rather than die out.

Chromosomal Disorders

In the process of meiosis, paired chromosomes normally separate from each other. They end up in different gametes. Sometimes, however, errors occur. The paired chromosomes fail to separate. When this happens, some gametes get an extra copy of a chromosome. Other gametes are missing a chromosome. If one of these gametes is fertilized and survives, a chromosomal disorder results. You can see examples of such disorders in **Table** 17.2

TABLE 17.2: Disorders caused by abnormal numbers of chromosomes

Genetic Disorder	Genotype	Phenotypic Effects
Down syndrome	Extra copy (complete or partial) of chromosome 21	Developmental delays, distinctive facial appearance, and other abnormalities
Turner's syndrome	One X chromosome and no other sex chromosome (XO)	Female with short height and inability to reproduce
Klinefelter's syndrome	One Y chromosome and two or more X chromosomes (XXY, XXXY)	Male with abnormal sexual development and reduced level of male sex hormone

Most chromosomal disorders involve the sex chromosomes. Can you guess why? The X and Y chromosomes are very different in size. The X is much larger than the Y. This difference in size creates problems. It increases the chances that the two chromosomes will fail to separate properly during meiosis.

Biotechnology

Treating genetic disorders is one use of biotechnology. **Biotechnology** is the use of technology to change the genetic makeup of living things for human purposes. It's also called genetic engineering. Besides treating genetic disorders, biotechnology is used to change organisms so they are more useful to people.

Methods in Biotechnology

Biotechnology uses a variety of methods, but some are commonly used in many applications. A common method is the polymerase chain reaction. Another common method is gene cloning.

- The polymerase chain reaction is a way of making copies of a gene. It uses high temperatures and an enzyme to make new DNA molecules. The process keeps cycling to make many copies of a gene.
- Gene cloning is another way of making copies of a gene. A gene is inserted into the DNA of a bacterial cell. **Figure** 17.3 shows how this is done. Bacteria multiply very rapidly by binary fission. Each time a bacterial cell divides, the inserted gene is copied.

Uses of Biotechnology

Biotechnology has many uses. It is especially useful in medicine and agriculture. Biotechnology is used to

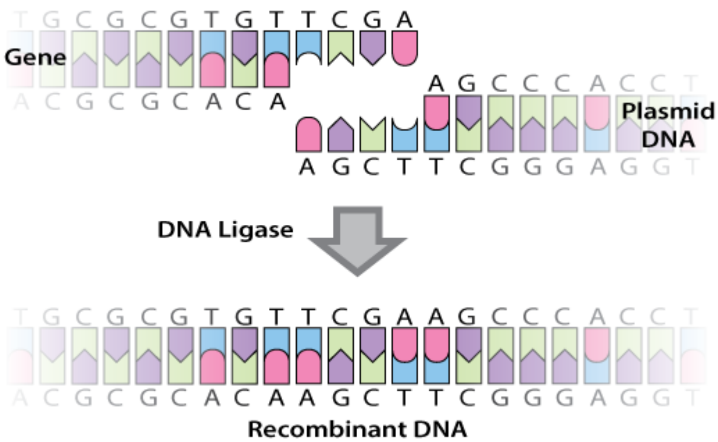

FIGURE 17.3

The enzyme DNA ligase joins together a gene and bacterial (plasmid) DNA. The DNA that results is called recombinant DNA.

- treat genetic disorders. For example, copies of a normal gene might be inserted into a patient with a defective gene. This is called **gene therapy**. Ideally, it can cure a genetic disorder.
- create **genetically modified organisms (GMOs)**. Many GMOs are food crops such as corn. Genes are inserted into plants to give them desirable traits. This might be the ability to get by with little water. Or it might be the ability to resist insect pests. The modified plants are likely to be healthier and produce more food. They may also need less pesticide.
- produce human proteins. Insulin is one example. This protein is needed to treat diabetes. The human insulin gene is inserted into bacteria. The bacteria reproduce rapidly. They can produce large quantities of the human protein. You can see another example in **Figure** 17.4.

Concerns about Biotechnology

Biotechnology has many benefits. Its pros are obvious. It helps solve human problems. However, biotechnology also raises many concerns. For example, some people worry about eating foods that contain GMOs. They wonder if GMOs might cause health problems. The person in **Figure** 17.5 favors the labeling of foods that contain GMOs. That way, consumers can know which foods contain them and decide for themselves whether to eat them.

Another concern about biotechnology is how it may affect the environment. Negative effects on the environment have already occurred because of some GMOs. For example, corn has been created that has a gene for a pesticide. The corn plants have accidentally cross-pollinated nearby milkweeds. Monarch butterfly larvae depend on milkweeds for food. When they eat milkweeds with the pesticide gene, they are poisoned. This may threaten the survival of the monarch species as well as other species that eat monarchs. Do the benefits of the genetically modified corn outweigh the risks? What do you think?

Lesson Summary

- A species' genome consists of all of its genetic information. One of the greatest advances in modern genetics was sequencing the human genome. This was achieved in 2003 by the Human Genome Project.
- Sequencing the human genome has increased our knowledge of genetic disorders. These are diseases caused by mutations. They may be caused by single gene mutations or the failure of chromosomes to separate correctly during meiosis.

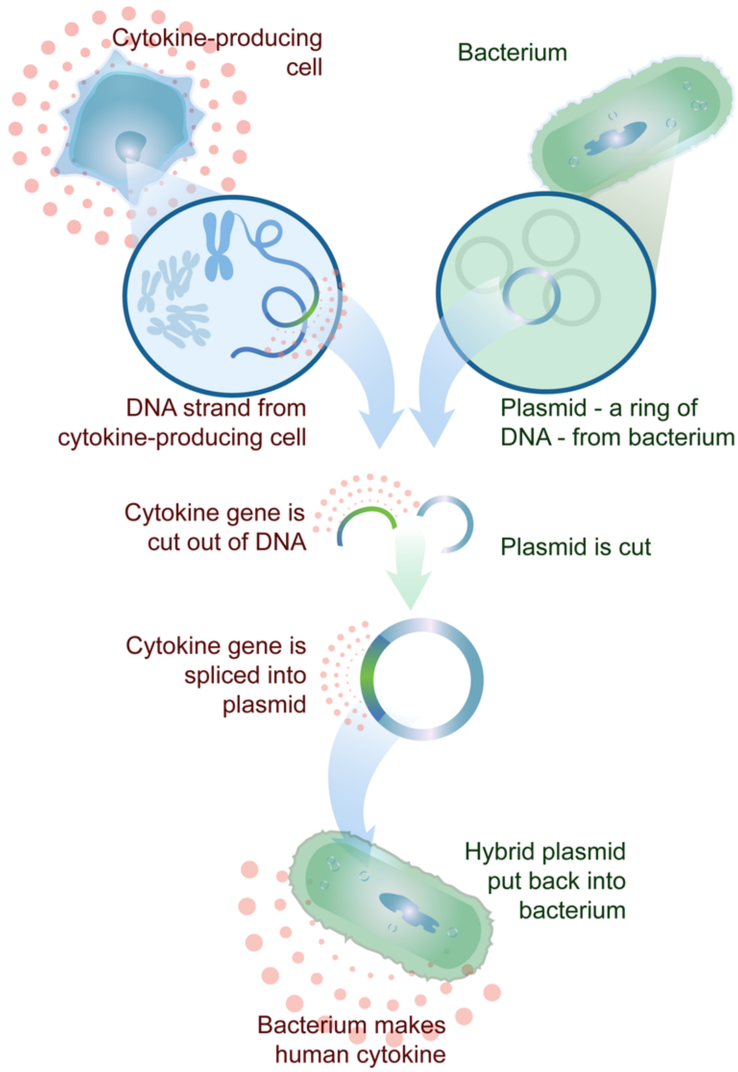

FIGURE 17.4
Bacteria are modified to produce the human protein cytokine. This is a protein that helps fight infections.

- Biotechnology is the use of technology to treat genetic disorders or change organisms so they are more useful to people. Methods include gene cloning. Applications include gene therapy and genetically modified food crops.

Lesson Review Questions

Recall

1. Define genome.
2. What was the Human Genome Project? What had it accomplished by 2003?
3. Identify and describe an autosomal recessive genetic disorder.

FIGURE 17.5
Chances are that some of the foods you eat contain GMOs. However, they may not be labeled that way.

Apply Concepts

4. Pedigrees show that a certain genetic disorder passes from mothers to about half of their sons or from fathers to all of their daughters. Only males are actually affected by the disorder. What type of disorder is it?

Think Critically

5. Compare and contrast the polymerase chain reaction and gene cloning.
6. Weigh the pros and cons of using biotechnology to produce genetically modified organisms.

Points to Consider

Biotechnology can be used to artificially change the genetic makeup of organisms in a species.

1. How can the genetic makeup of a species change naturally?
2. What might be the outcome of this type of change?

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4. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Bacteria can be modified to produce useful p roteins . CC BY-NC 3.0
5. Daniel Goehring. Some people favor the labeling of foods that contain GMOs. . CC-BY 2.0

Concept 18 Water on Earth

Lesson Objectives

- Describe how water is distributed on Earth.
- Describe what powers the water cycle and how water moves through this cycle.

Introduction

Water is a simple compound, made of two atoms of hydrogen and one atom of oxygen bonded together. More than any other substance on the Earth, water is important to life and has remarkable properties. Without water, life could probably not even exist on Earth. When looking at Earth from space, the abundance of water on Earth becomes obvious — see **Figure** 18.1. On land, water is also common: it swirls and meanders through streams, falls from the sky, freezes into snow flakes, and even makes up most of you and me. In this chapter, we'll look at the distribution of water on Earth, and also examine some of its unique properties.

FIGURE 18.1
Earth, the

Distribution of Earth's Water

As **Figure** 18.1 makes clear, water is the most abundant substance on the Earth's surface. About 71% of the Earth's surface is covered with water, most of which is found in the oceans. In fact, 97% of Earth's water, nearly all of it, is in the Earth's oceans. This means that just 3% of Earth's water is **fresh water**, water with low concentrations of salts (**Figure** 18.2). Most freshwater is found as ice in the vast glaciers of Greenland and the immense ice sheets of Antarctica. That leaves just 0.6% of Earth's water that is freshwater that humans can easily use. Most liquid freshwater is found under the Earth's surface as groundwater, while the rest is found in lakes, rivers, and streams, and water vapor in the sky.

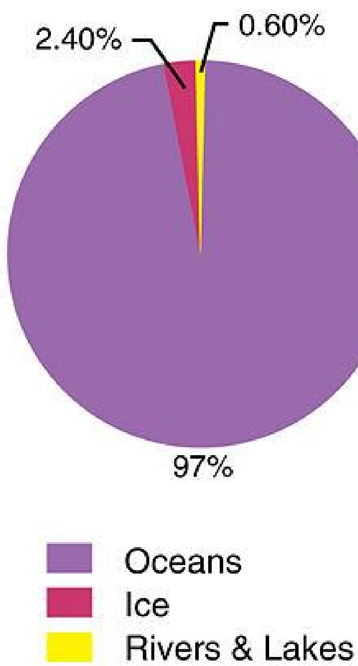

FIGURE 18.2
Earth

The Water Cycle

Water is a special substance. It is abundant on Earth and frequently appears as a gas, liquid, and solid. It is one of the few substances on Earth that is frequently found in all three phases of matter. Moreover, it can readily cycle through the globe: the same molecule can travel through many different regions on Earth.

Three States of Water

Part of the reason that water is unique is because of its melting point and boiling point. Under normal atmospheric conditions, water freezes at 0^{o}C (32^{o}F) and boils at 100^{o}C (212^{o}F). Because of our Earth's position in the solar system, Earth's temperature varies from far below the melting point of water to well above that melting point. Even though water does not boil at normal temperatures, it often becomes gaseous **water vapor** by evaporating. All this means that we frequently see water in its three phases on Earth (See **Figures** ice, water, and 18.4 clouds).

