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WCPSS Earth-Environmental Science

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Contents

CHAPTER 1 Preface

Chapter Outline

1.1 Acknowledgements

This FlexBook is designed to be a dynamic tool that should be adapted by each instructor to best fit their individual scope and sequence. I recognize that limits in time and resources have left gaps in the published material that will be improved upon in future editions of this textbook. I encourage you to contact me at koshinsky@wcpss.net if you would like to contribute material to this publication or future editions.

I would like to recognize the contributions of my Spring 2014 Earth/Environmental Science class. This academic-level class, where six different languages were spoken, worked tirelessly to help me design and construct this publication. Special acknowledgment is due to my professional learning team at Wakefield High School as well as my very patient family.

CHAPTER 2 Introduction to Earth-Environmental Science

Chapter Outline

2.1 Scientific Explanations and Interpretations

- Identify and define facts, explanations, and opinions.

"It used to be, everyone was entitled to their own opinion, but not their own facts. But that's not the case anymore." Stephen Colbert, AV Club Interview, January 2006

Can you tell a fact from an opinion? Can you tell when an idea follows logically from a fact? Basing ideas on facts is essential to good science. **Science** is a set of facts, and it is also a set of explanations that are based on those facts. Science relies on facts to explain the natural world.

Facts, Observations, Opinions

Scientists usually begin an investigation with facts. A **fact** is a bit of information that is true. Facts come from data collected from observations or from experiments that have already been run. **Data** is factual information that is not subject to opinion or bias.

What is a fact? Look at the following list and identify if the statement is a fact (from observation or prior experiments), an opinion, or a combination.

FIGURE 2.1
Can you be sure from the photo that Susan has a cold?

1. Susan has black hair.
2. Susan is sneezing and has itchy eyes. She is not well. She has a cold.
3. Colds are caused by viruses.
4. Echinacea is an herb that prevents colds.
5. Bill Gates is the smartest man in the United States.
6. People born under the astrological sign Leo are fiery, self-assured, and charming.
7. Average global temperature has been rising at least since 1960.

An Analysis

The following is an analysis of the statements above:

1. This is a fact made from observation.
2. The first part is from observations. The second is a fact drawn from the prior observations. The third is an opinion, since she might actually have allergies or the flu. Tests could be done to see what is causing her illness.
3. This is a fact. Many, many scientific experiments have shown that colds are caused by viruses.
4. While that sounds like a fact, the scientific evidence is mixed. One reputable study published in 2007 showed a decrease of 58%, but several other studies have shown no beneficial effect.

5. Bill Gates is the wealthiest man in the United States; that's a fact. But there's no evidence that he's also the smartest man, and chances are he's not. This is an opinion.
6. This sounds like a fact, but it is not. It is easy to test. Gather together a large number of subjects, each with a friend. Have the friends fill out a questionnaire describing the subject. Match the traits against the person's astrological sign to see if the astrological predictions fit. Are Leos actually more fiery, self assured, and charming? Tests like this have not supported the claims of astrologers, yet astrologers have not modified their opinions.
7. This is a fact. The **Figure** 2.2 shows the temperature anomaly since 1880. There's no doubt that temperature has risen overall since 1880 and especially since the late 1970s.

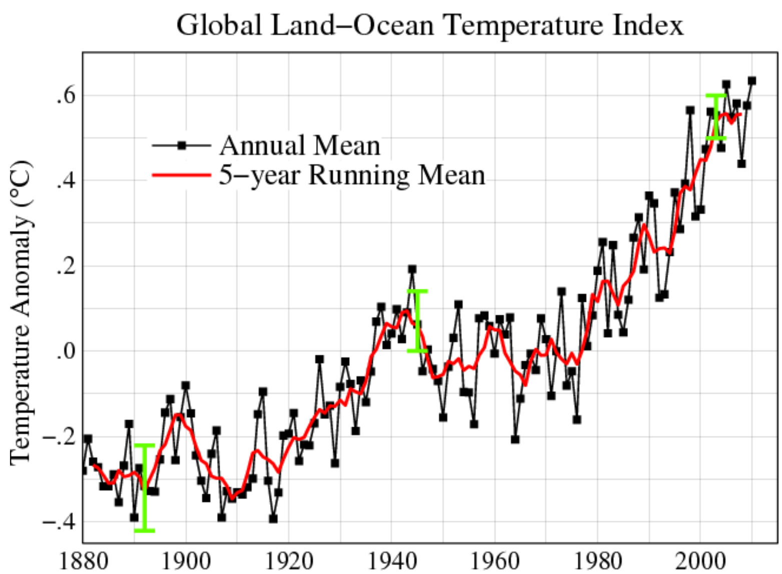


FIGURE 2.2

Global Average Annual Temperatures are Rising. This graph shows temperature anomaly relative to the 1951-1980 average (the average is made to be 0). The green bars show uncertainty.

Summary

- Facts are true. Data, gathered correctly, are facts.
- Some statements that appear to be facts are not.
- All scientific explanations and interpretations are based on facts.

Making Connections

MEDIA

Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=zcavPAFiG14

MEDIA

Click image to the left for more content.

1. What is science?
2. What is evidence?
3. List the steps of the scientific method (procedure).
4. What happens if a hypothesis is determined to be wrong?
5. Why is peer review important?
6. What is a theory?
7. Why might a theory be modified? When might it be thrown out?
8. Explain the importance of the scientific method.
9. How does technology show that scientific method works?

Review

1. Just because something appears in print doesn't mean it's true. Many stories circulate around the internet and appear to be true but are not. Take a look at http://www.snopes.com to see some interesting true and false tales. Think of something that you think is true, but may not be, and look it up. Here's one: a tooth placed in Coca-Cola will dissolve overnight.
2. Neuroscientists have shown that people are more likely to believe a statement if they have heard it before, whether it's true or not. Look in a newspaper or watch television news and find three statements that are not actually true but that the person saying them is hoping will be believed. Is this effective?
3. What is the relationship between observations and facts? What is the relationship between facts and opinions?

2.2 Branches of Earth Science

- Identify and define the major branches of Earth Science.

If science is the study of the natural world, what could be more obvious than to study the land, sky, water, and space surrounding us?

Earth scientists seek to understand the beautiful sphere on which we live. Earth is a very large, complex system or set of systems, so most Earth scientists specialize in studying one aspect of the planet. Since all of the branches of Earth science are connected, these researchers work together to answer complicated questions. The major branches of Earth science are described below.

Geology

Geology is the study of the Earth's solid material and structures and the processes that create them. Some ideas geologists might consider include how rocks and landforms are created or the composition of rocks, minerals, or various landforms. Geologists consider how natural processes create and destroy materials on Earth, and how humans can use Earth materials as resources, among other topics.

FIGURE 2.3
Geologists study rocks in the field to learn what they can from them.

Oceanography

Oceanography is the study of everything in the ocean environment, which covers about 70% of the Earth's surface. Recent technology has allowed people and probes to venture to the deepest parts of the ocean, but much of the ocean remains unexplored. Marine geologists learn about the rocks and geologic processes of the ocean basins.

Climatology and Meteorology

Meteorology includes the study of weather patterns, clouds, hurricanes, and tornadoes. Using modern technology such as radars and satellites, meteorologists are getting more accurate at forecasting the weather all the time.

Climatology is the study of the whole atmosphere, taking a long-range view. Climatologists can help us better understand how and why climate changes (**Figure** 2.4).

FIGURE 2.4
Carbon dioxide released into the atmosphere is causing the global climate to change.

Environmental Science

Environmental scientists study the effects people have on their environment, including the landscape, atmosphere, water, and living things. Climate change is part of climatology or environmental science.

Astronomy

Astronomy is the study of outer space and the physical bodies beyond the Earth. Astronomers use telescopes to see things far beyond what the human eye can see. Astronomers help to design spacecraft that travel into space and send back information about faraway places or satellites (**Figure** 2.5).

FIGURE 2.5
The Hubble Space Telescope.

Summary

- The study of Earth science includes many different fields, including geology, meteorology, oceanography, and astronomy.
- Each type of Earth scientist investigates the processes and materials of the Earth and beyond as a system.
- Geology, climatology, meteorology, environmental science, and oceanography are important branches of Earth science.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What tools do geoscientists use?
2. Do all Earth scientists study Earth's past?
3. What is fundamental about the study of Earth science?
4. Why is it important for people to study Earth science?
5. Why is Earth science called a combined science?
6. What issues will Earth science need to address in the future?

Review

1. What type of Earth scientist would be interested in understanding volcanic eruptions on the seafloor?
2. If it were to snow in Phoenix in July, which type of Earth scientist would be most surprised?
3. If people have been studying the natural world for centuries or even millennia, why are scientists learning so much about Earth science now?

2.3 Location on the Earth

- Identify and define latitude and longitude.
- Define the Prime Meridian.
- Understand how coordinates are used on a map.
- Summarize Global Positioning Systems.

How could you locate this feature?

Geologists, hikers, and many other people need to be able to say where they are. Or where they want to go. They need to be able to mark a location on a map. The opening photo is of Old Faithful Geyser in Yellowstone National Park. It is located at 44°30'N and 110°150'W. Let's explore what that means.

Location

To describe your location, you could use a coordinate system. To do this you need two points. For example, you could use streets. Maybe you are at the corner of Maple Avenue and Main Street. Or you could use a point of reference, a distance and an angle for direction. If you want to meet up with a friend, you could tell him "I am two blocks due north of your apartment." Can you identify the point of reference, the distance, and the angle?

Map Coordinates

Most maps use a grid of lines to help you to find your location. This grid system is called a geographic **coordinate system**. Using this system you can define your location by two numbers, latitude and longitude. Both numbers are angles between your location, the center of Earth, and a reference line (**Figure** 2.6).

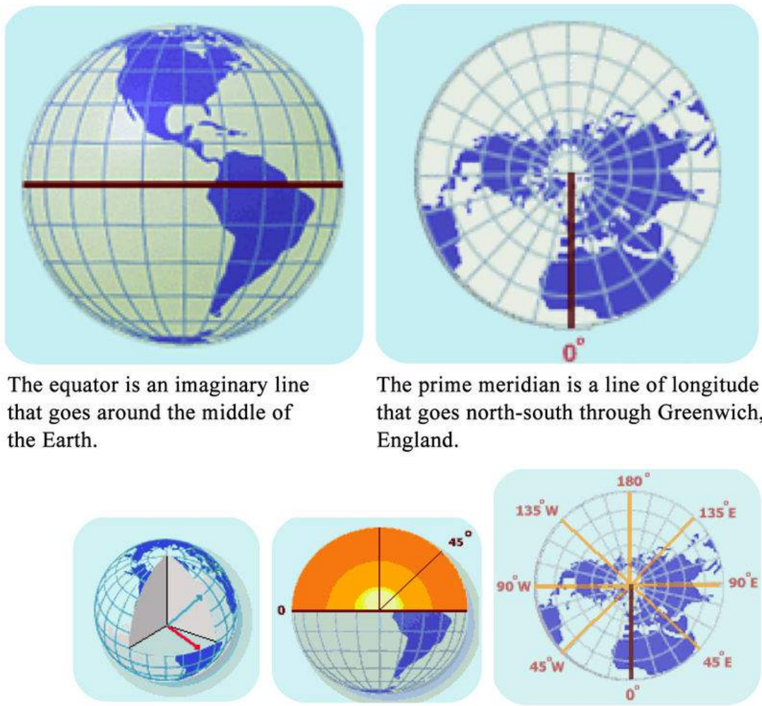


FIGURE 2.6
Lines of latitude start with the Equator. Lines of longitude begin at the prime meridian.

Latitude

Lines of **latitude** circle around Earth. The **Equator** is a line of latitude right in the middle of the planet. Latitude is divided into degrees: 90° north of the Equator and 90° south of the Equator. One degree is subdivided into 60 minutes. One minute is subdivided into 60 seconds. The Equator is at 0°. The Equator is an equal distance from both the North and South Poles. If you know your latitude, you know how far you are north or south of the Equator.