The Water Cycle

The water on Earth moves about the Earth in what is known as the **water cycle** (**Figure** 18.5). Because it is a cycle, there truly is no beginning and no end. The very same water molecule found in your glass of water today has probably been on the Earth for billions of years. It may have been in a glacier or far below the ground. It may have been high up in the atmosphere and deep in the belly of a dinosaur. Who knows where it will end up today, when you're done with it!

FIGURE 18.3
(a) Ice floating in the sea. Can you find all three phases of water in this image? (b) Liquid water. (c) Water vapor is invisible, but clouds that form when water vapor condenses are not.

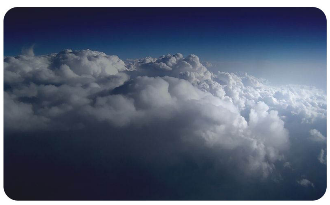

FIGURE 18.4
Water vapor is invisible to our eyes. However, we can see the clouds that form when water vapor condenses.

Let's study **Figure** 18.5 for a moment. The Sun, many millions of kilometers away, provides the energy which drives the water cycle. Since the ocean holds most of the Earth's water, let's begin there. As you can see in the illustration, water in the ocean evaporates as water vapor into the air. The salt in the ocean does not evaporate with the water, however, so the water vapor is fresh. Some of the invisible water vapor in the air **condenses** to form liquid droplets in clouds. The clouds are blown about the globe by wind. As the water particles in the clouds collide and grow, they fall from the sky as **precipitation.** Precipitation can occur in forms such as rain, sleet, hail, and snow. Sometimes precipitation falls right back into the ocean. Other times, however, it falls onto the solid earth as freshwater.

That freshwater, now on the Earth, may be found in a solid form as snow or ice. Some of it goes directly back into the air to form water vapor and clouds again. However, most of this solid water sits atop mountains and slowly melts over time to provide a steady flow of freshwater to streams, rivers, and lakes below. Some of that water enters the Earth's **groundwater**, seeping below the surface through pores in the ground. This water can form **aquifers** that store freshwater for centuries. Alternatively, it may come to the surface through springs or find its way back to the oceans.

When water falls from the sky is rain it form streams and rivers that flow downward to oceans and lakes. People use these natural resources as their source of water. They also create canals, aqueducts, dams, and wells to direct water to living areas to meet their needs (**Figure** 18.6). Sometimes, our manipulation or pollution of water greatly affects other species. Many scientists are seeking better ways of using Earth's water in a sustainable and efficient way.

Obviously, people are not the only creatures that rely on water. Plants and animals also depend on this vital resource. Plants play an important role in the water cycle because they release large amounts of water vapor into the air from their leaves. This process of **transpiration** moves liquid water from plants into the air. You can see transpiration in action if you cover a few leaves on a plant with a plastic bag. Within a few hours, water vapor released from the leaves will have condensed onto the surface of the bag.

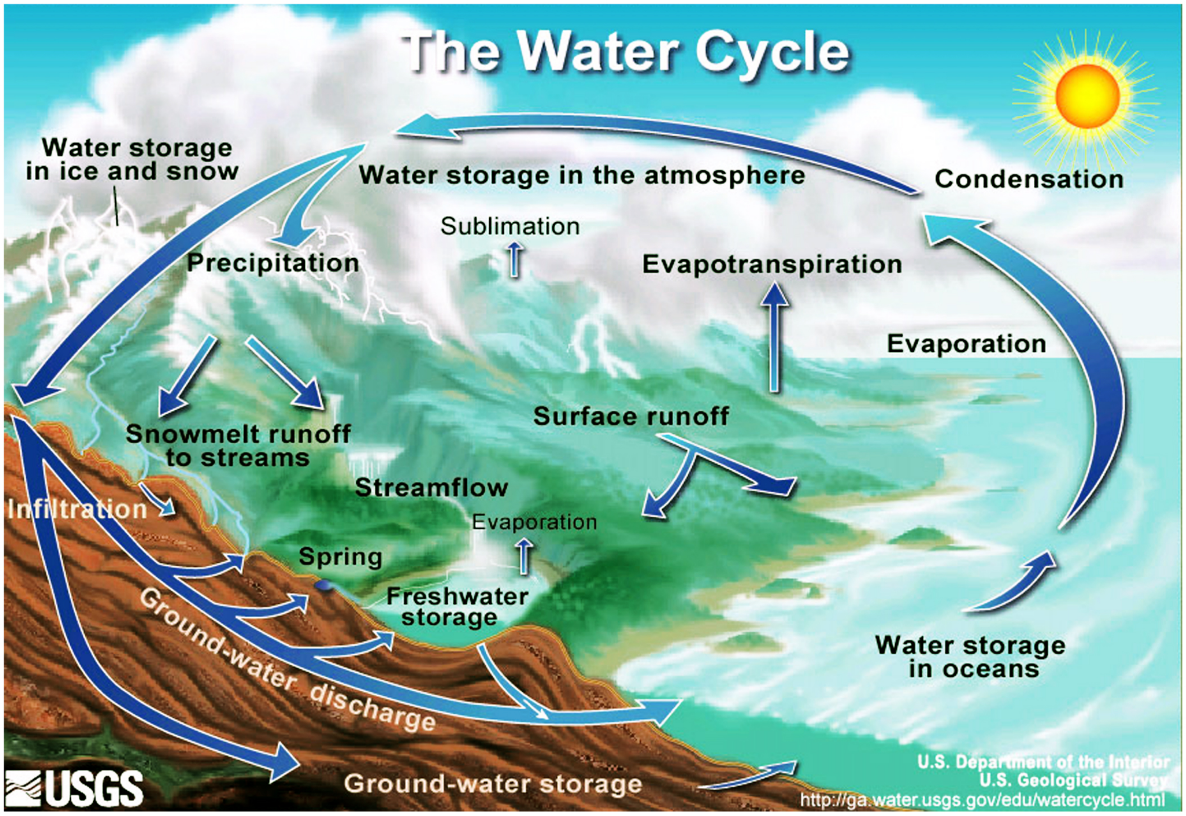

FIGURE 18.5
Water on Earth is constantly in motion.

Lesson Summary

- Earth's surface is mostly water covered. Most of that water is in our oceans, leaving only 3% freshwater.
- Water exists on Earth in all three phases: solid, liquid and gas.
- The water cycle moves water from the hydrosphere to the atmosphere to the land and back again.
- The major processes of the water cycle include evaporation and transpiration, condensation, precipitation and return to the oceans via runoff and groundwater supplies.

Review Questions

1. About what percent of the Earth's water is fresh water?
2. About what percent of all of Earth's water is found in groundwater, streams, lakes, and rivers?
3. Explain the following statement: The water on other planets is present in a different form than on Earth.
4. What powers the water cycle?
5. In what state would water be found at 130^{o}C? What state would water be at -45^{o}C?
6. Define the words condensation and evaporation.

FIGURE 18.6
Hoover Dam on the Colorado River.

7. Summarize the water cycle.
8. Why do you think the atmosphere is so important to the water cycle?
9. Suppose the sun grew much stronger in intensity. How would this affect the water cycle?

Further Reading / Supplemental Links

- http://www.freshwaterlife.org/
- http://www.usgs.gov/

Vocabulary

aquifer

A layer of rock, sand, or gravel that holds large amounts of groundwater. Humans often use aquifers as sources of freshwater.

condense

To turn from a gas to a liquid.

freshwater

Water with a low concentration of salts, which can be consumed and used by humans.

groundwater

Water that is found beneath the Earth's surface, between soil or rock particles.

precipitation

Water that falls to the Earth from the sky. Precipitation usually takes the form of rain, but can also occur as snow, sleet, or hail.

transpiration

The release of water vapor into the air through the leaves of plants; sometimes called evapotranspiration.

water cycle

The cycle through which water moves around the Earth, changing both its phase (between solid to liquid to gas) and its location (in the oceans, in clouds, in streams and lakes, and in groundwater).

water vapor

Water in the form of a gas. Water vapor is invisible to humans; when we see clouds, we actually are seeing liquid water in the clouds.

Points to Consider

- How does precipitation affect the topography of the Earth?
- What natural disasters are caused by the water cycle?
- How might pollution affect creatures far from the source of the pollution?
- How might building dams disrupt the natural water cycle?
- If the temperature of the Earth increases through global warming, how might the water cycle be altered?

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CONCEPT 19 Introduction to the Oceans

Lesson Objectives

- Describe how the oceans formed.
- State how the oceans influence Earth.
- Describe the makeup of ocean water.
- Identify ocean zones.

Vocabulary

- aphotic zone
- benthic zone
- intertidal zone
- neritic zone
- oceanic zone
- photic zone

Introduction

Much of Earth's surface is covered with oceans. That's why Earth is called the "water planet." Without all that water, Earth would be a very different place. The oceans affect Earth's atmosphere and influence its climate. An incredible diversity of living things inhabit the ocean as well. You might think that oceans have always covered Earth's surface, but you would be wrong!

How the Oceans Formed

When Earth formed 4.6 billion years ago, it would not have been called the "water planet." There were no oceans then. In fact, there was no liquid water at all. Early Earth was too hot for liquid water to exist. Earth's early years were spent as molten rock and metal.

Water on Early Earth

Over time, Earth cooled. The surface hardened to become solid rock. Volcanic eruptions, like the one in **Figure** 19.1, brought lava and gases to the surface. One of the gases was water vapor. More water vapor came from asteroids and comets that crashed into Earth. As Earth cooled still more, the water vapor condensed to make Earth's first liquid water. At last, the oceans could start to form.

FIGURE 19.1
Volcanoes were one source of water vapor on ancient Earth. What were other sources?

Ancient Oceans

Earth's crust consists of many tectonic plates that move over time. Due to plate tectonics, the continents changed their shapes and positions during Earth history. As the continents changed, so did the oceans. About 250 million years ago, there was one huge land mass known as Pangaea. There was also one huge ocean called Panthalassa. You can see it in **Figure** 19.2.

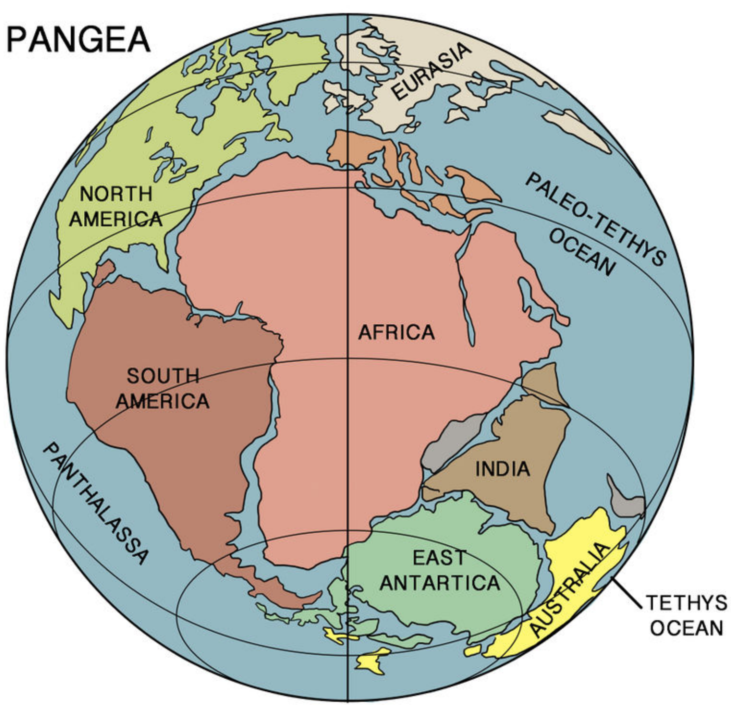

FIGURE 19.2
At the time shown, there was one vast ocean and two smaller ones. How many oceans are there today?

By 180 million years ago, Pangaea began to break up. The continents started to drift apart. They slowly moved to where they are today. The movement of the continents caused Panthalassa to break into smaller oceans. These oceans are now known as the Pacific, Atlantic, Indian, and Arctic Oceans. The waters of all the oceans are connected.

That's why some people refer to the oceans together as the "World Ocean."

The Oceans' Influence

Oceans cover more than 70 percent of Earth's surface and hold 97 percent of its surface water. It's no surprise that the oceans have a big influence on the planet. The oceans affect the atmosphere, climate, and living things.

Oceans and the Atmosphere

Oceans are the major source of water vapor in the atmosphere. Sunlight heats water near the sea surface, as shown in **Figure** 19.3. As the water warms, some of it evaporates. The water vapor rises into the air, where it may form clouds and precipitation. Precipitation provides the freshwater needed by plants and other living things.

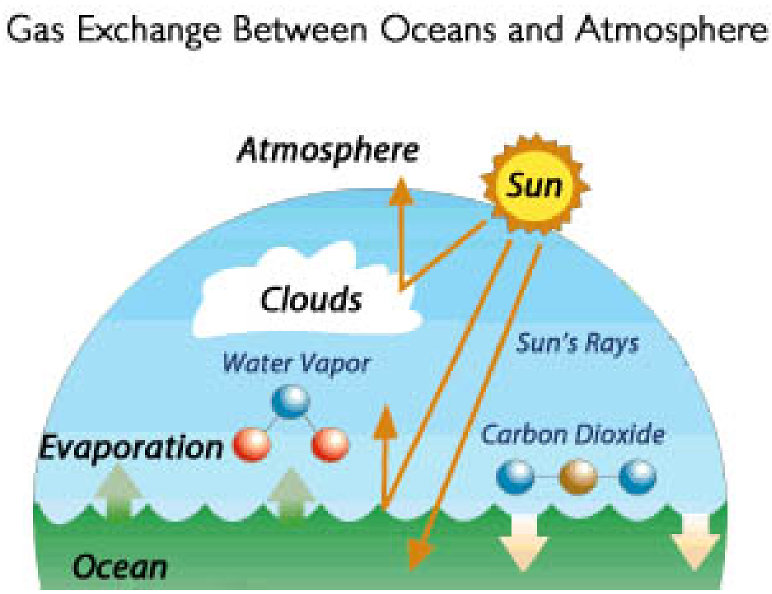

FIGURE 19.3
The oceans and atmosphere exchange gases. Why does water vapor enter the atmosphere from the water?

Ocean water also absorbs gases from the atmosphere. The most important are oxygen and carbon dioxide. Oxygen is needed by living things in the oceans. Much of the carbon dioxide sinks to the bottom of the seas. Carbon dioxide is a major cause of global warming. By absorbing carbon dioxide, the oceans help control global warming.

Oceans and Climate

Coastal areas have a milder climate than inland areas. They are warmer in the winter and cooler in the summer. That's because land near an ocean is influenced by the temperature of the oceans. The temperature of ocean water is moderate and stable. Why? There are two major reasons:

1. Water is much slower to warm up and cool down than land. As a result, oceans never get as hot or as cold as land.
2. Water flows through all the world's oceans. Warm water from the equator mixes with cold water from the poles. The mixing of warm and cold water makes the water temperature moderate.

Even inland temperatures are milder because of oceans. Without oceans, there would be much bigger temperature swings all over Earth. Temperatures might plunge hundreds of degrees below freezing in the winter. In the summer, lakes and seas might boil! Life as we know it could not exist on Earth without the oceans.

Oceans and Living Things

The oceans provide a home to many living things. In fact, a greater number of organisms lives in the oceans than on land. Coral reefs, like the one in **Figure** 19.4, have more diversity of life forms than almost anywhere else on Earth.

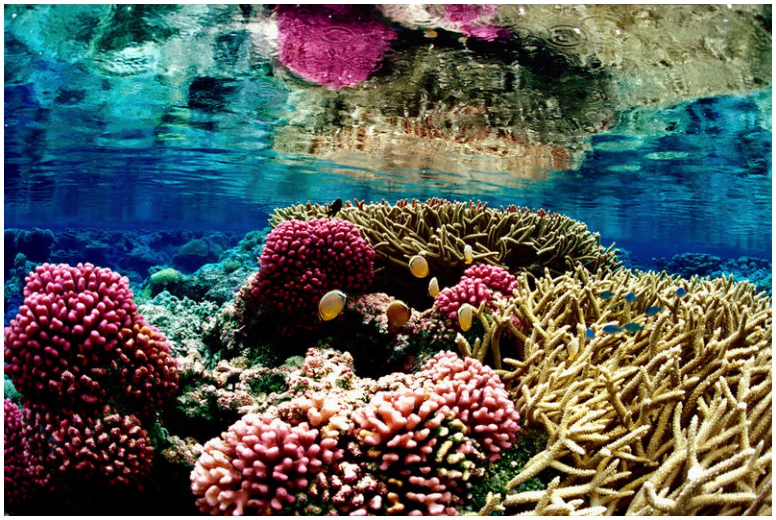

FIGURE 19.4
Coral reefs teem with life.

Makeup of Ocean Water

You know that ocean water is salty. But do you know why? How salty is it?

Why Is Ocean Water Salty?

Ocean water is salty because water dissolves minerals out of rocks. This happens whenever water flows over or through rocks. Much of this water and its minerals flow in rivers that end up in the oceans. Minerals dissolved in water form salts. When the water evaporates, it leaves the salts behind. As a result, ocean water is much saltier than other water on Earth.

How Salty Is Ocean Water?

Have you ever gone swimming in the ocean? If you have, then you probably tasted the salts in the water. By mass, salts make up about 3.5 percent of ocean water. **Figure** 19.5 shows the most common minerals in ocean water. The main components are sodium and chloride. Together they form the salt known as sodium chloride. You may know the compound as table salt or the mineral halite.

The amount of salts in ocean water varies from place to place. For example, near the mouth of a river, ocean water may be less salty. That's because river water contains less salt than ocean water. Where the ocean is warm, the water may be more salty. Can you explain why? (Hint: More water evaporates when the water is warm.)

FIGURE 19.5
What percentage of the salts in ocean water is sodium chloride?

Ocean Zones

In addition to the amount of salts, other conditions in ocean water vary from place to place. One is the amount of nutrients in the water. Another is the amount of sunlight that reaches the water. These conditions depend mainly on two factors: distance from shore and depth of water. Oceans are divided into zones based on these two factors. The ocean floor makes up another zone. **Figure** 19.6 shows all the ocean zones.

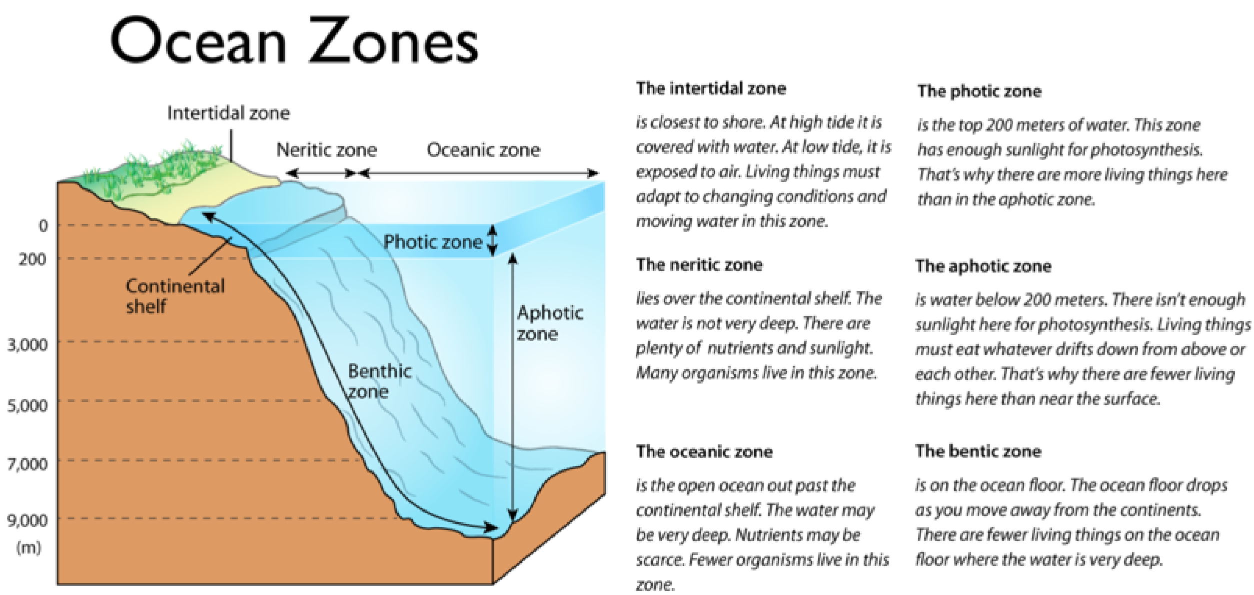

FIGURE 19.6
Distance from shore and depth of water define ocean zones. Which zone is on the ocean floor?

Zones Based on Distance from Shore

There are three main ocean zones based on distance from shore. They are the **intertidal zone**, **neritic zone**, and **oceanic zone**. Distance from shore influences how many nutrients are in the water. Why? Most nutrients are washed into ocean water from land. Therefore, water closer to shore tends to have more nutrients. Living things need nutrients. So distance from shore also influences how many organisms live in the water.

Zones Based on Depth of Water

Two main zones based on depth of water are the photic zone and aphotic zone. The **photic zone** is the top 200 meters of water. The **aphotic zone** is water deeper than 200 meters. The deeper you go, the darker the water gets. That's because sunlight cannot penetrate very far under water. Sunlight is needed for photosynthesis. So the depth of water determines whether photosynthesis is possible. There is enough sunlight for photosynthesis only in the photic zone. Water also gets colder as you go deeper. The weight of the water pressing down from above increases as well. At great depths, life becomes very difficult. The pressure is so great that only specially adapted creatures can live there.

Lesson Summary

- Early Earth was too hot for liquid water to exist. Eventually Earth cooled. Water vapor from volcanoes and objects in space condensed. Oceans finally formed. The oceans changed size and shape as continents drifted.
- Oceans have a big influence on Earth. They exchange gases with the atmosphere. They prevent very hot and very cold temperatures. They are home to many living things.
- Dissolved mineral salts wash into the ocean. As ocean water evaporates, it leaves the salts behind. This makes the water saltier. Ocean water is about 3.5 percent salts. The main salt is sodium chloride.
- The ocean is divided into many zones. Some are based on distance from shore. Some are based on depth of water. The ocean floor is another zone.

Lesson Review Questions

Recall

1. State why there was no liquid water on ancient Earth.
2. Describe how the oceans influence Earth's atmosphere.
3. What is the makeup of ocean water?
4. Describe how ocean water changes as you go deeper in the water.
5. What is the benthic zone?
6. Define the intertidal zone.

Apply Concepts

7. Look at the map (**Figure** 19.7) of Washington State. Washington is on the Pacific coast. Find Raymond and Pullman on the map. Apply lesson concepts to predict how their temperatures compare. Explain your predictions.
8. Describe the causes of high and low tides on Earth.

Think Critically

9. Compare and contrast the photic and aphotic zones.

FIGURE 19.7
Map of Washington State.

10. Imagine that you are going down to the bottom of the ocean in a tiny submarine. What might you see as you go down? Where will it be light? Where will you see the most life forms?

11. Relate ocean zones to nutrients and sunlight in ocean water.

Points to Consider

Most nutrients enter ocean water from the land. However, they may be carried far from shore by currents.

- Many large ocean currents have names. Can you name any ocean currents?
- Currents are like rivers flowing through the ocean. Rivers always flow downhill because of gravity. What do you think causes ocean currents to flow?

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1. Courtesy of the National Park Service. http://commons.wikimedia.org/wiki/File:Volcano_q.jpg . Public Domain
2. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
3. Courtesy of NASA's Earth Observatory, modified by CK-12 Foundation. http://earthobservatory.nasa.gov/Features/OceanClimate/ocean-atmos_chem.php . Public Domain
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CONCEPT 20 Ocean Movements

Lesson Objectives

- Describe how waves move through water.
- Explain what causes tides.
- Give an overview of surface currents.
- Identify the cause of deep currents.
- Describe upwelling.