Longitude

Lines of **longitude** are circles that go around Earth from pole to pole, like the sections of an orange. Longitude is also measured in degrees, which are subdivided into minutes and seconds. Lines of longitude start at the Prime Meridian, which is 0°. The **Prime Meridian** is a circle that runs north to south and passes through Greenwich, England. Longitude tells you how far you are east or west from the Prime Meridian (**Figure** 2.7). On the opposite side of the planet from the Prime Meridian is the International Date Line. It is at 180°. This is the place where a new day first arrives.

You can remember latitude and longitude by doing jumping jacks. When your hands are above your head and your feet are together, say longitude (your body is long!). When you put your arms out to the side horizontally, say latitude (your head and arms make a cross, like the "t" in latitude). While you are jumping, your arms are going the same way as each of these grid lines: horizontal for latitude and vertical for longitude.

Using Latitude and Longitude on a Map

If you know the latitude and longitude of a place, you can find it on a map. Simply place one finger on the latitude on the vertical axis of the map. Place your other finger on the longitude along the horizontal axis of the map. Move your fingers along the latitude and longitude lines until they meet. For example, say the location you want to find is at 30°N and 90°W. Place your right finger along 30°N at the right of the map. Place your left finger along the bottom

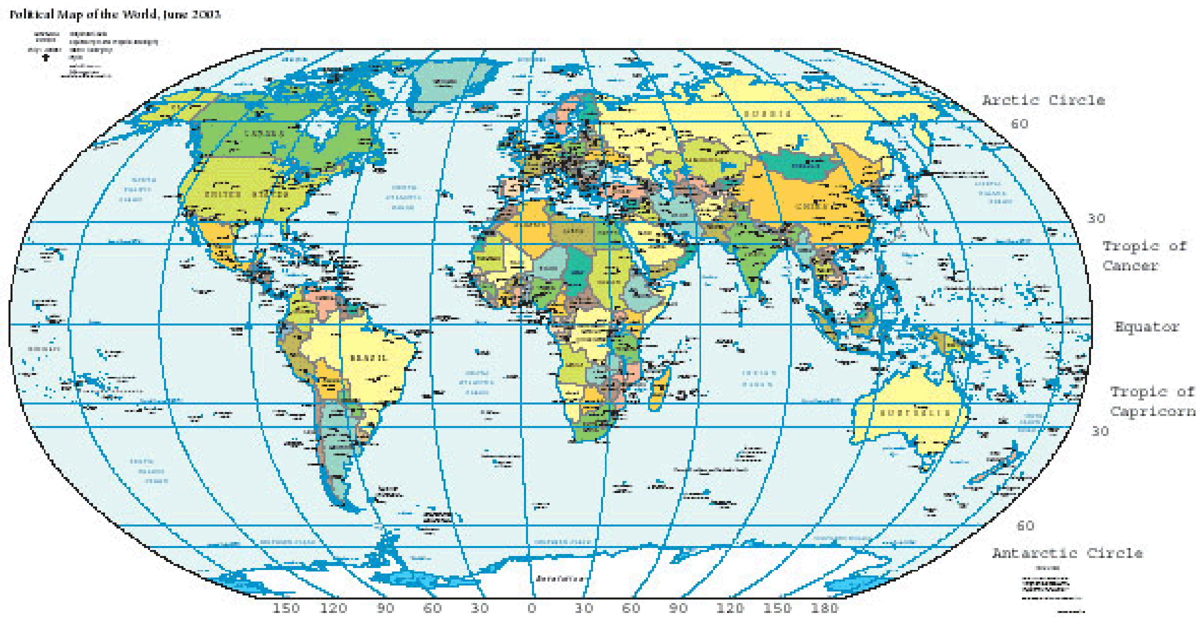


FIGURE 2.7

Lines of latitude and longitude form convenient reference points on a map.

at 90°W. Move your fingers along the lines until they meet. Your location should be near New Orleans, Louisiana, along the Gulf coast of the United States. Now can you locate Old Faithful, 44°30’N and 110°150’W, on a map?

What if you want to know the latitude and longitude of your location? If you know where you are on a map, point to the place with your fingers. Take one finger and move it along the latitude line to find your latitude. Then move another finger along the longitude line to find your longitude.

Global Positioning System

In order to get latitude, longitude, and elevation you need several instruments. What if you could do the same thing with only one instrument? A **Global Positioning System (GPS)** receiver is all that is needed to locate your position on the Earth’s surface in many places.

By 1993, the United States military had launched 24 satellites to help soldiers locate their positions on battlefields. This system of satellites was called the Global Positioning System (GPS). Later, the United States government allowed the public to use this system. Here’s how it works.

You must have a GPS receiver to use the system. You can buy many types of these in stores. The GPS receiver detects radio signals from nearby GPS satellites. There are precise clocks on each satellite and in the receiver. The receiver measures the time for radio signals from satellites to reach it. The receiver uses the time and the speed of radio signals to calculate the distance between the receiver and the satellite. The receiver does this with at least four different satellites to locate its position on the Earth’s surface (**Figure** 2.8). GPS receivers are now being built into many items, such as cell phones and cars.

You can use a GPS meter to tell you how to get to Old Faithful.

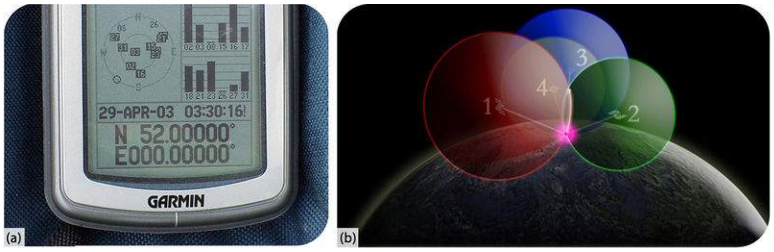


FIGURE 2.8
(a) You need a GPS receiver to use the GPS system. (b) It takes signals from four GPS satellites to find your location precisely on the surface.

Vocabulary

- **coordinate system**: Numbers on a grid that locate a particular point.
- **Equator**: Line connecting all the points equal distance between the North and South Poles. The zero degree line.
- **global positioning system (GPS)**: System of satellites designed to give location information. Satellite signals are picked up by special devices that use triangulation.
- **latitude**: Location of a place between the North and South Poles relative to the Equator.
- **longitude**: Location of a place relative to the Prime Meridian, which runs north-south through Greenwich, England.
- **Prime Meridian**: Zero degree line for longitude; goes through Greenwich, England.

Summary

- Latitude is the distance north or south of the Equator. It is expressed as a number between 0° and 90° north or south.
- Longitude is the distance east or west of the Prime Meridian. It is expressed as a number between 0° and 180° east or west.
- The global positioning system uses satellites to display very accurate location information on a special receiver.

Practice

Use the resource below to answer the questions that follow.

- **Latitude and Longitude** at http://www.youtube.com/watch?v=swKBi6hHHMA (3:14)

MEDIA
Click image to the left for more content.

1. What are lines of latitude?
2. How far apart are the lines of latitude, in degrees and in miles?
3. What are the latitudes of the Equator, the Tropic of Cancer, and the Tropic of Capricorn? What are the characteristics of the regions found between the Tropic of Cancer and the Tropic of Capricorn?

4. Where are the Arctic and Antarctic Circles? What are the characteristics of the regions that are found between these circles and the tropics?
5. What are lines of longitude?
6. Where do the meridians meet?
7. What is the Prime Meridian? Where is it located?
8. How are longitude and latitude measured?

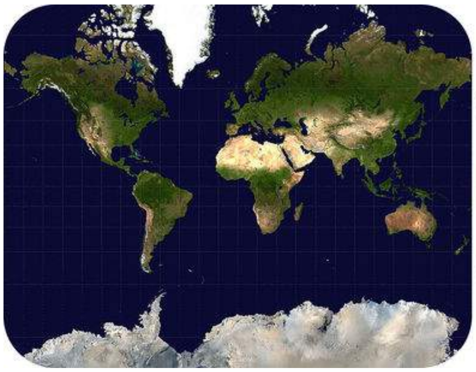
Practice your skills at identifying latitude and longitude at **Latitude and Longitude Map Match Game** at http://www.kidsgeo.com/geography-games/latitude-longitude-map-game.php . The game is simple to start but becomes more challenging (and fun!) as you progress through the levels. Can you get to level 10?

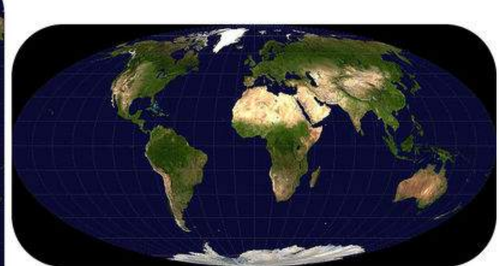
Review

1. What would a latitude number in the Southern Hemisphere look like?
2. Define latitude and longitude.
3. Why are GPS devices so accurate?

2.4 Map Projections

- Identify and define types of map projections.





How does Greenland change size?

Greenland does not change size! Different map projections make Greenland appear to be a different size. The Mercator projection makes everything that is near the polar areas appear too large. The Mollweide projection distorts the size of the polar regions much less. To see the actual size of Greenland, look at a globe.

Map Projections

Earth is a round, three-dimensional ball. In a small area, Earth looks flat, so it is not hard to make accurate maps of a small place. When mapmakers want to map the round Earth on flat paper, they use projections. What happens if you try to flatten out the skin of a peeled orange? Or if you try to gift wrap a soccer ball? To flatten out, the orange peel must rip, and its shape must become distorted. To wrap a round object with flat paper requires lots of extra cuts and folds. A **projection** is a way to represent Earth's curved surface on flat paper (**Figure** 2.9).

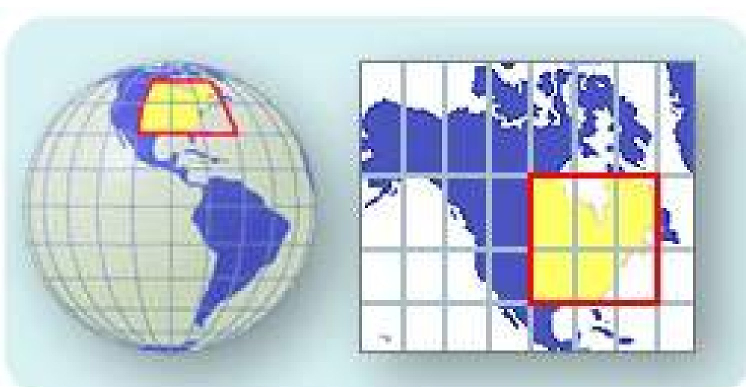


FIGURE 2.9
A map projection translates Earth's curved surface onto two dimensions.

There are many types of projections. Each uses a different way to change three dimensions into two dimensions.

There are two basic methods that the mapmaker uses in projections:

- The mapmaker "slices" the sphere in some way and unfolds it to make a flat map. This is like flattening out an orange peel.
- The mapmaker can look at the sphere from a certain point and then translate this view onto a flat paper.

Let's look at a few commonly used projections.

Mercator Projection

In 1569, Gerardus Mercator (1512-1594) (**Figure** 2.10) figured out a way to make a flat map of our round world. This is called the Mercator projection.

Imagine wrapping the round, ball-shaped Earth with a big, flat piece of paper. First you make a tube or a cylinder. The cylinder touches Earth at the Equator. The poles are the farthest points from the cylinder. Now shine a light from the inside of your model Earth out to the cylinder. The image projected onto the paper is a Mercator projection. Where does the projection represent Earth best? Where is it worst? Your map would be most correct at the Equator. The shapes and sizes of continents become more stretched out near the poles. Early sailors and navigators found the Mercator map useful because most explorations were located near the Equator. Many world maps still use the Mercator projection.

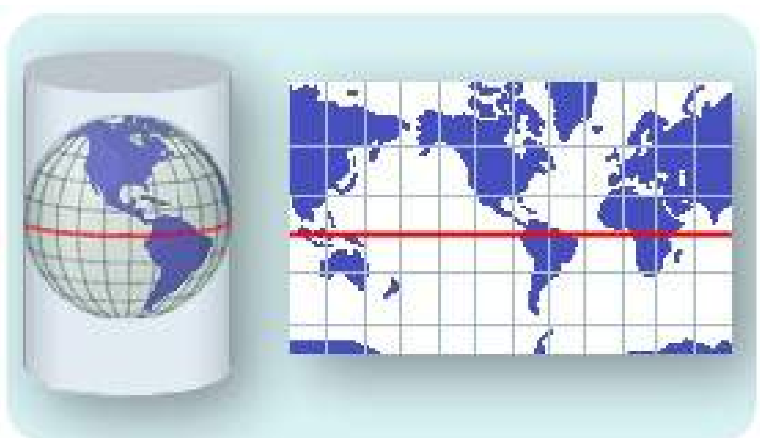


FIGURE 2.10
A Mercator projection translates the curved surface of Earth onto a cylinder.

The Mercator projection is best within 15° north or south of the Equator. Landmasses or countries outside that zone get stretched out of shape. The further the feature is from the Equator, the more out of shape it is stretched. For example, if you look at Greenland on a globe, you see it is a relatively small country near the North Pole. But look at the Mercator projection above. Greenland looks almost as big the United States. Because Greenland is closer to the pole, the continent's shape and size are greatly increased. The United States is closer to its true dimensions. Why is this true?

In a Mercator projection, all compass directions are straight lines. This makes it a good type of map for navigation. The top of the map is north, the bottom is south, the left side is west and the right side is east. However, because it is a flat map of a curved surface, a straight line on the map is not the shortest distance between the two points it connects.

Conic Projection

Instead of a cylinder, you could wrap the flat paper into a cone. Conic map projections use a cone shape to better represent regions near the poles (**Figure** 2.11). Conic projections are best where the cone shape touches the globe. This is along a line of latitude, usually the Equator.

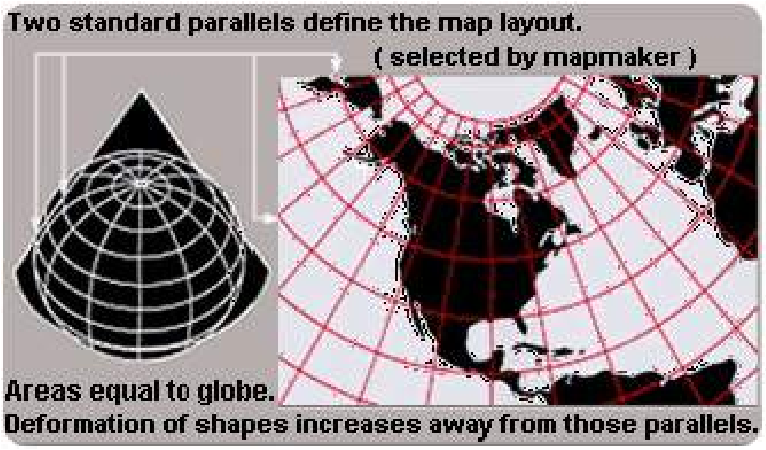


FIGURE 2.11
A conic map projection wraps Earth with a cone shape rather than a cylinder.

Gnomonic Projection

What if you want a different approach? Let's say you don't want to wrap a flat piece of paper around a round object. You could put a flat piece of paper right on the area that you want to map. This type of map is called a gnomonic map projection (**Figure** 2.12). The paper only touches Earth at one point. The sizes and shapes of countries near that point are good. The poles are often mapped this way to avoid distortion. A gnomic projection is best for use over a small area.

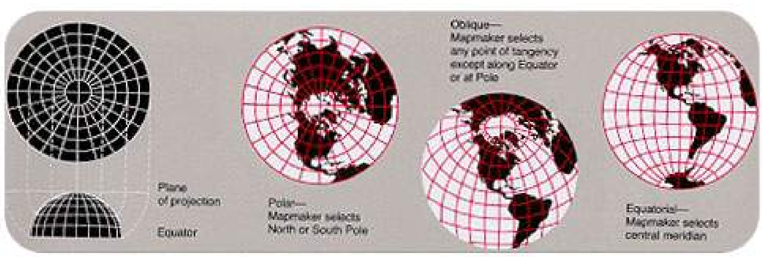


FIGURE 2.12
A gnomonic projection places a flat piece of paper on a point somewhere on Earth and projects an image from that point.

Robinson Projection

In 1963, Arthur Robinson made a map with more accurate sizes and shapes of land areas. He did this using mathematical formulas. The formulas could directly translate coordinates onto the map. This type of projection is shaped like an oval rather than a rectangle (**Figure** 2.13).

Robinson's map is more accurate than a Mercator projection. The shapes and sizes of continents are closer to true. Robinson's map is best within 45° of the Equator. Distances along the Equator and the lines parallel to it are true. However, the scales along each line of latitude are different. In 1988, the National Geographic Society began to use Robinson's projection for its world maps.

Vocabulary

- **projection**: Way to represent a three-dimensional figure in two dimensions.

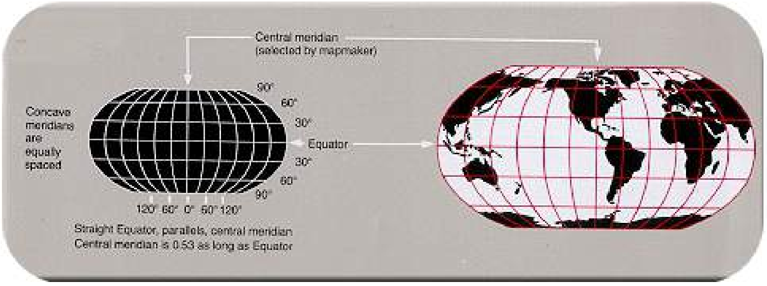


FIGURE 2.13
A Robinson projection better represents the true shapes and sizes of land areas.

Summary

- A map projection is a way to show a three-dimensional figure in two dimensions.
- All map projections have some distortion. Different types have distortions in different locations and of different amounts.
- Robinson's project is different from the rest because it uses mathematical formulas. Other projections are best at one point.

Practice

Use the resource below to answer the questions that follow.

- **Map Projections** at http://www.youtube.com/watch?v=pZ1z4IW8f_E (1:00)

MEDIA
Click image to the left for more content.

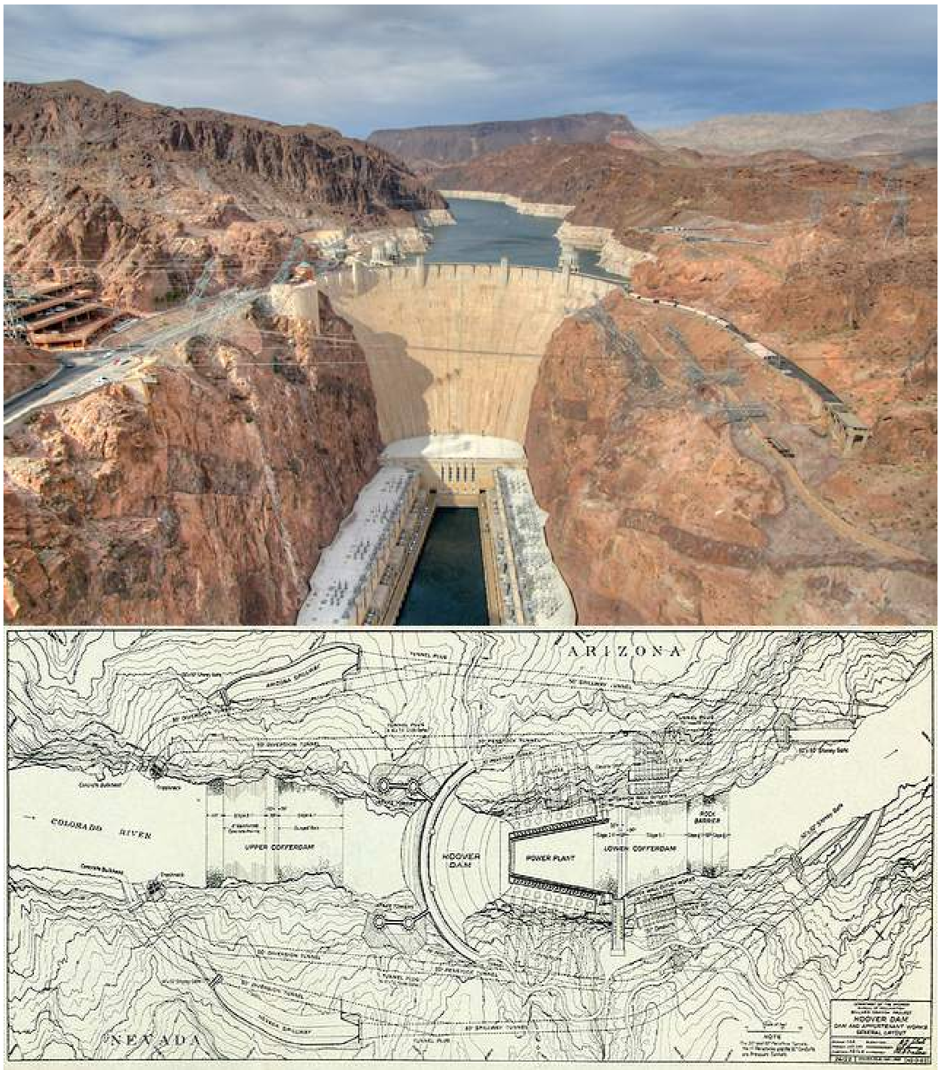
1. What type of object is our planet?
2. What type of object is a map?
3. What is a map projection?
4. What shapes are used to make map projections?

Review

1. Why does a map projection distort Earth's features? Where does it distort the features most?
2. Which type of projection is best for someone interested in studying Greenland? The worst?
3. Why would the Mercator projection have been okay for use in the 16th century?

2.5 Topographic and Geologic Maps

- Understand contours and contour maps.



Can a map help you understand a place even if you've never been there?

Hills, streams, valleys, and snowfields all show up on some types of maps. With practice, people can look at a topographic map and see what the landscape is really like. Of course, it's not the same as being there! But a topographic map can give you a good feel for an area before you go. It can also help you to identify features once you are there. What does this map tell you about the region? Can you identify features that appear in the photo on the map?

Topographic Maps

The topography of a region can be shown on a map. **Topographic maps** represent geographical features, such as hills and valleys. Topographic maps use contour lines to show geographical features. A **contour line** is a line of equal elevation. If you walk along a contour line, you will not go uphill or downhill. Topographic maps are also called contour maps. The rules of topographic maps are:

- Each line connects all points of a specific elevation.
- Contour lines never cross. After all, a single point can only have one elevation.
- Every fifth contour line is bolded and labeled.
- Adjacent contour lines are separated by a constant difference in elevation (such as 20 feet or 100 feet). The difference in elevation is the **contour interval**. The contour interval is indicated in the map legend.
- Scales indicate horizontal distance and are also found on the map legend.

Interpreting Contour Maps

How does a topographic map tell you about the terrain? Let's consider the following principles:

1. **The spacing of contour lines shows the slope of the land**. Contour lines that are close together indicate a steep slope. This is because the elevation changes quickly in a small area. Contour lines that seem to touch indicate a very steep slope, like a cliff. When contour lines are spaced far apart, the slope is gentle. So contour lines help us see the three-dimensional shape of the land.

Look at the topographic map of Stowe, Vermont (**Figure** 2.14). There is a steep hill rising just to the right of the city of Stowe. You can tell this because the contour lines there are closely spaced. The contour lines also show that the hill has a sharp rise of about 200 feet. Then the slope becomes less steep toward the right.