Vocabulary

- convection current
- Coriolis effect
- deep current
- density
- neap tide
- spring tide
- surface current
- tide
- upwelling
- wave

Introduction

If you've ever visited an ocean shore, then you know that ocean water is always moving. Waves ripple through the water, as shown in **Figure** 20.1. The water slowly rises and falls because of tides. You may see signs warning of currents that flow close to shore. What causes all these ocean motions? Different types of motions have different causes.

Waves

Most ocean waves are caused by winds. A **wave** is the transfer of energy through matter. A wave that travels across miles of ocean is traveling energy, not water. Ocean waves transfer energy from wind through water. The energy of a wave may travel for thousands of miles. The water itself moves very little. **Figure** 20.2 shows how water molecules move when a wave goes by.

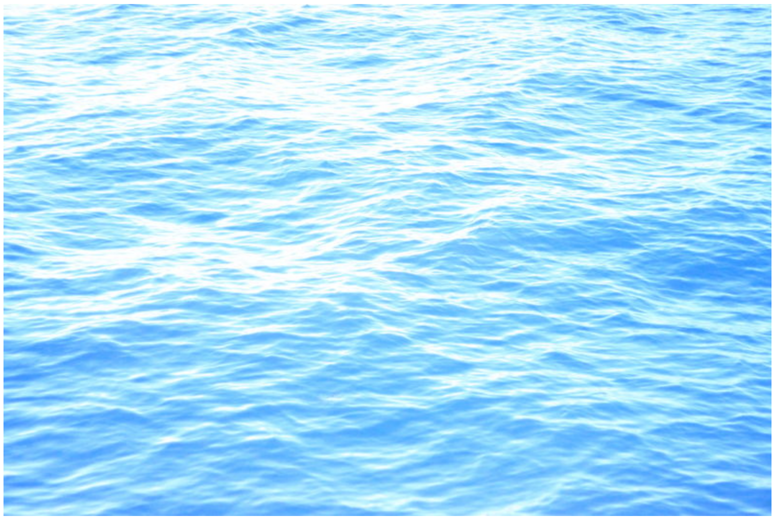

FIGURE 20.1
Waves cause the rippled surface of the ocean.

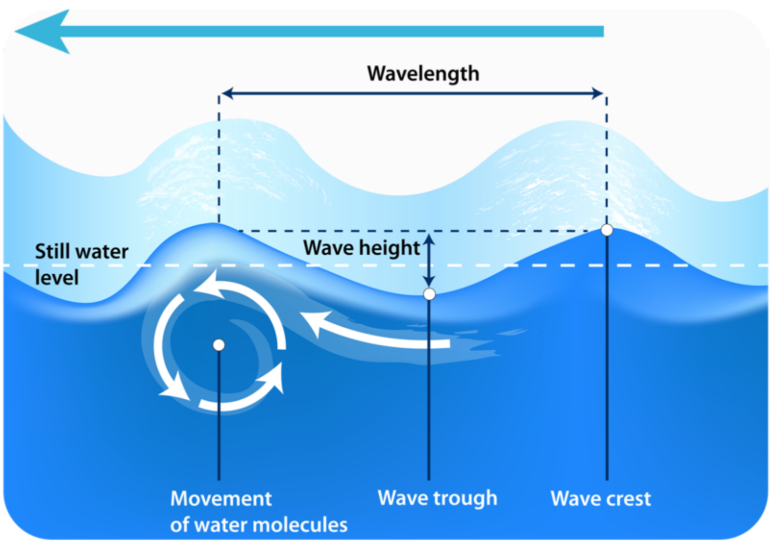

FIGURE 20.2
A wave travels through the water. How would you describe the movement of water molecules as a wave passes through?

The Size of Waves

Figure 20.2 also shows how the size of waves is measured. The highest point of a wave is the crest. The lowest point is the trough. The vertical distance between a crest and a trough is the height of the wave. Wave height is also called amplitude. The horizontal distance between two crests is the wavelength. Both amplitude and wavelength are measures of wave size. The size of an ocean wave depends on how fast, over how great a distance, and how long the wind blows. The greater each of these factors is, the bigger a wave will be. Some of the biggest waves occur with hurricanes. A hurricane is a storm that forms over the ocean. Its winds may blow more than 150 miles per hour! The winds also travel over long distances and may last for many days.

Breaking Waves

Figure 20.3 shows what happens to waves near shore. As waves move into shallow water, they start to touch the bottom. The base of the waves drag and slow. Soon the waves slow down and pile up. They get steeper and unstable as the top moves faster than the base. When they reach the shore, the waves topple over and break.

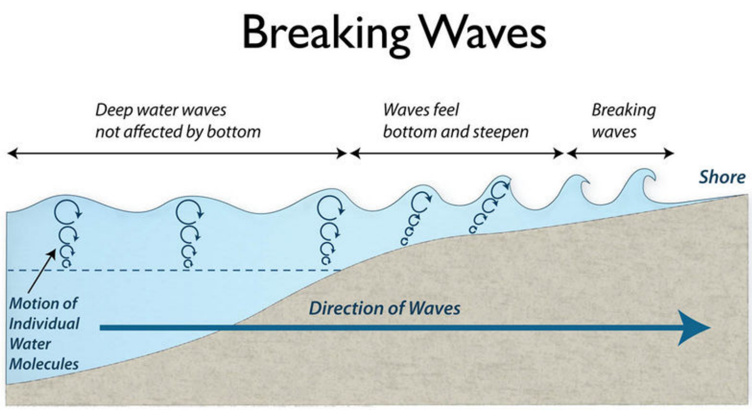

FIGURE 20.3
Waves break when they reach the shore.

Tsunamis

Not all waves are caused by winds. A shock to the ocean can also send waves through water. A tsunami is a wave or set of waves that is usually caused by an earthquake. As we have seen in recent years, the waves can be enormous and extremely destructive. Usually tsunami waves travel through the ocean unnoticed. But when they reach the shore they become enormous. Tsunami waves can flood entire regions. They destroy property and cause many deaths. **Figure** 20.4 shows the damage caused by a tsunami in the Indian Ocean in 2004.

FIGURE 20.4
A 2004 tsunami caused damage like this all along the coast of the Indian Ocean. Many lives were lost.

Tides

Tides are daily changes in the level of ocean water. They occur all around the globe. High tides occur when the water reaches its highest level in a day. Low tides occur when the water reaches its lowest level in a day. Tides keep cycling from high to low and back again. In most places the water level rises and falls twice a day. So there are two high tides and two low tides approximately every 24 hours. In **Figure** 20.5, you can see the difference between high and low tides. This is called the tidal range.

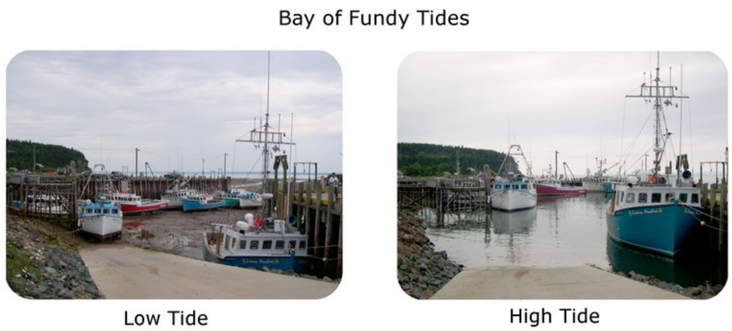

FIGURE 20.5
Where is the intertidal zone in this picture?

Why Tides Occur

Figure 20.6 shows why tides occur. The main cause of tides is the pull of the moon's gravity on Earth. The pull is greatest on whatever is closest to the moon. Although the gravity pulls the land, only the water can move. As a result:

- Water on the side of Earth facing the moon is pulled hardest by the moon's gravity. This causes a bulge of water on that side of Earth. That bulge is a high tide.
- Earth itself is pulled harder by the moon's gravity than is the ocean on the side of Earth opposite the moon. As a result, there is bulge of water on the opposite side of Earth. This creates another high tide.
- With water bulging on two sides of Earth, there's less water left in between. This creates low tides on the other two sides of the planet.

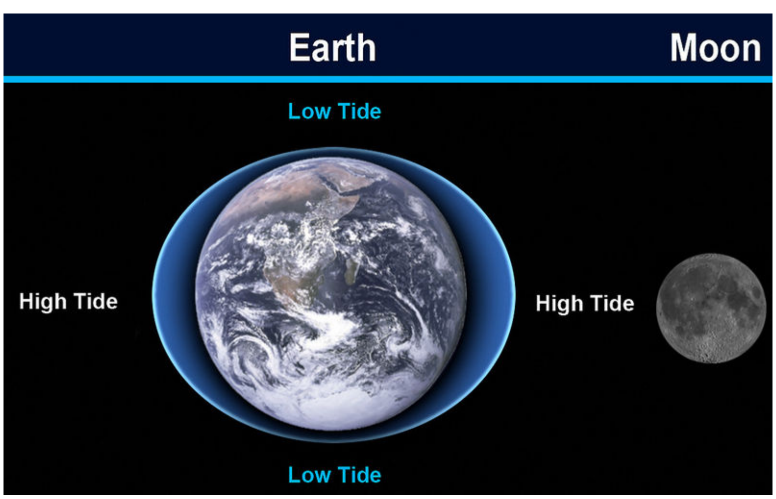

FIGURE 20.6
High and low tides are due mainly to the pull of the moon's gravity.

Spring Tides and Neap Tides

The sun's gravity also pulls on Earth and its oceans. Even though the sun is much larger than the moon, the pull of the sun's gravity is much less because the sun is much farther away. The sun's gravity strengthens or weakens the moon's influence on tides. **Figure** 20.7 shows the position of the moon relative to the sun at different times during the month. The positions of the moon and sun relative to each other determines how the sun affects tides. This creates spring tides or neap tides.

- **Spring tides** occur during the new moon and full moon. The sun and moon are in a straight line either on the same side of Earth or on opposite sides. Their gravitational pull combines to cause very high and very low tides. Spring tides have the greatest tidal range.
- **Neap tides** occur during the first and third quarters of the moon. The moon and sun are at right angles to each other. Their gravity pulls on the oceans in different directions so the highs and lows are not as great. Neap tides have the smallest tidal range.

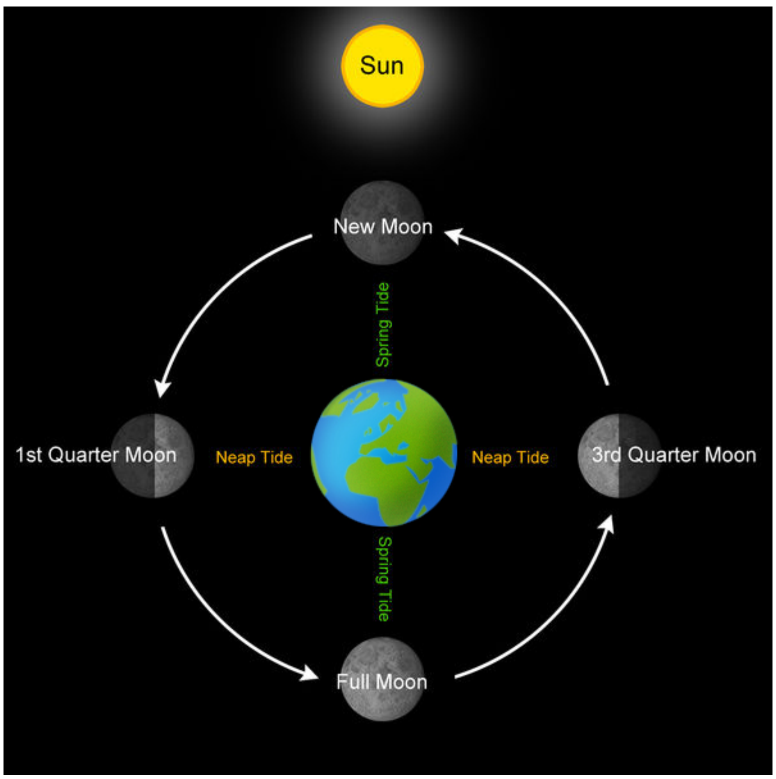

FIGURE 20.7
The sun and moon both affect Earth's tides.

This animation shows the effect of the Moon and Sun on the tides: http://www.onr.navy.mil/focus/ocean/motion/tides1.htm .

Surface Currents

Another way ocean water moves is in currents. A current is a stream of moving water that flows through the ocean. **Surface currents** are caused mainly by winds, but not the winds that blow and change each day. Surface currents are caused by the major wind belts that blow in the same direction all the time.

The major surface currents are shown in **Figure** 20.8. They flow in a clockwise direction in the Northern Hemisphere. In the Southern Hemisphere, they flow in the opposite direction.

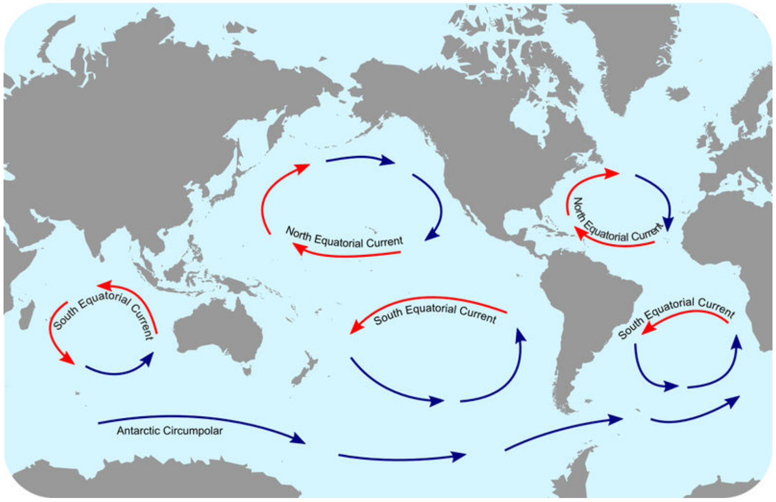

FIGURE 20.8
Earth's surface currents flow in the patterns shown here.

Coriolis Effect

Winds and surface currents tend to move from the hot equator north or south toward the much cooler poles. That's because of differences in the temperature of air masses over Earth's surface. But Earth is spinning on its axis underneath the wind and water as they move. The Earth rotates from west to east. As a result, winds and currents actually end up moving toward the northeast or southeast. This effect of Earth's rotation on the direction of winds and currents is called the **Coriolis effect**.

Surface Currents and Climate

Large ocean currents can have a big impact on the climate of nearby coasts. The Gulf Stream, for example, carries warm water from near the equator up the eastern coast of North America. Look at the map in **Figure** 20.9. It shows how the Gulf Stream warms both the water and land along the coast.

Deep Currents

Currents also flow deep below the surface of the ocean. **Deep currents** are caused by differences in density at the top and bottom. **Density** is defined as the amount of mass per unit of volume. More dense water takes up less space than less dense water. It has the same mass but less volume. Water that is more dense sinks. Less dense water rises. What can make water more dense?

Water becomes more dense when it is colder and when it has more salt. In the North Atlantic Ocean, cold winds chill the water at the surface. Sea ice grows in this cold water, but ice is created from fresh water. The salt is left behind in the seawater. This cold, salty water is very dense, so it sinks to the bottom of the North Atlantic. Downwelling can take place in other places where surface water becomes very dense (see **Figure** 20.10).

When water sinks it pushes deep water along at the bottom of the ocean. This water circulates through all of the ocean basins in deep currents.

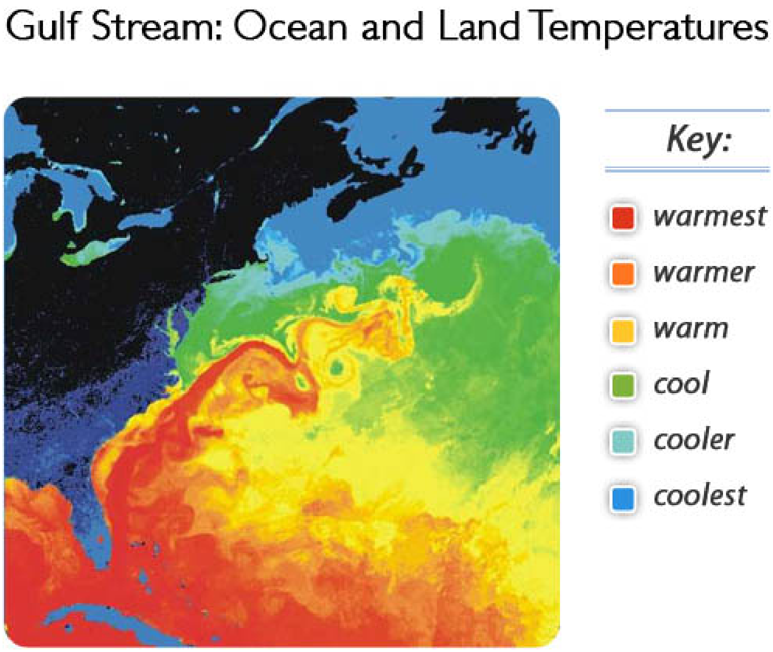

FIGURE 20.9
In this satellite photo, different colors indicate the temperatures of water and land. The warm Gulf Stream can be seen snaking up eastern North America.

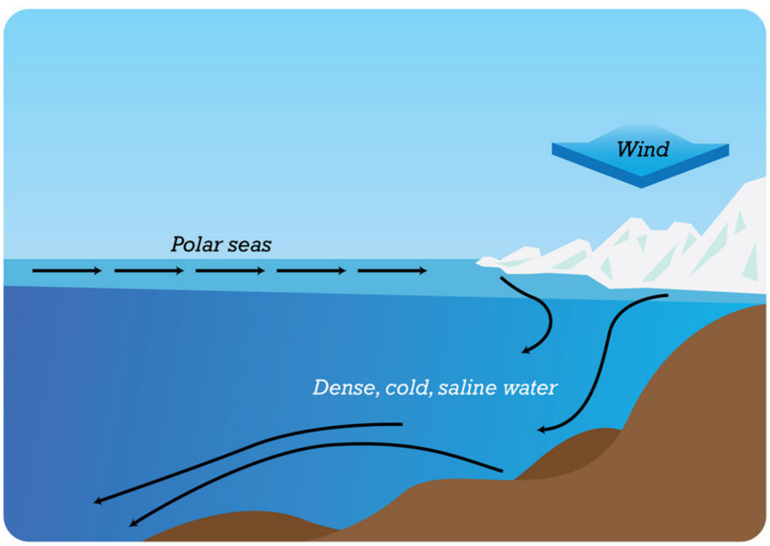

FIGURE 20.10
Deep currents flow because of differences in density of ocean water.

Upwelling

Sometimes deep ocean water rises to the surface. This is called **upwelling**. **Figure** 20.11 shows why it happens. Strong winds blow surface water away from shore. This allows deeper water to flow to the surface and take its place.

When water comes up from the deep, it brings a lot of nutrients with it. Why is deep water so full of nutrients? Over time, dead organisms and other organic matter settle to the bottom water and collect. The nutrient-rich water that comes to the surface by upwelling supports many living things.

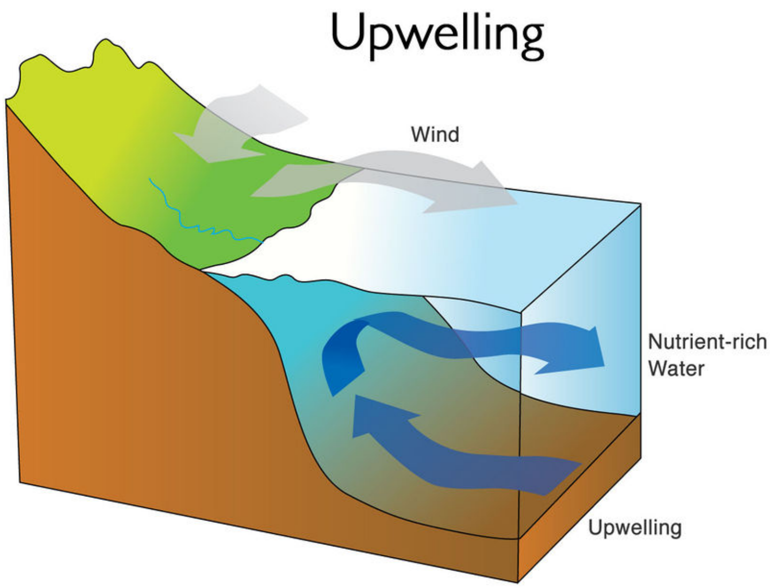

FIGURE 20.11
An upwelling occurs when deep ocean water rises to the surface.

Lesson Summary

- Most ocean waves are caused by winds. The size of a wave depends on how fast, how far, and how long the wind blows. Tsunamis are waves caused by earthquakes.
- Tides are daily changes in the level of ocean water. They are caused mainly by the pull of the moon's gravity on Earth and its oceans. The sun's gravity also influences tides.
- Surface currents are like streams flowing through the surface of the ocean. They are caused mainly by winds. Earth's rotation influences their direction. This is called the Coriolis effect. Surface currents may affect the climate of nearby coasts.
- Deep currents are convection currents that occur far below the surface. They are caused by differences in the density of ocean water.
- Upwelling occurs when deep ocean water rises to the surface. The water brings nutrients with it. These nutrients support many organisms.

Lesson Review Questions

Recall

1. Identify two causes of ocean waves.
2. What factors determine how big a wave is?
3. What is the Coriolis effect?
4. Define density. How is the density of water related to its temperature?
5. Describe upwelling. State why it occurs.

Apply Concepts

6. The crest of an ocean wave is 3 meters above the still water level. The trough is 3 meters below the still water level. The horizontal distance between the crest and trough is 8 meters. Draw a diagram of this wave. Label the crest, trough, and distances. Then calculate the wave's amplitude and wavelength.

7. Assume that a spring tide occurs on September 1. Predict when the next neap tide will occur. When will the next spring tide occur? Explain your answers.

Think Critically

8. Explain why waves break on the shore.

9. If the tidal cycle was actually 12 hours then high tides would occur at the same time every day. In reality, high tides occur about every 12 hours and 25 minutes. Can you think of why this would be the case?

10. Are deep currents the same as surface currents except that they are near the ocean bottom?

Points to Consider

Upwelling brings nutrients to the surface from the ocean floor. Nutrients are important resources for ocean life. However, they aren't the only resources on the ocean floor.

- What other resources do you think might be found on the ocean floor?
- It's hard to get resources from the ocean floor. Can you explain why?

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2. Hana Zavadska. Anatomy of a wave . CC BY-NC 3.0
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5. Dylan Kereluk. Left: http://commons.wikimedia.org/wiki/File:Bay_of_Fundy_-_Tide_Out.jpg; Right: http://commons.wikimedia.org/wiki/File:Bay_of_Fundy_-_Tide_In.jpg . CC BY 2.0
6. Hana Zavadska, using Earth image courtesy of NASA, moon image courtesy of NASA/GSFC/Arizona State University. CK-12 Foundation (Earth: http://commons.wikimedia.org/wiki/File:The_Earth_seen_from_Apollo_17_with_transparent_background.png, Moon: http://photojournal.jpl.nasa.gov/catalog/PIA14011) . CC BY-NC 3.0 (Earth and moon: public domain)
7. Zappy's. CK-12 Foundation . CC BY-NC 3.0
8. Map: courtesy of Wereon and US Geological Survey; modified by CK-12 Foundation. Map: http://commons.wikimedia.org/wiki/File:Usgs_map_mercator.svg . CC BY-NC 3.0 (map available in the public domain)
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CONCEPT 21 The Atmosphere

Lesson Objectives

- Explain why Earth's atmosphere is important.
- Describe the composition of the atmosphere.
- List properties of the atmosphere.