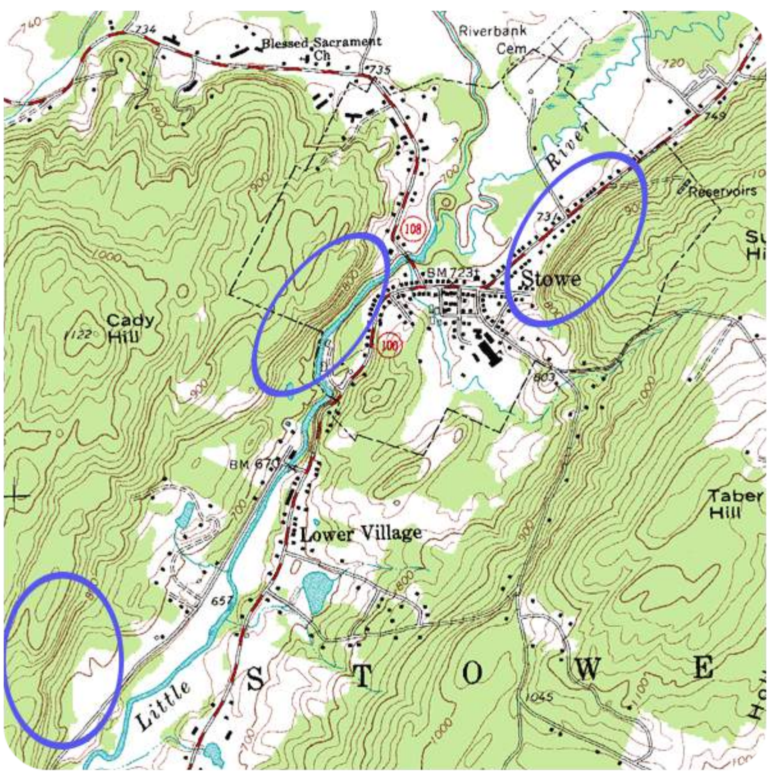


FIGURE 2.14
Portion of a USGS topographic map of Stowe, VT.

2. **Concentric circles indicate a hill**. Pictured below is another side of the topographic map of Stowe, Vermont (**Figure** 2.15). When contour lines form closed loops, there is a hill. The smallest loops are the higher elevations on the hill. The larger loops encircling the smaller loops are downhill. If you look at the map, you can see Cady Hill in the lower left and another, smaller hill in the upper right.

FIGURE 2.15

Portion of a USGS topographic map of Stowe, VT. Cady Hill (elevation 1122 feet) is shown by concentric circles in the lower left portion of the map. Another hill (elevation ~ 960 feet) is on the upper right portion of the map.

3. **Hatched concentric circles indicate a depression**. The hatch marks are short, perpendicular lines inside the circle. The innermost hatched circle represents the deepest part of the depression (**Figure** 2.16). The outer hatched circles represent higher elevations.

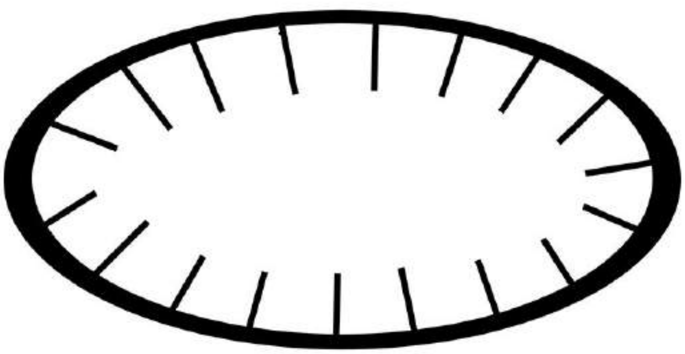


FIGURE 2.16

On a contour map, a circle with inward hatches indicates a depression.

4. **V-shaped portions of contour lines indicate stream valleys**. The "V" shape of the contour lines point uphill. There is a V shape because the stream channel passes through the point of the V. The open end of the V represents the downstream portion. A blue line indicates that there is water running through the valley. If there is not a blue line, the V pattern indicates which way water flows. Below, you can see examples of V-shaped markings (**Figure** 2.17). Try to find the direction a stream flows.

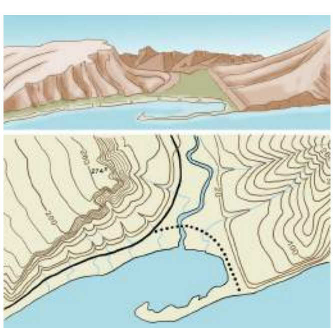


FIGURE 2.17

Illustrations of three-dimensional ground configurations (top) and corresponding topographic map (bottom). Note that the V-shaped markings on the topographic maps correspond to drainage channels. Also, the closely-spaced contour lines denote the rapid rising cliff face on the left side.

5. **Like other maps, topographic maps have a scale so that you can find the horizontal distance**. You can use the horizontal scale to calculate the slope of the land (vertical height/horizontal distance). Common scales used in United States Geological Service (USGS) maps include the following:

- 1:24,000 scale –1 inch = 2000 feet
- 1:100,000 scale –1 inch = 1.6 miles
- 1:250,000 scale –1 inch = 4 miles

Including contour lines, contour intervals, circles, and V-shapes allows a topographic map to show three-dimensional information on a flat piece of paper. A topographic map gives us a good idea of the shape of the land.

Geologic Maps

A geologic map shows the different rocks that are exposed at the surface of a region. The geology is often put on a contour map. Rock units are shown in a color identified in a key. On the geologic map of the Grand Canyon, for example, different rock types are shown in different colors. Some people call the Grand Canyon "layer cake geology" because most of the rock units are in layers. Rock units show up on both sides of a stream valley.

A geologic map looks very complicated in a region where rock layers have been folded. Faults are seen on this geologic map cutting across rock layers. When rock layers are tilted, you will see stripes of each layer on the map. There are symbols on a geologic map that tell you which direction the rock layers slant. Often there is a cut away diagram, called a **cross section**. A cross section shows what the rock layers look like below the surface. A large-scale geologic map will just show geologic provinces. They do not show the detail of individual rock layers.

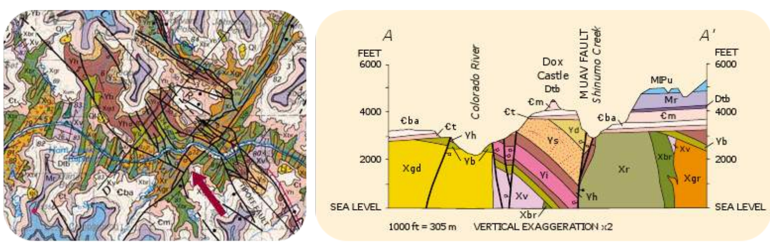


FIGURE 2.18
A portion of the geologic map of the Grand Canyon, Arizona.

Vocabulary

- **contour interval**: Difference in elevation between two contour lines.
- **contour line**: Line of constant elevation on a topographic map.
- **geologic map**: Map showing the geologic features, such as rock units and structures, of a region.
- **topographic map**: Map that shows elevations above sea level to indicate geographic feature; also called contour map;
- **topography**: Changes in elevation that create geographic features.

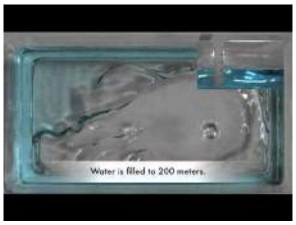
Summary

- Topographic maps reveal the shape of a landscape. Elevations indicate height above sea level.
- Contour lines are lines of equal elevation. Contour intervals are the difference in elevation between two contour lines.
- Geologic maps show rock units and geologic features, like faults and folds.

Practice

Use the resource below to answer the questions that follow.

- **Understanding Topographic Maps** at http://www.youtube.com/watch?v=EqyfJMgFL-U (2:49)



MEDIA

Click image to the left for more content.

1. What is sea level?
2. How far apart are topographic lines?
3. What do the contour lines represent?
4. How do you know that there's a crater at the top of the volcano rather than a peak?
5. What is the purpose of a topographic map?

Review

1. What is a contour line? What is a contour interval?
2. What will a hill look like on a topographic map? How will a basin look different from a hill?
3. How do contour lines indicate a steep slope? How do they indicate a stream?
4. Why might a geologic map be useful to geologists?

2.6 References

1. Flickr:mcfarlandmo. Does this picture allow you to tell if the woman has a cold?. CC BY 2.0
2. Courtesy of NASA Goddard Institute for Space Studies. Graph showing rising global average annual temperatures. Public Domain
3. Flickr:miguelb. Geologist studying rocks in the field. CC BY 2.0
4. Walter Siegmund. Carbon dioxide released into the atmosphere by this factory is causing the global climate to change. CC BY 2.5
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14. Courtesy of the US Geological Survey. Closely spaced contour lines on a topographic map indicate a steep slope. Public Domain
15. Courtesy of the US Geological Survey. Concentric circles on a topographic map indicate a hill. Public Domain
16. Sam McCabe. On a contour map, a circle with inward hatches indicates a depression. CC BY-NC 3.0
17. Laura Guerin, based on image by the U.S. Geological Survey. A 3D ground model and its topographic map. CC BY-NC 3.0
18. Courtesy of the US Geological Survey. A portion of the geologic map of the Grand Canyon, Arizona. Public Domain

CHAPTER 3 Astronomy

Chapter Outline

3.1 The History of Astronomy

- Identify major occurrences in the history of astrophysics and identify the individuals who make the contribution.

This is a classic spiral galaxy known as the Whirlpool Galaxy. It is found in the Canes Venatici constellation. This constellation represents the hunting dogs, Asterion and Chara.

The History of Astronomy

Astronomy and the Ancient Greeks

The Astronomy of the ancient Greeks was linked to mathematics, and Greek astronomers sought to create geometrical models that could imitate the appearance of celestial motions. This tradition originated around the 6^{th} century BCE, with the followers of the mathematician Pythagoras (~580 –500 BCE). Pythagoras believed that everything was related to mathematics and that through mathematics everything could be predicted and measured in rhythmic patterns or cycles. He placed astronomy as one of the four mathematical arts, the others being arithmetic, geometry and music.

While best known for the Pythagorean Theorem, Pythagoras did have some input into astronomy. By the time of Pythagoras, the five planets visible to the naked eye - Mercury, Venus, Mars, Jupiter and Saturn - had long been identified. The names of these planets were initially derived from Greek mythology before being given the equivalent Roman mythological names, which are the ones we still use today. The word 'planet' is a Greek term meaning 'wanderer', as these bodies move across the sky at different speeds from the stars, which appear fixed in the same positions relative to each other.

For part of the year Venus appears in the eastern sky as an early morning object before disappearing and reappearing a few weeks later in the evening western sky. Early Greek astronomers thought this was two different bodies and assigned the names 'Phosphorus' and 'Hesperus' to the morning and evening apparitions respectively. Pythagoras is given credit for being the first to realize that these two bodies were in fact the same planet, a notion he arrived at through observation and geometrical calculations.

Pythagoras was also one of the first to think that the Earth was round, a theory that was finally proved around 330 BCE by Aristotle. (Although, as you are probably aware, many people in 1642 CE still believed the earth to be flat.)

Aristotle (384 BCE –322 BCE) demonstrates in his writings that he knew we see the moon by the light of the sun, how the phases of the moon occur, and understood how eclipses work. He also knew that the earth was a sphere. Philosophically, he argued that each part of the earth is trying to be pulled to the center of the earth, and so the earth would naturally take on a spherical shape. He then pointed out observations that support the idea of a spherical earth. First, the shadow of the earth on the moon during a lunar eclipse is always circular. The only shape that always casts a circular shadow is a sphere. Second, as one traveles more north or south, the positions of the stars in the sky change. There are constellations visible in the north that one cannot see in the south and vice versa. He related this to the curvature of the earth. Aristotle talked about the work of earlier Greeks, who had developed an earth centered model of the planets. In these models, the center of the earth is the center of all the other motions. While it is not sure if the earlier Greeks actually thought the planets moved in circles, it is clear that Aristotle did.

Aristotle rejected a moving earth for two reasons. Most importantly he didn't understand inertia. To Aristotle, the natural state for an object was to be at rest. He believed that it takes a force in order for an object to move. Using Aristotle's ideas, if the earth were moving through space, if you tripped, you would not be in contact with the earth, and so would get left behind in space. Since this obviously does not happen, the earth must not move. This misunderstanding of inertia confused scientists until the time of Galileo. A second, but not as important, reason Aristotle rejected a moving earth is that he recognized that if the earth moved and rotated around the sun, there would be an observable parallax of the stars. One cannot see stellar parallax with the naked-eye, so Aristotle concluded that the earth must be at rest. (The stars are so far away, that one needs a good telescope to measure stellar parallax, which was first measured in 1838.)

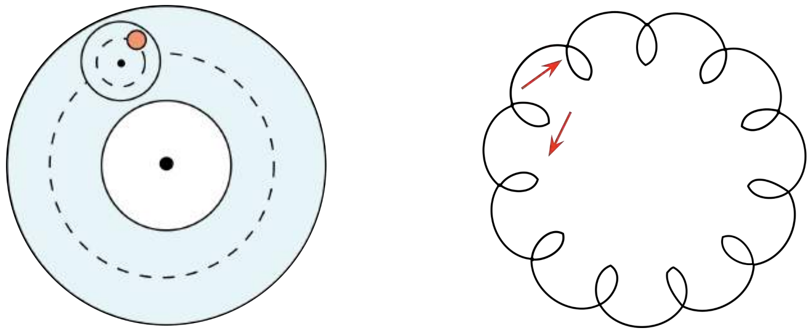
Aristotle believed that the objects in the heavens are perfect and unchanging. Since he believed that the only eternal motion is circular with a constant speed, the motions of the planets must be circular. This came to be called "The Principal of Uniform Circular Motion." Aristotle and his ideas became very important because they became incorporated into the Catholic Church's theology in the twelfth century by Thomas Aquinas. In the early 16^{th} century, the Church banned new interpretations of scripture and this included a ban on ideas of a moving earth.

Claudius Ptolemy (90 –168 CE) was a citizen of Egypt which was under Roman rule during Ptolemy's lifetime. During his lifetime he was a mathematician, astronomer, and geographer. His theories dominated the world's understanding of astronomy for over a thousand years.

While it is known that many astronomers published works during this time, only Ptolemy's work *The Almagest* survived. In it, he outlined his geometrical reasoning for a geocentric view of the Universe. As outlined in the Almagest, the Universe according to Ptolemy was based on five main points: 1) the celestial realm is spherical, 2) the celestial realm moves in a circle, 3) the earth is a sphere, 4) the celestial realm orbit is a circle centered on the earth, and 5) earth does not move. Ptolemy also identified eight circular orbits surrounding earth where the other planets existed. In order, they were the moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the sphere of fixed stars.

A serious problem with the earth-centered system was the fact that at certain times in their orbits, some of the planets appeared to move in the opposite direction of their normal movement. This reverse direction movement is referred to as " **retrograde motion**." If the earth was to remain motionless at the center of the system, some very intricate designs were necessary to explain the movement of the retrograde planets.

In the Ptolemaic system, each retrograde planet moved by two spheres.



The Ptolemaic system had circles within circles that produced **epicycles**. In the sketch above on the left, the red ball moved clockwise in its little circle while the entire orbit also orbited clockwise around the big circle. This process produced a path like that shown in the sketch above on the right. As the red ball moved around its path, at some times it would be moving clockwise and then for a short period, it would move counterclockwise. This motion was able to explain the retrograde motion noted for some planets.

Astronomy and the Late Middle Ages

It was not until 1543, when Copernicus (1473 –1543) introduced a sun-centered design (**heliocentric**), that Ptolemy's astronomy was seriously questioned and eventually overthrown.

Copernicus studied at the University of Bologna, where he lived in the same house as the principal astronomer there. Copernicus assisted the astronomer in some of his observations and in the production of the annual astrological forecasts for the city. It is at Bologna that he probably first encountered a translation of Ptolemy's *Almagest* that would later make it possible for Copernicus to successfully refute the ancient astronomer.

Later, at the University of Padua, Copernicus studied medicine, which was closely associated with astrology at that time due to the belief that the stars influenced the dispositions of the body. Returning to Poland, Copernicus secured a teaching post at Wroclaw, where he primarily worked as a medical doctor and manager of Church affairs. In his spare time, he studied the stars and the planets (decades before the telescope was invented), and applied his mathematical understanding to the mysteries of the night sky. In so doing, he developed his theory of a system in which the Earth, like all the planets, revolved around the sun, and which simply and elegantly explained the curious retrograde movements of the planets.

Copernicus wrote his theory in *De Revolutionibus Orbium Coelestium* ("On the Revolutions of the Celestial Orbs"). The book was completed in 1530 or so, but it wasn't published until the year he died, 1543. It has been suggested that Copernicus knew the publication would incur the wrath of the Catholic church and he didn't want to deal with problems so he didn't publish his theory until he was on his death bed. Legend has it that a copy of the printer's proof was placed in his hands as he lay in a coma, and he woke long enough to recognize what he was holding before he died.

Tycho Brahe (1546 –1601) was born in a part of southern Sweden that was part of Denmark at the time. While attending the university to study law and philosophy, he became interested in astronomy and spent most evenings observing the stars. One of Tycho Brahe's first contributions to astronomy was the detection and correction of several serious errors in the standard astronomical tables. Then, in 1572, he discovered a supernova located in the constellation of Cassiopeia. Tycho built his own instruments and made the most complete and accurate observations available without the use of a telescope. Eventually, his fame led to an offer from King Frederick II of Denmark & Norway to fund the construction of an astronomical observatory. The island of Van was chosen and in 1576, construction began. Tycho Brahe spent twenty years there, making observations on celestial bodies.

During his life, Tycho Brahe did not accept Copernicus' model of the universe. He attempted to combine it with the Ptolemaic model. As a theoretician, Tycho was a failure but his observations and the data he collected was far superior to any others made prior to the invention of the telescope. After Tycho Brahe's death, his assistant, Johannes Kepler used Tycho Brahe's observations to calculate his own three laws of planetary motion.

In 1600, Johannes Kepler (1571 –1630) began working as Tycho's assistant. They recognized that neither the Ptolemaic (geocentric) or Copernican (heliocentric) models could predict positions of Mars as accurately as they could measure them. Tycho died in 1601 and after that Kepler had full access to Tycho's data. He analyzed the data for 8 years and tried to calculate an orbit that would fit the data, but was unable to do so. Kepler later determined that the orbits were not circular but elliptical.

Kepler's Laws of Planetary Motion

1. The orbits of the planets are elliptical.
2. An imaginary line connecting a planet and the sun sweeps out equal areas during equal time intervals. (Therefore, the earth's orbital speed varies at different times of the year. The earth moves fastest in its orbit when closest to the sun and slowest when farthest away.) Kepler's Second Law of Planetary Motion was calculated for Earth, then the hypothesis was tested using data for Mars, and it worked!
3. Kepler's Third Law of Planetary Motion showed the relationship between the size of a planet's orbit radius, R ($\frac{1}{2}$ the major axis), and its orbital period, T. $R^2 = T^3$ This law is true for all planets if you use astronomical units (that is, distance in multiples of earth's orbital radium and time in multiples of earth years). Kepler's three laws replaced the cumbersome epicycles to explain planetary motion with three mathematical laws that allowed the positions of the planets to be predicted with accuracies ten times better than Ptolemaic or Copernican models.

Galileo and Newton

Galileo Galilei (1564-1642) was a very important person in the development of modern astronomy, both because of his contributions directly to astronomy, and because of his work in physics. He provided the crucial observations that proved the Copernican hypothesis, and also laid the foundations for a correct understanding of how objects moved on the surface of the earth and of gravity. One could, with considerable justification, view Galileo as the father both of modern astronomy and of modern physics.

Galileo did not invent the telescope, but he was the first to turn his telescope toward the sky to study the heavens systematically. His telescope was poorer than even a cheap modern amateur telescope, but what he observed in the heavens showed errors in Aristotle's opinion of the universe and the worldview that it supported. Observations through Galileo's telescope made it clear that the "earth-centered" and "earth doesn't move" solar system of Aristotle was incorrect. Since church officials had made some of Aristotle's opinions a part of the religious views of the church, proving Aristotle's views to be incorrect also pointed out flaws in the church.

Galileo observed four points of light that changed their positions around the planet Jupiter and he concluded that these were moons in orbit around Jupiter. These observations showed that there were new things in the heavens that Aristotle and Ptolemy had known nothing about. Furthermore, they demonstrated that a planet could have moons circling it that would not be left behind as the planet moved around its orbit. One of the arguments against the Copernican system had been that if the moon were in orbit around the Earth and the Earth in orbit around the Sun, the Earth would leave the Moon behind as it moved around its orbit.

Galileo used his telescope to show that Venus, like the moon, went through a complete set of phases. This observation was extremely important because it was the first observation that was consistent with the Copernican system but not the Ptolemaic system. In the Ptolemaic system, Venus should always be in crescent phase as viewed from the Earth because the sun is beyond Venus, but in the Copernican system Venus should exhibit a complete set of phases over time as viewed from the Earth because it is illuminated from the center of its orbit.

It is important to note that this was the first empirical evidence (coming almost a century after Copernicus) that allowed a definitive test of the two models. Until that point, both the Ptolemaic and Copernican models described the available data. The primary attraction of the Copernican system was that it described the data in a simpler fashion, but here finally was conclusive evidence that not only was the Ptolemaic universe more complicated, it also was *incorrect*.

As each new observation was brought to light, increasing doubt was cast on the old views of the heavens. It also raised the credibility issue: could the authority of Aristotle and Ptolemy be trusted concerning the nature of the Universe if there were so many things in the Universe about which they had been unaware and/or incorrect?

Galileo's challenge of the Church's authority through his refutation of the Aristotelian concept of the Universe eventually got him into deep trouble. Late in his life he was forced, under threat of torture, to publicly recant his Copernican views and spent his last years under house arrest. Galileo's life is a sad example of the conflict between the scientific method and unquestioned authority.

Sir Isaac Newton (1642-1727), who was born the same year that Galileo died, would build on Galileo's ideas to demonstrate that the laws of motion in the heavens and the laws of motion on the earth were the same. Thus Galileo began, and Newton completed, a synthesis of astronomy and physics in which astronomy was recognized as but a part of physics, and that the opinions of Aristotle were almost completely eliminated from both.

Many scientists consider Newton to be a peer of Einstein in scientific thinking. Newton's accomplishments had even greater scope than those of Einstein. The poet Alexander Pope wrote of Newton:

Nature and Nature's laws lay hid in night;

God said, Let Newton be! and all was light.

In terms of astronomy, Newton gave reasons for and corrections to Kepler's Laws. Kepler had proposed three Laws of Planetary motion based on Tycho Brahe's data. These Laws were supposed to apply only to the motions of the planets. Further, they were purely empirical, that is, they worked, but no one knew why they worked. Newton changed all of that. First, he demonstrated that the motion of objects on the Earth could be described by three new Laws of motion, and then he went on to show that Kepler's three Laws of Planetary Motion were but special cases of Newton's three Laws when his gravitational force was postulated to exist between all masses in the Universe. In fact, Newton showed that Kepler's Laws of planetary motion were only approximately correct, and supplied the quantitative corrections that with careful observations proved to be valid.

The Big Bang Theory

The **Big Bang Theory** is the dominant and highly supported theory of the origin of the universe. It states that the universe began from an initial point which has expanded over billions of years to form the universe as we now know it.

In 1922, Alexander Friedman found that the solutions to Einstein's general relativity equations resulted in an expanding universe. Einstein, at that time, believed in a static, eternal universe so he added a constant to his equations to eliminate the expansion. Einstein would later call this the biggest blunder of his life.

In 1924, Edwin Hubble was able to measure the distance to observed celestial objects that were thought to be nebula and discovered that they were so far away they were not actually part of the Milky Way (the galaxy containing our sun). He discovered that the Milky Way was only one of many galaxies.