Vocabulary

- air pressure
- altitude
- sound

Introduction

Why is Earth the only planet in the solar system known to have life? The main reason is Earth's atmosphere. The atmosphere is a mixture of gases that surrounds the planet. We also call it air. The gases in the air include nitrogen, oxygen, and carbon dioxide. Along with water vapor, air allows life to survive. Without it, Earth would be a harsh, barren world.

Why the Atmosphere Is Important

We are lucky to have an atmosphere on Earth. The atmosphere supports life, and is also needed for the water cycle and weather. The gases of the atmosphere even allow us to hear.

The Atmosphere and Living Things

Most of the atmosphere is nitrogen, but it doesn't do much. Carbon dioxide and oxygen are the gases in the atmosphere that are needed for life.

- Plants need carbon dioxide for photosynthesis. They use sunlight to change carbon dioxide and water into food. The process releases oxygen. Without photosynthesis, there would be very little oxygen in the air.
- Other living things depend on plants for food. These organisms need the oxygen plants release to get energy out of the food. Even plants need oxygen for this purpose.

The Atmosphere and the Sun's Rays

The atmosphere protects living things from the sun's most harmful rays. Gases reflect or absorb the strongest rays of sunlight. **Figure** 21.1 models this role of the atmosphere.

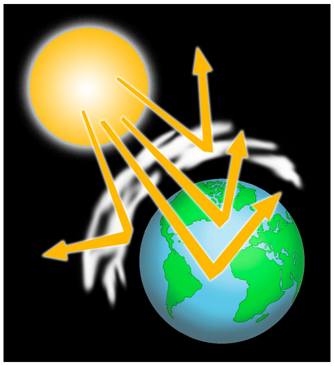

FIGURE 21.1
The atmosphere shields Earth from harmful solar rays.

The Atmosphere and Earth's Temperature

Gases in the atmosphere surround Earth like a blanket. They keep the temperature in a range that can support life. The gases keep out some of the sun's scorching heat during the day. At night, they hold the heat close to the surface, so it doesn't radiate out into space.

The Atmosphere and Earth's Water

Figure 21.2 shows the role of the atmosphere in the water cycle. Water vapor rises from Earth's surface into the atmosphere. As it rises, it cools. The water vapor may then condense into water droplets and form clouds. If enough water droplets collect in clouds they may fall as rain. This how freshwater gets from the atmosphere back to Earth's surface.

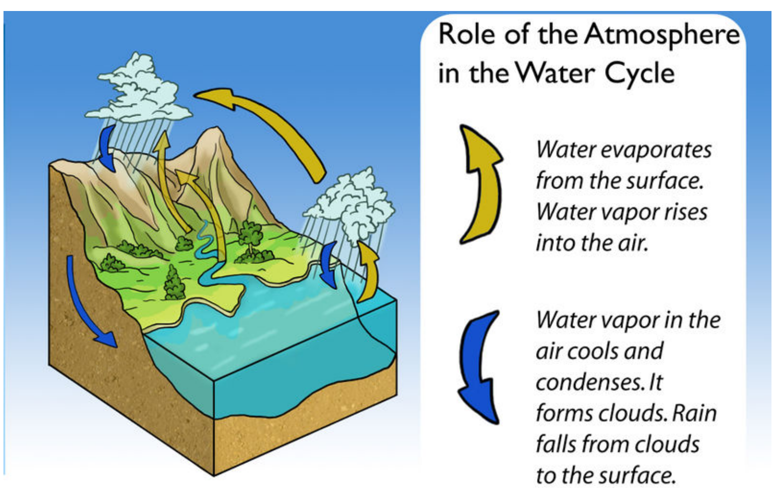

FIGURE 21.2
The atmosphere is a big part of the water cycle. What do you think would happen to Earth's water without it?

The Atmosphere and Weather

Without the atmosphere, there would be no clouds or rain. In fact, there would be no weather at all. Most weather occurs because the atmosphere heats up more in some places than others.

The Atmosphere and Weathering

Weather makes life interesting. Weather also causes weathering. Weathering is the slow wearing down of rocks on Earth's surface. Wind-blown sand scours rocks like sandpaper. Glaciers of ice scrape across rock surfaces like a file. Even gentle rain may seep into rocks and slowly dissolve them. If the water freezes, it expands. This eventually causes the rocks to crack. Without the atmosphere, none of this weathering would happen.

The Atmosphere and Sound

Sound is a form of energy that travels in waves. Sound waves can't travel through empty space, but they can travel through gases. Gases in the air allow us to hear most of the sounds in our world. Because of air, you can hear birds singing, horns tooting, and friends laughing. Without the atmosphere, the world would be a silent, eerie place.

Composition of Air

Air is easy to forget about. We usually can't see it, taste it, or smell it. We can only feel it when it moves. But air is actually made of molecules of many different gases. It also contains tiny particles of solid matter.

Gases in Air

Figure 21.3 shows the main gases in air. Nitrogen and oxygen make up 99 percent of air. Argon and carbon dioxide make up much of the rest. These percentages are the same just about everywhere in the atmosphere.

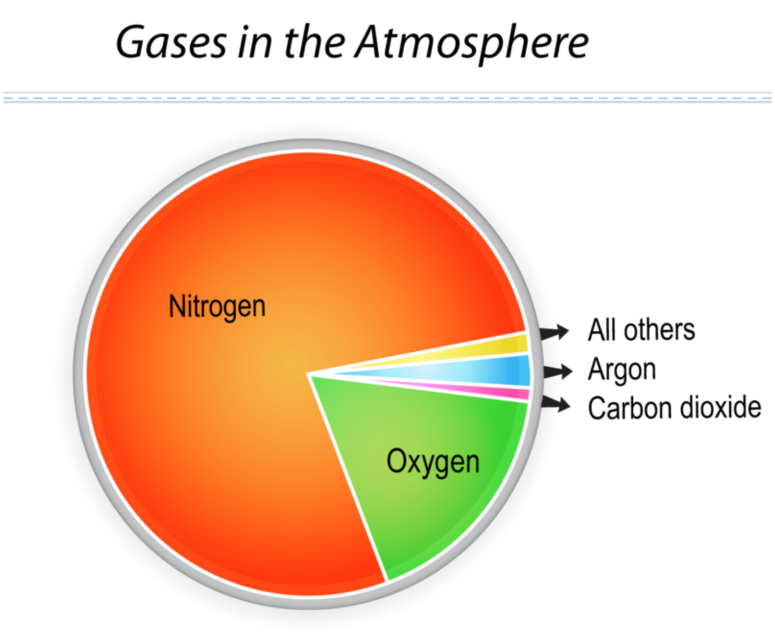

FIGURE 21.3
This graph identifies the most common gases in air.

Air also includes water vapor. The amount of water vapor varies from place to place. That's why water vapor isn't included in **Figure** 21.3. It can make up as much as 4 percent of the air. Ozone is a molecule made of three oxygen atoms. Ozone collects in a layer in the stratosphere.

Particles in the Air

Air includes many tiny particles. The particles may consist of dust, soil, salt, smoke, or ash. Some particles pollute the air and may make it unhealthy to breathe. But having particles in the air is very important. Tiny particles are needed for water vapor to condense on. Without particles, water vapor could not condense. Then clouds could not form and Earth would have no rain.

Properties of Air

We usually can't sense the air around us unless it is moving. But air has the same basic properties as other matter. For example, air has mass, volume and, of course, density.

Density of Air

Density is mass per unit volume. Density is a measure of how closely molecules are packed together. The closer together they are, the greater the density. Since air is a gas, the molecules can pack tightly or spread out.

The density of air varies from place to place. Air density depends on several factors. One is temperature. Like other materials, warm air is less dense than cool air. Since warmer molecules have more energy, they are more active. The molecules bounce off each other and spread apart. Another factor that affects the density of air is altitude.

Altitude and Density

Altitude is height above sea level. The density of air decreases with height. There are two reasons. At higher altitudes, there is less air pushing down from above. Also, gravity is weaker farther from Earth's center. So at higher altitudes, air molecules can spread out more. Air density decreases. You can see this in **Figure** 21.4.

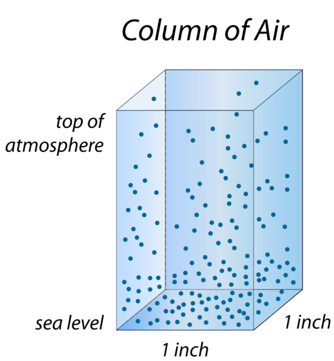

FIGURE 21.4
This drawing represents a column of air. The column rises from sea level to the top of the atmosphere. Where does air have the greatest density?

Air Pressure

Because air is a gas, its molecules have a lot of energy. Air molecules move a lot and bump into things. For this reason, they exert pressure. **Air pressure** is defined as the weight of the air pressing against a given area.

At sea level, the atmosphere presses down with a force of about 1 kilogram per square centimeter (14.76 pounds per square inch). If you are standing at sea level, you have more than a ton of air pressing against you. Why doesn't the pressure crush you? Air presses in all directions at once. Other molecules of air are pushing back.

Altitude and Air Pressure

Like density, the pressure of the air decreases with altitude. There is less air pressing down from above the higher up you go. Look at the bottle in **Figure** 21.5. It was drained by a hiker at the top of a mountain. Then the hiker screwed the cap on the bottle and carried it down to sea level. At the lower altitude, air pressure crushed it. Can you explain why?

FIGURE 21.5
At sea level, pressure was greater outside than inside the bottle. The greater outside pressure crushed the bottle.

Lesson Summary

- Gases in the atmosphere are needed by living things. They protect life from the sun's harmful rays. They also keep temperatures in a range that can support life. Gases in air play a major part in the water cycle, weather, and weathering. They are also needed to transmit most sounds.
- Nitrogen and oxygen make up about 99 percent of the air. Argon and carbon dioxide make up much of the rest. The air also contains water vapor. The amount of water vapor varies from place to place.
- Air has mass and volume. It also has density and exerts pressure. Both the density and pressure of air decrease with altitude.

Lesson Review Questions

Recall

1. State how living things interact with the atmosphere.
2. How does the atmosphere keep Earth warm at night?
3. What role does the atmosphere play in the water cycle?
4. Why does weathering on Earth's surface depend on the atmosphere?
5. Describe the composition of air.

Apply Concepts

6. Create a graph that shows how air pressure changes with altitude. Use the data in **Table** 21.1 as a guide.

TABLE 21.1: short caption

Air Pressure (atm)	Altitude (m)	Altitude (ft)
1	0	0
3/4	2,750	7,902
1/2	5,486	18,000
1/3	8,376	27,480
1/10	16,132	52,926
1/100	30,901	101,381
1/1,000	48,467	159,013
1/10,000	69,464	227,899
1/100,000	86,282	283,076

Think Critically

7. Explain how and why the density of air changes with altitude.

8. Review **Figure** 21.5 and its caption. What would the bottle look like if the hiker hadn't screwed on the cap before returning to sea level? Explain your answer.

Points to Consider

In this lesson, you read that air density and pressure change with altitude. The temperature of the air also changes with altitude. Air temperature measures the heat energy of air molecules.

- What heats the atmosphere? Where does air gets its energy?
- What causes the atmosphere to lose energy and become cooler?

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5. User:Quantockgoblin/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Plastic_bottle_at_14000_feet,_9000_feet_and_1000_feet,_sealed_at_14000_feet.png . Public Domain

CONCEPT 22 Energy in the Atmosphere

Lesson Objectives

- Define energy.
- Describe solar energy.
- State how heat moves through the atmosphere.
- Describe how solar energy varies across Earth's surface.
- Explain the greenhouse effect.

Vocabulary

- electromagnetic spectrum
- energy
- greenhouse effect
- greenhouse gas
- infrared light
- photon
- ultraviolet (UV) light
- visible light

Introduction

Picture yourself sitting by the campfire in **Figure** 22.1. You and your friends are using the fire to heat soup in a pot. As the sun goes down, the air gets chilly. You move closer to the fire. Heat from the fire warms you. Light from the fire allows you to see your friends.

What Is Energy?

What explains all of these events? The answer can be summed up in one word: energy. **Energy** is defined as the ability to do work. Doing anything takes energy. A campfire obviously has energy. You can feel its heat and see its light.

Forms of Energy

Heat and light are forms of energy. Other forms are chemical and electrical energy. Energy can't be created or destroyed. It can change form. For example, a piece of wood has chemical energy stored in its molecules. When the wood burns, the chemical energy changes to heat and light energy.

FIGURE 22.1
These campers can feel and see the energy of their campfire.

Movement of Energy

Energy can move from one place to another. It can travel through space or matter. That's why you can feel the heat of a campfire and see its light. These forms of energy travel from the campfire to you.

Energy from the Sun

Almost all energy on Earth comes from the sun. The sun's energy heats the planet and the air around it. Sunlight also powers photosynthesis and life on Earth.

Photons of Energy

The sun gives off energy in tiny packets called **photons**. Photons travel in waves. **Figure** 22.2 models a wave of light. Notice the wavelength in the figure. Waves with shorter wavelengths have more energy.

Electromagnetic Spectrum

Energy from the sun has a wide range of wavelengths. The total range of energy is called the **electromagnetic spectrum**. You can see it in **Figure** 22.3.

Visible light is the only light that humans can see. Different wavelengths of visible light appear as different colors. Radio waves have the longest wavelengths. They also have the least amount of energy. **Infrared light** has wavelengths too long for humans to see, but we can feel them as heat. The atmosphere absorbs the infrared light. **Ultraviolet (UV) light** is in wavelengths too short for humans to see. The most energetic UV light is harmful to life. The atmosphere absorbs most of this UV light from the sun. Gamma rays have the highest energy and they are the most damaging rays. Fortunately, gamma rays don't penetrate Earth's atmosphere.

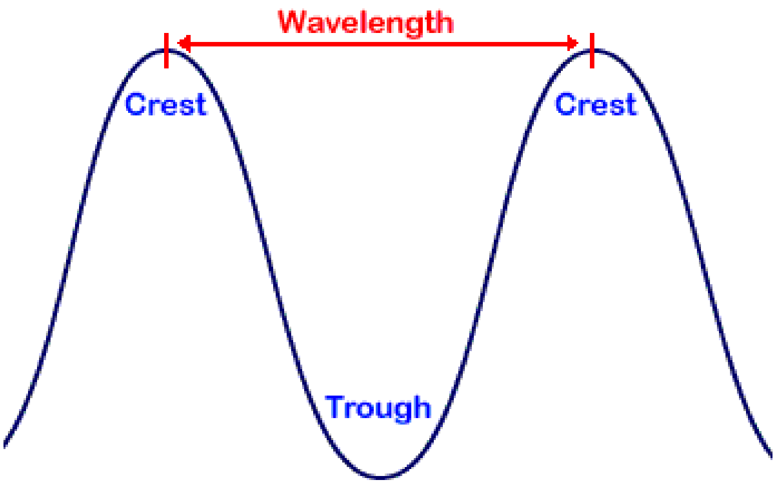

FIGURE 22.2
This curve models a wave. Based on this figure, how would you define wavelength?

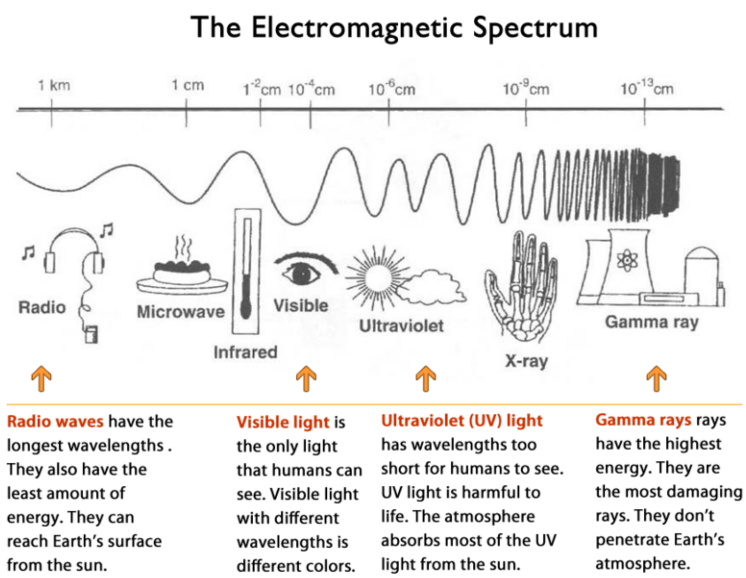

FIGURE 22.3
Compare the wavelengths of radio waves and gamma rays. Which type of wave has more energy?

How Energy Moves Through the Atmosphere

Energy travels through space or material. Heat energy is transferred in three ways: radiation, conduction, and convection.

Radiation

Radiation is the transfer of energy by waves. Energy can travel as waves through air or empty space. The sun's energy travels through space by radiation. After sunlight heats the planet's surface, some heat radiates back into the atmosphere.

Conduction

In conduction, heat is transferred from molecule to molecule by contact. Warmer molecules vibrate faster than cooler ones. They bump into the cooler molecules. When they do they transfer some of their energy. Conduction happens mainly in the lower atmosphere. Can you explain why?

Convection

Convection is the transfer of heat by a current. Convection happens in a liquid or a gas. Air near the ground is warmed by heat radiating from Earth's surface. The warm air is less dense, so it rises. As it rises, it cools. The cool air is dense, so it sinks to the surface. This creates a convection current, like the one in **Figure** 22.4. Convection is the most important way that heat travels in the atmosphere.

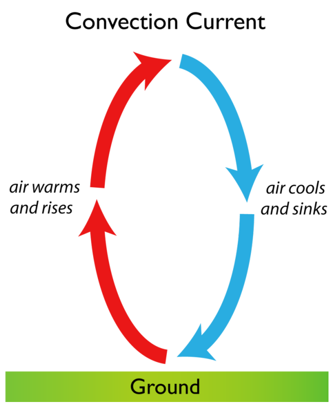

FIGURE 22.4

Convection currents are the main way that heat moves through the atmosphere. Why does warm air rise?

Energy and Latitude

Different parts of Earth's surface receive different amounts of sunlight. You can see this in **Figure** 22.5. The sun's rays strike Earth's surface most directly at the equator. This focuses the rays on a small area. Near the poles, the sun's rays strike the surface at a slant. This spreads the rays over a wide area. The more focused the rays are, the more energy an area receives and the warmer it is.

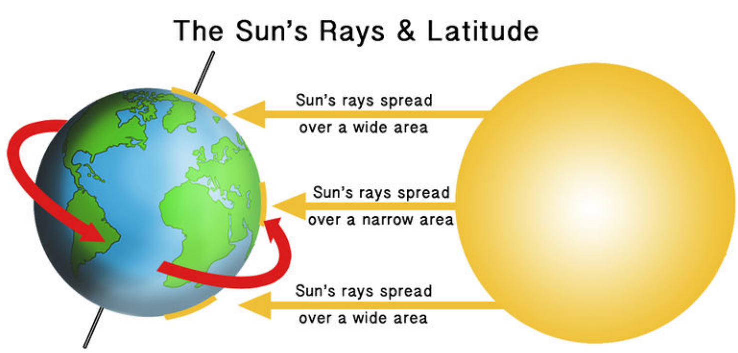

FIGURE 22.5

The lowest latitudes get the most energy from the sun. The highest latitudes get the least.

How do the differences in energy striking different latitudes affect Earth? The planet is much warmer at the equator than at the poles. In the atmosphere, the differences in heat energy cause winds and weather. On the surface, the differences cause ocean currents. Can you explain how?

The Greenhouse Effect

When sunlight heats Earth's surface, some of the heat radiates back into the atmosphere. Some of this heat is absorbed by gases in the atmosphere. This is the **greenhouse effect**, and it helps to keep Earth warm. The greenhouse effect allows Earth to have temperatures that can support life.

Gases that absorb heat in the atmosphere are called **greenhouse gases**. They include carbon dioxide and water vapor. Human actions have increased the levels of greenhouse gases in the atmosphere. This is shown in **Figure** 22.6. The added gases have caused a greater greenhouse effect. How do you think this affects Earth's temperature?

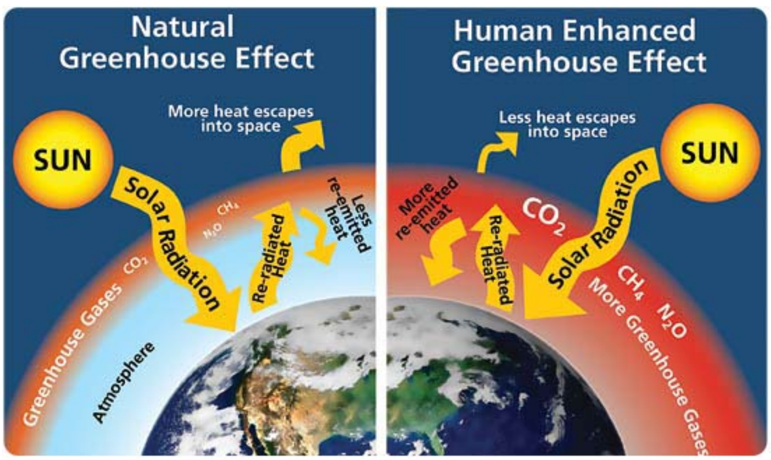

FIGURE 22.6

Human actions have increased the natural greenhouse effect.

Lesson Summary

- Energy is the ability to do work. Heat and light are forms of energy. Energy can change form. It can also move from place to place.
- Earth gets its energy from the sun. The sun gives off photons of energy that travel in waves. All the wavelengths of the sun's energy make up the electromagnetic (EM) spectrum.
- Energy moves in three ways. By radiation, it travels in waves across space. By conduction, it moves between molecules that are in contact. By convection, it moves in a current through a liquid or gas.
- Energy from the sun is more focused at the equator than the poles. Differences in energy by latitude cause winds and weather.
- Greenhouse gases in the atmosphere absorb heat. This is called the greenhouse effect and it makes the planet warmer. Human actions have increased the greenhouse effect.

Lesson Review Questions

Recall

1. Define energy. List three forms of energy.
2. Describe the electromagnetic spectrum.
3. How is wavelength related to the energy of light?
4. What is the greenhouse effect?
5. List two greenhouse gases.

Apply Concepts

6. Look at **Figure** 22.1. Apply lesson concepts to explain three ways that heat from the campfire can travel.

Think Critically

7. Why is Earth colder at the poles than the equator?
8. Explain how human actions have increased the greenhouse effect.

Points to Consider

Energy from the sun heats the air in Earth's atmosphere. You might predict that air temperature would increase steadily with altitude. After all, the higher you go, the closer you are to the sun. But it's not that simple.

- Besides the sun, what might heat up the atmosphere?
- How do you think air temperature might change with altitude?

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CONCEPT 23 Layers of the Atmosphere

Lesson Objectives

- Describe how the temperature of the atmosphere changes with altitude.
- Outline the properties of the troposphere.
- Explain the role of the ozone layer in the stratosphere.
- Describe conditions in the mesosphere.
- Explain how the sun affects the thermosphere.
- Identify the exosphere.

Vocabulary

- exosphere
- mesosphere
- ozone
- stratosphere
- temperature inversion
- thermosphere
- troposphere

Introduction

Earth's atmosphere is divided into five major layers. The layers are based on temperature.

Temperature of the Atmosphere

Air temperature changes as altitude increases. In some layers of the atmosphere, the temperature decreases. In other layers, it increases. You can see this in **Figure** 23.1. Refer to this figure as you read about the layers below.

Troposphere

The **troposphere** is the lowest layer of the atmosphere. In it, temperature decreases with altitude. The troposphere gets some of its heat directly from the sun. Most, however, comes from Earth's surface. The surface is heated by the sun and some of that heat radiates back into the air. This makes the temperature higher near the surface than at higher altitudes.