In 1927, Georges Lemaitre, a physicist, suggested that the universe must be expanding. Lemaitre's theory was supported by Hubble in 1929 when he found that the galaxies most distant from us also had the greatest red shift (were moving away from us with the greatest speed). The idea that the most distance galaxies were moving away from us at the greatest speed was exactly what was predicted by Lemaitre.

In 1931, Lemaitre went further with his predictions and by extrapolating backwards, found that the matter of the universe would reach an infinite density and temperature at a finite time in the past (around 15 billion years). This meant that the universe must have begun as a small, extremely dense point of matter.

At the time, the only other theory that competed with Lemaitre's theory was the "Steady State Theory" of Fred Hoyle. The steady state theory predicted that new matter was created which made it appear that the universe was expanding but that the universe was constant. It was Hoyle who coined the term "Big Bang Theory" which he used as a derisive name for Lemaitre's theory.

George Gamow (1904 –1968) was the major advocate of the Big Bang theory. He predicted that cosmic microwave background radiation should exist throughout the universe as a remnant of the Big Bang. As atoms formed from sub-atomic particles shortly after the Big Bang, electromagnetic radiation would be emitted and this radiation would still be observable today. Gamow predicted that the expansion of the universe would cool the original radiation so that now the radiation would be in the microwave range. The debate continued until 1965 when two Bell Telephone scientists stumbled upon the microwave radiation with their radio telescope.

Summary

- Pythagoras was one of the first scientists to think that the earth was round.
- Aristotle concluded that the earth does not move and the celestial objects rotate around the earth in circular orbits.
- Ptolemy designed the "wheels within wheels" design of the cosmos to agree with Aristotle's ideas and to provide an explanation of the retrograde motion of planets.
- Copernicus suggested a sun-centered system with the earth being one of the planets that revolve around the sun.
- Galileo provided powerful support for the Copernican system with observations from his telescope.
- Kepler produced his three laws of planetary motion based on Tycho's observations.
- Newton contributed his three laws of motion and the concept of gravity which provides the reasons for objects following Kepler's laws.
- Hubble provided evidence that the universe is larger than just the Milky Way and also provided evidence that all other galaxies are moving away from our own galaxy.
- Lemaitre suggested the Big Bang Theory.
- Gamow predicted the 3K background radiation.
- Radio astronomers Arno Penzias and Robert Wilson 'stumbled upon' the 3K background radiation while researching other topics.

Practice

Questions

http://www.youtube.com/watch?v=i6B9j-SB1XU

MEDIA

Click image to the left for more content.

Follow up questions:

1. What type of telescope was used by Penzias and Wilson?
2. What did Penzias and Wilson first suspect was causing the extra radiation they were seeing?
3. What award did Wilson and Penzias win for their work?

Review

Questions

1. What was the name of the model of the universe with the earth at the center?
2. Who was the first to suggest a sun-centered solar system?
3. Why were epicycles necessary in Ptolemy's model of the universe?
4. Tycho Brahe's greatest contribution was
   (a) his theory that the solar system was heliocentric.
   (b) his invention of the telescope.
   (c) his accurate observations of stars and planets.
5. Astronomer Johannes Kepler
   (a) published 'Almagest'.
   (b) suggested elliptical orbits for planets.
   (c) invented the first radio telescope.

- **retrograde motion:** The temporary apparent motion of a body in a direction opposite to that of the motion of most members of the solar system.
- **epicycles:** A construct of the geocentric model of the solar system which was necessary to explain observed retrograde motion. Each planet rides on a small epicycle whose center in turn rides on a larger circle.
- **heliocentric:** The heliocentric model of astronomy is the theory that places the sun at the center of the solar system, with all the planets orbiting around it.
- **Big Bang theory:** A theory that deduces a cataclysmic birth of the universe from the observed expansion of the universe, cosmic background radiation, abundance of the elements, and the laws of physics.

3.2 The Universe

Lesson Objectives

- Explain the evidence for an expanding universe.
- Describe the formation of the universe according to the Big Bang Theory.

Essential Knowledge

1. Evaluate the evidence we have that supports the Big Bang Theory. 2. Examine how the Red Shift is useful in supporting the Big Bang Theory.

Vocabulary

- Big Bang Theory
- cosmology
- Doppler Effect
- redshift
- universe

Introduction

The study of the universe is called **cosmology**. Cosmologists study the structure and changes in the present universe. The **universe** contains all of the star systems, galaxies, gas and dust, plus all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe includes all of space and time.

Evolution of Human Understanding of the Universe

What did the ancient Greeks recognize as the universe? In their model, the universe contained Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. This idea held for many centuries until Galileo's telescope helped allow people to recognize that Earth is not the center of the universe. They also found out that there are many more stars than were visible to the naked eye. All of those stars were in the Milky Way Galaxy.

In the early 20th century, an astronomer named Edwin Hubble **Figure** 3.1 discovered that what scientists called the Andromeda Nebula was actually over 2 million light years away —many times farther than the farthest distances that had ever been measured. Hubble realized that many of the objects that astronomers called nebulas were not actually clouds of gas, but were collections of millions or billions of stars —what we now call galaxies.

Hubble showed that the universe was much larger than our own galaxy. Today, we know that the universe contains about a hundred billion galaxies—about the same number of galaxies as there are stars in the Milky Way Galaxy.

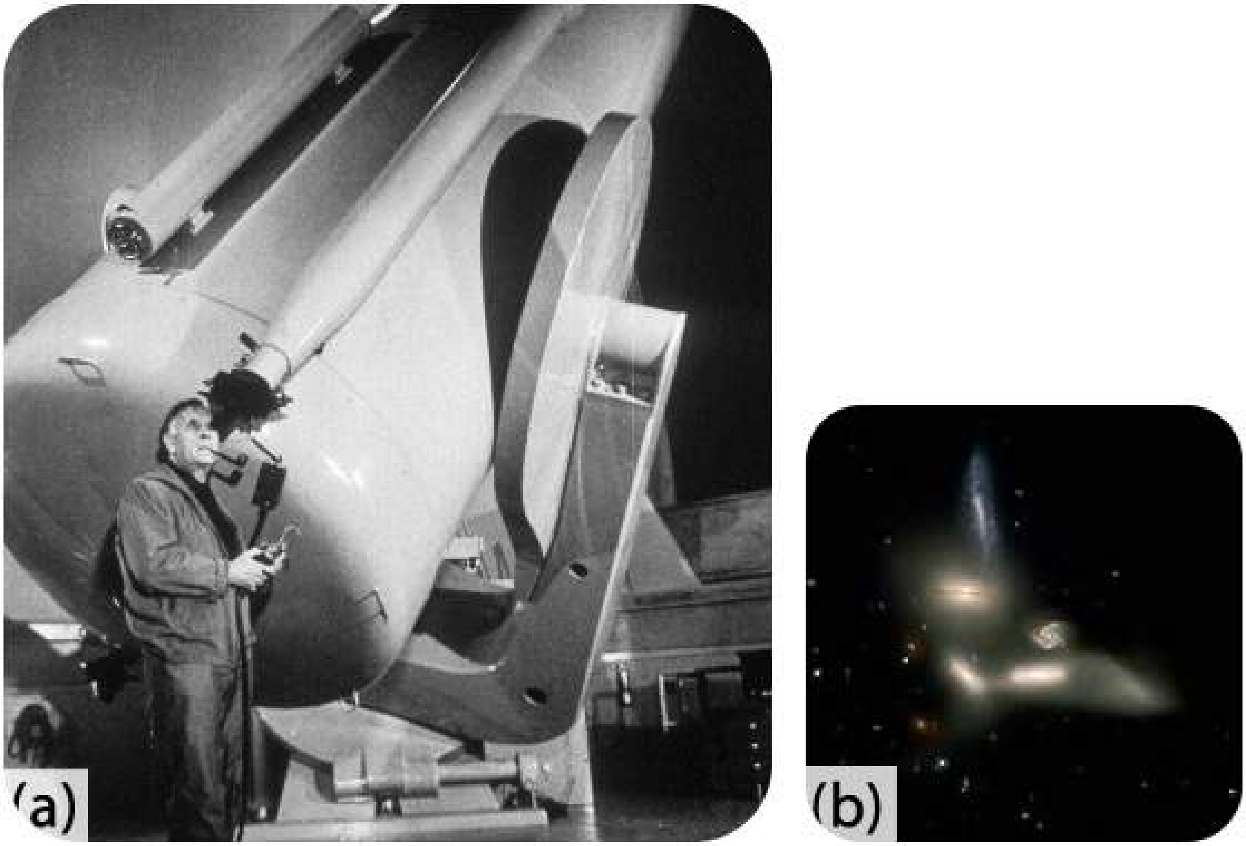


FIGURE 3.1

(a) Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light were galaxies. (b) Hubble's namesake space telescope spotted this six galaxy group. Edwin Hubble demonstrated the existence of galaxies.

Expansion of the Universe

After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed.

Redshift

If you look at a star through a prism, you will see a spectrum, or a range of colors through the rainbow. The spectrum will have specific dark bands where elements in the star absorb light of certain energies. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun —not on Earth —by analyzing the absorption lines in the spectrum of the Sun.

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in **Figure** 3.2. This shift of absorption bands toward the red end of the spectrum is known as **redshift**.

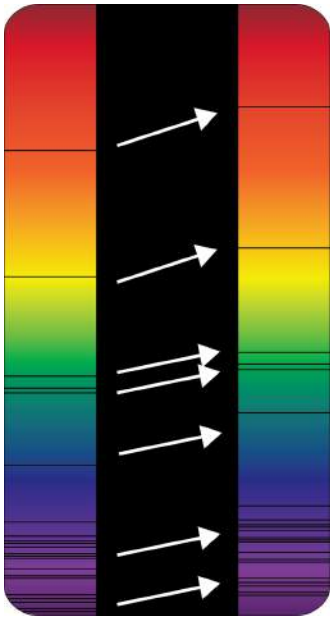


FIGURE 3.2
Redshift is a shift in absorption bands toward the red end of the spectrum. What could make the absorption bands of a star shift toward the red?

Redshift occurs when the light source is moving away from the observer or when the space between the observer and the source is stretched. What does it mean that stars and galaxies are redshifted? When astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth.

If galaxies were moving randomly, would some be redshifted but others be blueshifted? Of course. Since almost every galaxy in the universe has a redshift, almost every galaxy is moving away from Earth.

Redshift can occur with other types of waves too. This phenomenon is called the **Doppler Effect**. An analogy to redshift is the noise a siren makes as it passes you. You may have noticed that an ambulance seems to lower the pitch of its siren after it passes you. The sound waves shift towards a lower pitch when the ambulance speeds away from you. Though redshift involves light instead of sound, a similar principle operates in both situations.

An animation of Doppler Effect http://projects.astro.illinois.edu/data/Doppler/index.html .

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: The farther away a galaxy is, the faster it is moving away from us. What could this mean about the universe? It means that the universe is expanding.

Figure 3.3 shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. Also the dots farther away from you on the balloon would move away faster than dots nearby.

Expansion of the Universe Diagram

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching

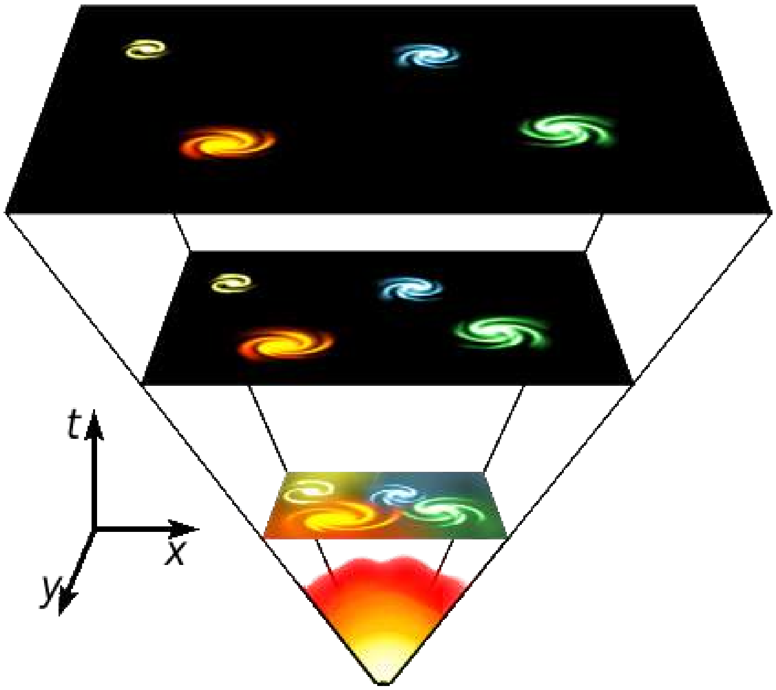


FIGURE 3.3

In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

out between galaxies like the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the universe.