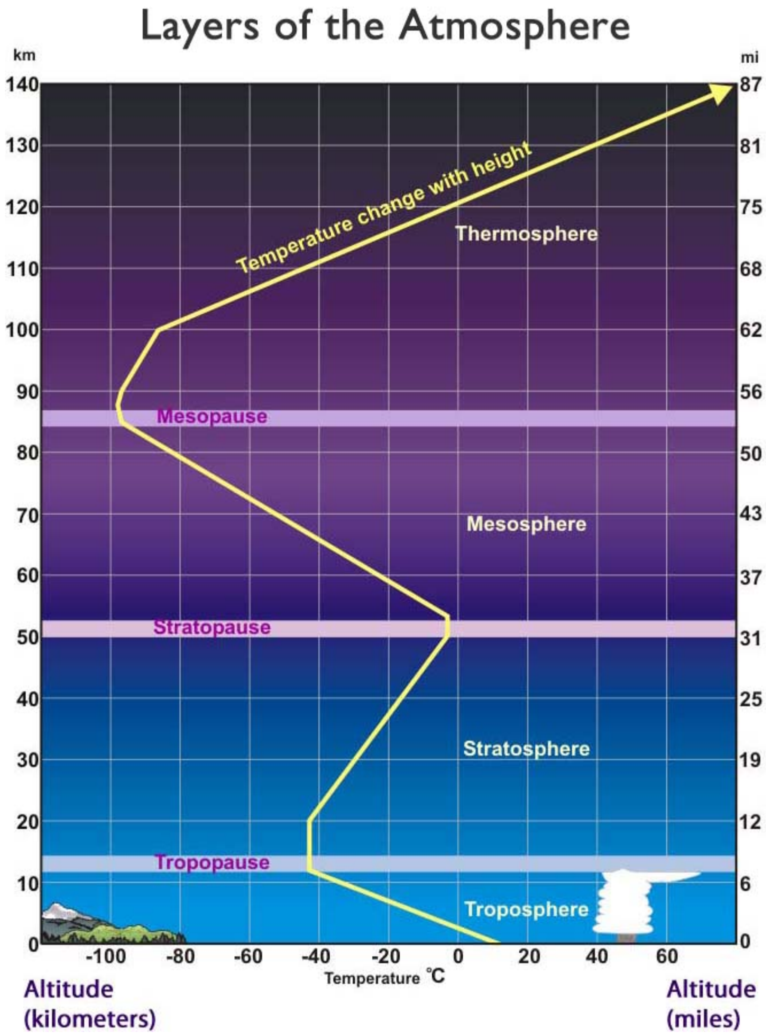

FIGURE 23.1

How does air temperature change in the layer closest to Earth?

Properties of the Troposphere

Look at the troposphere in **Figure** 23.1. This is the shortest layer of the atmosphere. It rises to only about 12 kilometers (7 miles) above the surface. Even so, this layer holds 75 percent of all the gas molecules in the atmosphere. That's because the air is densest in this layer.

Mixing of Air

Air in the troposphere is warmer closer to Earth's surface. Warm air is less dense than cool air, so it rises higher in the troposphere. This starts a convection cell. Convection mixes the air in the troposphere. Rising air is also a main cause of weather. All of Earth's weather takes place in the troposphere.

Temperature Inversion

Sometimes air doesn't mix in the troposphere. This happens when air is cooler close to the ground than it is above. The cool air is dense, so it stays near the ground. This is called a **temperature inversion**. An inversion can trap air pollution near the surface. Temperature inversions are more common in the winter. Can you explain why?

FIGURE 23.2
Temperature Inversion and Air Pollution. How does a temperature inversion affect air quality?

Tropopause

At the top of the troposphere is a thin layer of air called the tropopause. You can see it in **Figure** 23.1. This layer acts as a barrier. It prevents cool air in the troposphere from mixing with warm air in the stratosphere.

Stratosphere

The **stratosphere** is the layer above the troposphere. The layer rises to about 50 kilometers (31 miles) above the surface.

Temperature in the Stratosphere

Air temperature in the stratosphere layer increases with altitude. Why? The stratosphere gets most of its heat from the sun. Therefore, it's warmer closer to the sun. The air at the bottom of the stratosphere is cold. The cold air is dense, so it doesn't rise. As a result, there is little mixing of air in this layer.

The Ozone Layer

The stratosphere contains a layer of ozone gas. **Ozone** consists of three oxygen atoms (O_3). The ozone layer absorbs high-energy UV radiation. As you can see in **Figure** 23.3, UV radiation splits the ozone molecule. The split creates an oxygen molecule (O_2) and an oxygen atom (O). This split releases heat that warms the stratosphere. By absorbing UV radiation, ozone also protects Earth's surface. UV radiation would harm living things without the ozone layer.

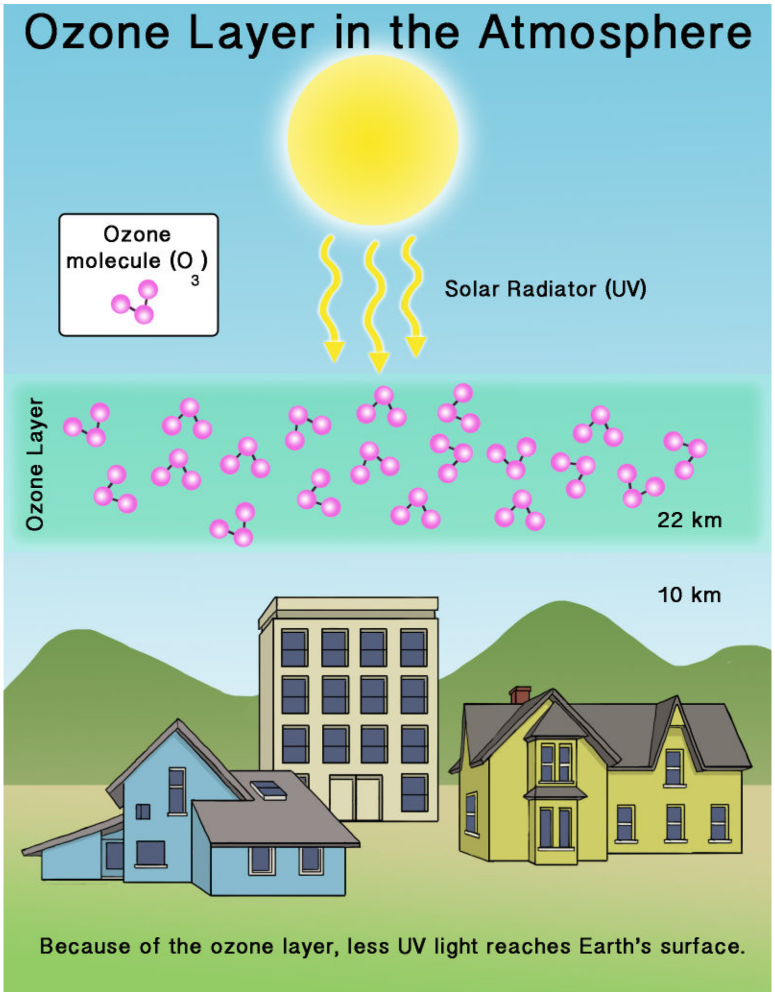

FIGURE 23.3
How does the ozone layer protect Earth's surface from UV light?

Stratopause

At the top of the stratosphere is a thin layer called the stratopause. It acts as a boundary between the stratosphere and the mesosphere.

Mesosphere

The **mesosphere** is the layer above the stratosphere. It rises to about 85 kilometers (53 miles) above the surface. Temperature decreases with altitude in this layer.

Temperature in the Mesosphere

There are very few gas molecules in the mesosphere. This means that there is little matter to absorb the sun's rays and heat the air. Most of the heat that enters the mesosphere comes from the stratosphere below. That's why the mesosphere is warmest at the bottom.

Meteors in the Mesosphere

Did you ever see a meteor shower, like the one in **Figure** 23.4? Meteors burn as they fall through the mesosphere. The space rocks experience friction with the gas molecules. The friction makes the meteors get very hot. Many meteors burn up completely in the mesosphere.

FIGURE 23.4
Friction with gas molecules causes meteors to burn up in the mesosphere.

Mesopause

At the top of the mesosphere is the mesopause. Temperatures here are colder than anywhere else in the atmosphere. They are as low as -100° C (-212° F)! Nowhere on Earth's surface is that cold.

Thermosphere

The **thermosphere** is the layer above the mesosphere. It rises to 600 kilometers (372 miles) above the surface. The International Space Station orbits Earth in this layer as in **Figure** 23.5.

Temperature in the Thermosphere

Temperature increases with altitude in the thermosphere. Surprisingly, it may be higher than 1000° C (1800° F) near the top of this layer! The sun's energy there is very strong. The molecules absorb the sun's energy and are heated up. But there are so very few gas molecules, that the air still feels very cold. Molecules in the thermosphere gain or lose electrons. They then become charged particles called ions.

Northern and Southern Lights

Have you ever seen a brilliant light show in the night sky? Sometimes the ions in the thermosphere glow at night. Storms on the sun energize the ions and make them light up. In the Northern Hemisphere, the lights are called the northern lights, or aurora borealis. In the Southern Hemisphere, they are called southern lights, or aurora australis.

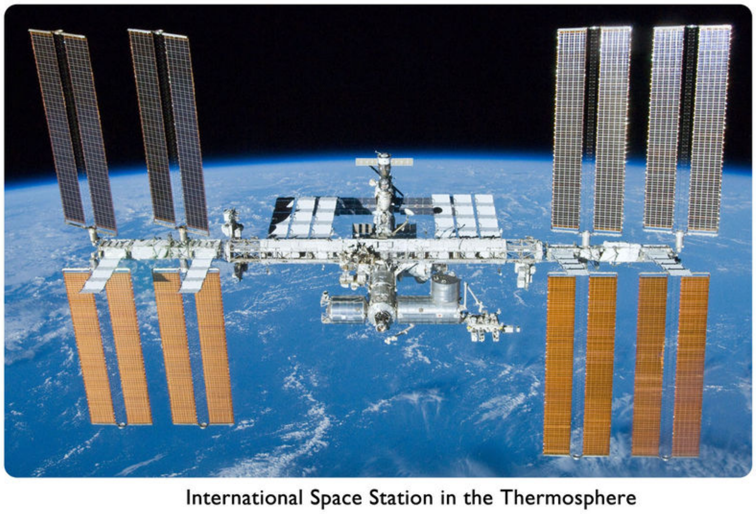

FIGURE 23.5
The International Space Station orbits in the thermosphere.

FIGURE 23.6
Glowing ions in the thermosphere light up the night sky.

Exosphere

The **exosphere** is the layer above the thermosphere. This is the top of the atmosphere. The exosphere has no real upper limit; it just gradually merges with outer space. Gas molecules are very far apart in this layer, but they are really hot. Earth's gravity is so weak in the exosphere that gas molecules sometimes just float off into space.

Lesson Summary

- Earth's atmosphere is divided into five major layers. The layers are based on temperature.
- The troposphere is the lowest layer. Temperature decreases with altitude in this layer. All weather takes place here.

- The stratosphere is the layer above the troposphere. Temperature increases with altitude in this layer. The ozone layer occurs here.
- The mesosphere is the layer above the stratosphere. Temperature decreases with altitude in this layer. Meteors burn up here.
- The thermosphere is the layer above the mesosphere. Temperature increases with altitude in this layer. The northern and southern lights occur here.
- The exosphere is the highest layer. Air molecules are very far apart. They may escape Earth's gravity and float into space.

Lesson Review Questions

Recall

1. How does temperature change in the troposphere?
2. What is a temperature inversion?
3. Why is the ozone layer in the stratosphere important to life on Earth?
4. Where does the mesosphere get its heat?

Apply Concepts

5. Think of a creative way you could model the layers of the atmosphere. Describe your model. How does it show temperature differences between the layers?

Think Critically

6. How is a temperature inversion like the temperatures of the stratosphere and troposphere?
7. Explain why air mixes in the troposphere but not in the stratosphere.
8. Why is there a hole in the ozone layer? What do you think the consequences of that hole are?

Points to Consider

Energy from the sun is responsible for winds that blow in the troposphere.

- What is wind?
- How does energy cause winds to blow?

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