An animation of an expanding universe is shown here: http://www.astro.ubc.ca/~scharein/a311/Sim/bang/BigBang.html .

One other difference between the universe and a balloon involves the actual size of the galaxies. On balloon, the dots will become larger in size as you inflate it. In the universe, the galaxies stay the same size, just the space between the galaxies increases.

Formation of the Universe

Before Hubble, most astronomers thought that the universe didn't change. But if the universe is expanding, what does that say about where it was in the past? If the universe is expanding, the next logical thought is that in the past it had to have been smaller.

The Big Bang Theory

The **Big Bang theory** is the most widely accepted cosmological explanation of how the universe formed. If we start at the present and go back into the past, the universe is contracting – getting smaller and smaller. What is the end result of a contracting universe?

According to the Big Bang theory, the universe began about 13.7 billion years ago. Everything that is now in the universe was squeezed into a very small volume. Imagine all of the known universe in a single, hot, chaotic mass. An enormous explosion —a big bang —caused the universe to start expanding rapidly. All the matter and energy in the universe, and even space itself, came out of this explosion.

What came before the Big Bang? There is no way for scientists to know since there is no remaining evidence.

After the Big Bang

In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a few seconds, protons, neutrons, and electrons could form. After a few minutes, those subatomic particles came together to create hydrogen. Energy in the universe was great enough to initiate nuclear fusion and hydrogen nuclei were fused into helium nuclei. The first neutral atoms that included electrons did not form until about 380,000 years later.

The matter in the early universe was not smoothly distributed across space. Dense clumps of matter held close together by gravity were spread around. Eventually, these clumps formed countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

If you look at an image of galaxies at the far edge of what we can see, you are looking at great distances. But you are also looking across a different type of distance. What do those far away galaxies represent? Because it takes so long for light from so far away to reach us, you are also looking back in time (**Figure** 3.4).

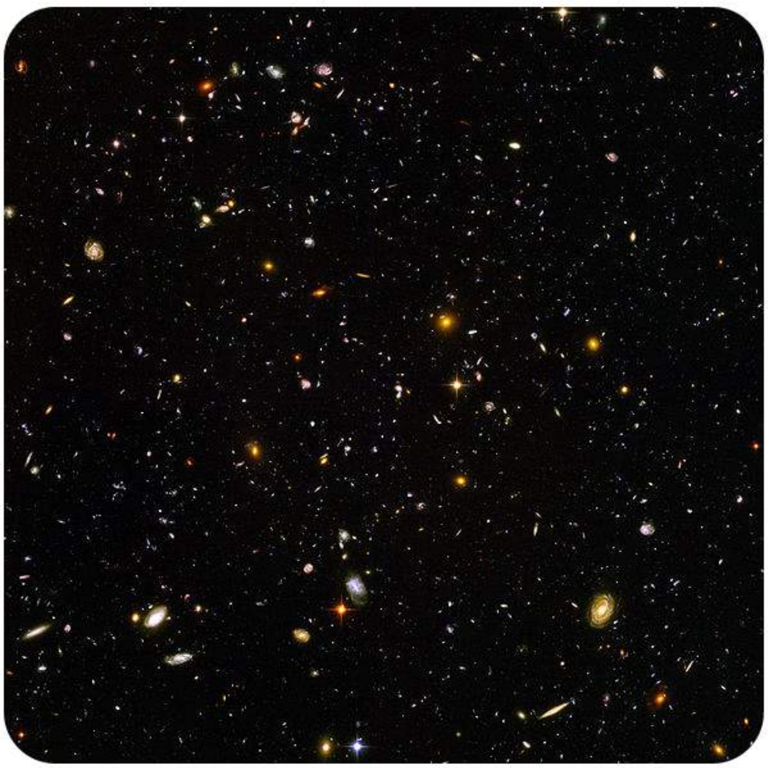


FIGURE 3.4
Images from very far away show what the universe was like not too long after the Big Bang.

After the origin of the Big Bang hypothesis, many astronomers still thought the universe was static. Nearly all came around when an important line of evidence for the Big Bang was discovered in 1964. In a static universe, the space between objects should have no heat at all; the temperature should measure 0 K (Kelvin is an absolute temperature scale). But two researchers at Bell Laboratories used a microwave receiver to learn that the background radiation in the universe is not 0 K, but 3 K (**Figure** 3.5). This tiny amount of heat is left over from the Big Bang. Since nearly all astronomers now accept the Big Bang hypothesis, what is it usually referred to as?

An explanation of the Big Bang: http://dvice.com/archives/2009/08/big-bang-animat.php .

How we know about the early universe: http://www.youtube.com/watch?v=uihNu9Icaeo&feature=channel .

History of the Universe, part 2: http://www.youtube.com/watch?v=bK6_p5a-Hbo&feature=channel . *The Evidence for the Big Bang in 10 Little Minutes* provides a great deal of scientific evidence for the Big Bang **(2g)**: http://www.y

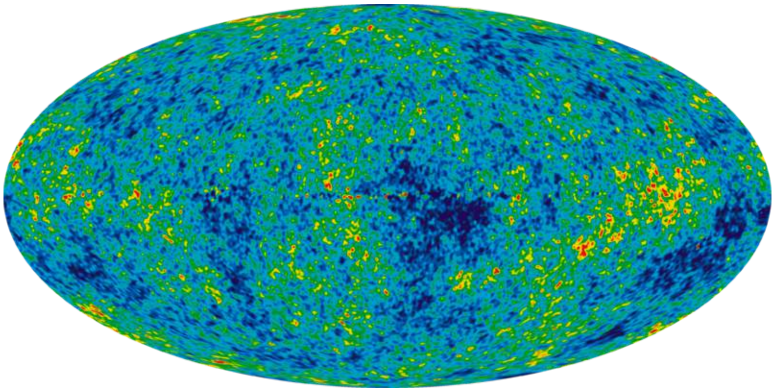


FIGURE 3.5
Background radiation in the universe was good evidence for the Big Bang Theory.

outube.com/watch?v=uyCkADmNdNo (10:10).

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KQED: Nobel Laureate George Smoot and the Origin of the Universe

George Smoot, a scientist at Lawrence Berkeley National Lab, shared the 2006 Nobel Prize in Physics for his work on the origin of the universe. Using background radiation detected by the Cosmic Background Explorer Satellite (COBE), Smoot was able to make a picture of the universe when it was 12 hours old. Learn more at: http://science.kqed.org/quest/video/nobel-laureate-george-smoot-and-the-origin-of-the-universe/ .

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Dark Matter and Dark Energy

The Big Bang theory is still the best scientific model we have for explaining the formation of the universe and many lines of evidence support it. However, recent discoveries continue to shake up our understanding of the universe. Astronomers and other scientists are now wrestling with some unanswered questions about what the universe is made of and why it is expanding. A lot of what cosmologists do is create mathematical models and computer simulations to account for these unknown phenomena.

Dark Matter

The things we observe in space are objects that emit some type of electromagnetic radiation. However, scientists think that matter that emits light makes up only a small part of the matter in the universe. The rest of the matter, about 80%, is dark matter.

Dark matter emits no electromagnetic radiation so we can't observe it directly. However, astronomers know that dark matter exists because its gravity affects the motion of objects around it. When astronomers measure how spiral galaxies rotate, they find that the outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than they can see.

Gravitational lensing occurs when light is bent from a very distant bright source around a super-massive object (**Figure** 3.6). To explain strong gravitational lensing, more matter than is observed must be present.

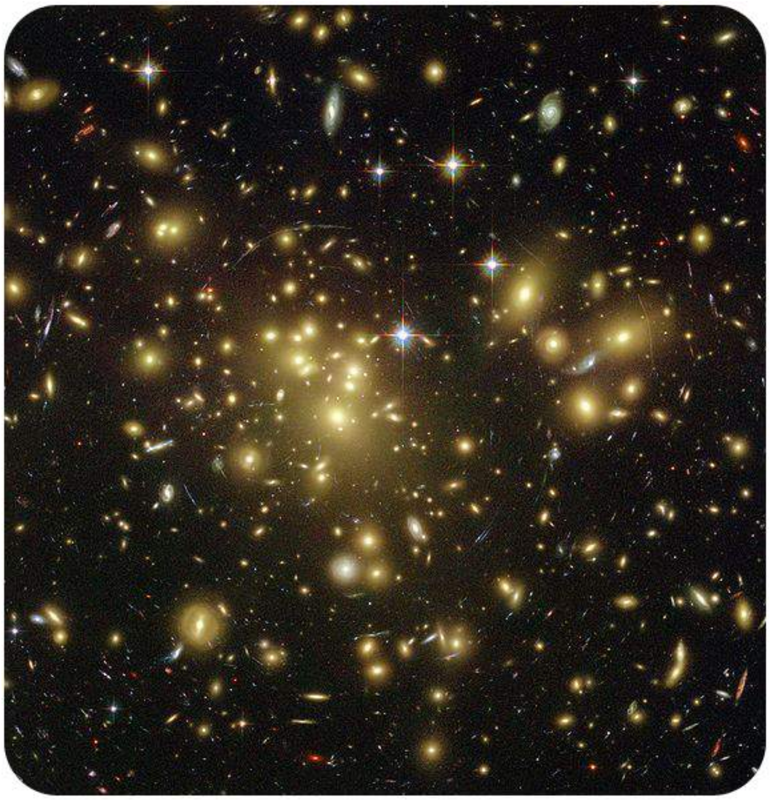


FIGURE 3.6
The arc around the galaxies at the center of this image is caused by gravitational lensing. The addition of gravitational pull from dark matter is required to explain this phenomenon.

With so little to go on, astronomers don't really know much about the nature of dark matter. One possibility is that it could just be ordinary matter that does not emit radiation in objects such as black holes, neutron stars, and brown dwarfs – objects larger than Jupiter but smaller than the smallest stars. But astronomers cannot find enough of these types of objects, which they have named MACHOS (massive astrophyiscal compact halo object), to account for all the dark matter, so they are thought to be only a small part of the total.

Another possibility is that the dark matter is thought to be much different from the ordinary matter we see. Some appear to be particles that have gravity, but don't otherwise appear to interact with other particles. Scientists call these theoretical particles WIMPs, which stands for Weakly Interactive Massive Particles.

Most scientists who study dark matter think that the dark matter in the universe is a combination of MACHOS and some type of exotic matter such as WIMPs. Researching dark matter is an active area of scientific research, and astronomers' knowledge about dark matter is changing rapidly.

A video explaining dark matter is here: http://www.youtube.com/watch?v=gCgTJ6ID6ZA .

Lesson Summary

- The universe contains all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe also includes all of space and time.
- Redshift is a shift of element lines toward the red end of the spectrum. Redshift occurs when the source of light is moving away from the observer.
- Light from almost every galaxy is redshifted. The farther away a galaxy is, the more its light is redshifted, and the faster it is moving away from us.
- The redshift of galaxies means that the universe is expanding.
- The universe was squeezed into a very small volume and then exploded in the Big Bang theory about 13.7 billion years ago.

Review Questions

1. What is redshift, and what causes it to occur? What does redshift indicate?
2. What is Hubble's law?
3. What is the cosmological theory of the formation of the universe called?
4. How old is the universe, according to the Big Bang theory?
5. What evidence do we have to support the Big Bang Theory?
6. Explain why scientists think the universe is expanding faster than ever?

Further Reading / Supplemental Links

- The science of dark matter: http://cdms.berkeley.edu/Education/DMpages/index.shtml
- More about cosmology: http://stardate.org/resources/btss/cosmology/
- The Big Bang: http://hurricanes.nasa.gov/universe/science/bang.html

Points to Consider

- The expansion of the universe is sometimes modeled using a balloon with dots marked on it, as described earlier in the lesson. In what ways is this a good model, and it what ways does it not correctly represent the expanding universe? Can you think of a different way to model the expansion of the universe?
- The Big Bang theory is currently the most widely accepted scientific theory for how the universe formed. What is another explanation of how the universe could have formed? Is your explanation one that a scientist would accept?

Opening image courtesy of NASA and European Space Agency. http://en.wikipedia.org/wiki/File:Messier51_sRGB.jpg . Public Domain.

3.3 Expansion of the Universe

- Explain how astronomers use red-shift to determine that the universe is expanding.

What is Doppler Effect?

The sound of a siren on an emergency vehicle changes as it passes you: it shifts from higher to lower pitch. As the vehicle moves toward you, the sound waves are pushed together. As the vehicle moves past you, the waves are spread apart. Though redshift involves light instead of sound, a similar principle operates in both situations.

Expansion of the Universe

After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed.

Redshift

If you look at a star through a prism, you will see a spectrum, or a range of colors through the rainbow. The spectrum will have specific dark bands where elements in the star absorb light of certain energies. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun —not on Earth —by analyzing the absorption lines in the spectrum of the Sun.

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in **Figure** 3.7. This shift of absorption bands toward the red end of the spectrum is known as **redshift**.

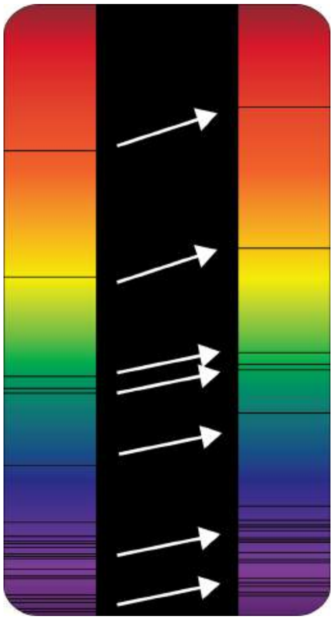


FIGURE 3.7
Redshift is a shift in absorption bands toward the red end of the spectrum. What could make the absorption bands of a star shift toward the red?

Redshift occurs when the light source is moving away from the observer or when the space between the observer and the source is stretched. What does it mean that stars and galaxies are redshifted? When astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth.

If galaxies were moving randomly, would some be redshifted but others be blueshifted? Of course. Since almost every galaxy in the universe has a redshift, almost every galaxy is moving away from Earth.

An animation of Doppler Effect: http://projects.astro.illinois.edu/data/Doppler/index.html .

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: the farther away a galaxy is, the faster it is moving away from us. What could this mean about the universe? It means that the universe is expanding.

Figure 3.8 shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. Also, the dots farther away from you on the balloon would move away faster than dots nearby.

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies, just as the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the universe.

An animation of an expanding universe is shown here: http://www.astro.ubc.ca/~scharein/a311/Sim/bang/BigBang.html .

One other difference between the universe and a balloon involves the actual size of the galaxies. On a balloon, the dots will become larger in size as you inflate it. In the universe, the galaxies stay the same size; only the space between the galaxies increases.

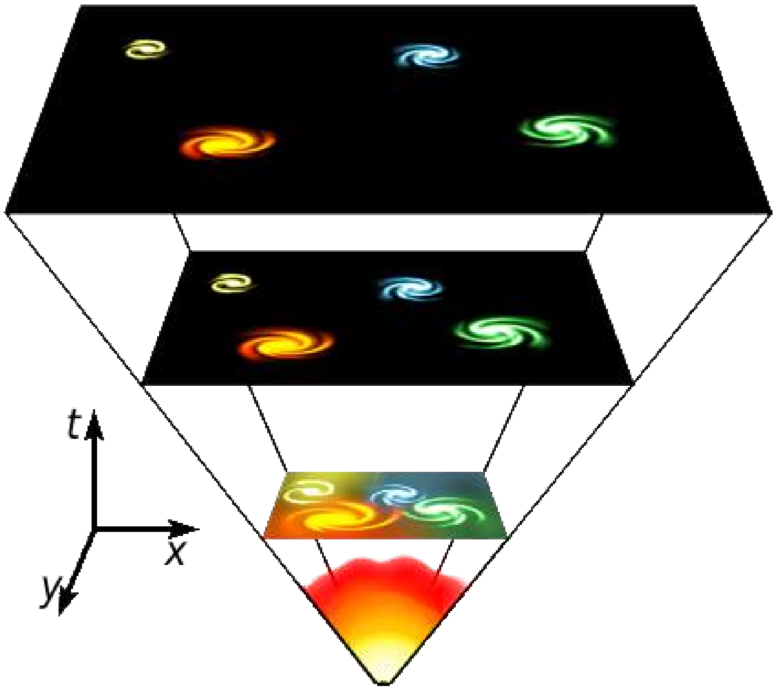


FIGURE 3.8
In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

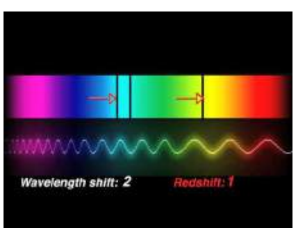
Summary

- Almost every galaxy is moving away from us.
- The spectrum from stars is shifted toward the red; this is known as red-shift and is evidence that the universe is expanding.
- Hubble's Law states that the farther away a galaxy is, the faster it is moving away from us.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=8FPVIV-LzYM



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1. What does dark energy do?
2. What are Cephied variables?
3. What are the Cephieds used for?
4. What happens to light as it reaches us?
5. What is the Doppler effect?
6. What is red shift?

7. What is Hubble's law?
8. What causes red shift?
9. How is red shift measured?
10. What is the successor for the Hubble Space Telescope? What will it allow scientists to do?

Review

1. How did Hubble determine that the universe is expanding?
2. How do astronomers determine the composition of distant stars?
3. What is the significance of the idea that the universe is expanding?

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3.4 Formation of the Sun and Planets

- Sun and planets formed from a solar nebula about 4.6 billion years ago.

Do scientists just make this stuff up?

No! Although our Solar System formed nearly 5 billion years ago, we can see stars forming elsewhere in the galaxy, such as in the Large Magellanic cloud 160,000 light years away. Although we can't know for sure, astronomers think that our early solar system looked very much like this.

Formation of the Solar System

The most widely accepted explanation of how the solar system formed is called the **nebular hypothesis**. According to this hypothesis, the Sun and the planets of our solar system formed about 4.6 billion years ago from the collapse of a giant cloud of gas and dust, called a **nebula**.

The nebula was drawn together by gravity, which released gravitational potential energy. As small particles of dust and gas smashed together to create larger ones, they released kinetic energy. As the nebula collapsed, the gravity at the center increased and the cloud started to spin because of its angular momentum. As it collapsed further, the spinning got faster, much as an ice skater spins faster when he pulls his arms to his sides during a spin.

Much of the cloud's mass migrated to its center but the rest of the material flattened out in an enormous disk. The disk contained hydrogen and helium, along with heavier elements and even simple organic molecules.

Formation of the Sun and Planets

As gravity pulled matter into the center of the disk, the density and pressure at the center became intense. When the pressure in the center of the disk was high enough, nuclear fusion began. A star was born—the Sun. The burning star stopped the disk from collapsing further.

Meanwhile, the outer parts of the disk were cooling off. Matter condensed from the cloud and small pieces of dust started clumping together. These clumps collided and combined with other clumps. Larger clumps, called planetesimals, attracted smaller clumps with their gravity. Gravity at the center of the disk attracted heavier particles,

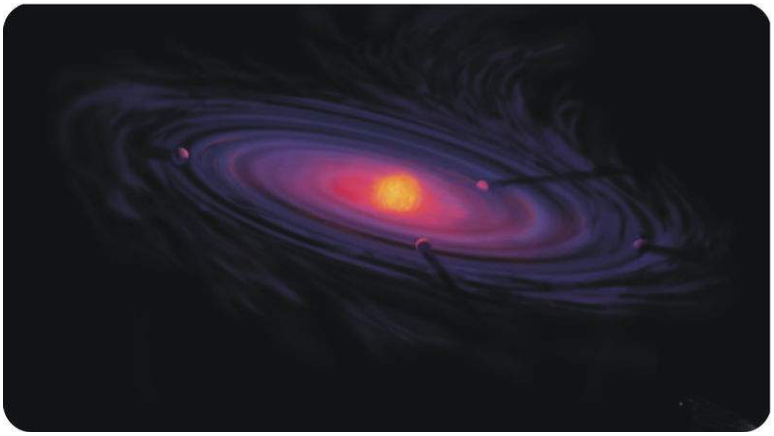


FIGURE 3.9
An artist's painting of a protoplanetary disk.

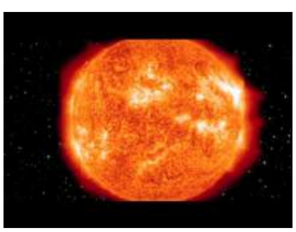
such as rock and metal and lighter particles remained further out in the disk. Eventually, the planetesimals formed protoplanets, which grew to become the planets and moons that we find in our solar system today.

Because of the gravitational sorting of material, the inner planets —Mercury, Venus, Earth, and Mars —formed from dense rock and metal. The outer planets —Jupiter, Saturn, Uranus and Neptune —condensed farther from the Sun from lighter materials such as hydrogen, helium, water, ammonia, and methane. Out by Jupiter and beyond, where it's very cold, these materials form solid particles.

The nebular hypothesis was designed to explain some of the basic features of the solar system:

- The orbits of the planets lie in nearly the same plane with the Sun at the center
- The planets revolve in the same direction
- The planets mostly rotate in the same direction
- The axes of rotation of the planets are mostly nearly perpendicular to the orbital plane
- The oldest moon rocks are 4.5 billion years

This video, from the ESA, discusses the Sun, planets, and other bodies in the Solar System and how they formed **(1a, 1d)**. The first part of the video explores the evolution of our view of the solar system starting with the early Greeks who reasoned that since some points of light - which they called planets - moved faster than the stars, they must be closer: http://www.youtube.com/watch?v=-NxfBOhQ1CY (8:34).



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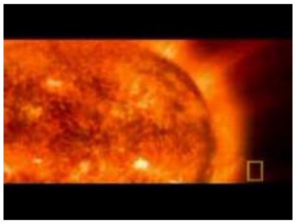
Summary

- A giant cloud of dust and gas, called a nebula, collapsed to form the solar system; this is the nebular hypothesis.
- The nebular hypothesis explains many of the features of the solar system like the orbital plane, the revolution and rotation of the planets, the relationship of the axes of rotation and the orbital plane and the age of moon rocks.
- Planets nearer the Sun are similar because they formed of denser metal and rocks, but planets further out are lighter and gaseous.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=B1AXbpYndGc



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1. What is a protostar?
2. When does nuclear fusion begin?
3. When was our star born?
4. How long with the star burn?
5. How do scientists think our Sun was born?
6. What was the Big Bang?

Review

1. What is the nebular hypothesis?
2. How do features we see elsewhere in our galaxy help us to understand the origin of our solar system?
3. How does the nebular hypothesis account for the observable features of the solar system?

3.5 Galaxies

Lesson Objectives

- Distinguish between star systems and star clusters.
- Identify different types of galaxies.
- Describe our own galaxy, the Milky Way Galaxy.

Essential Knowledge

1. Describe the Milky Way.

2. Distinguish between the different types of galaxies.

Vocabulary

- binary star
- dwarf galaxy
- elliptical galaxy
- galaxy
- globular cluster
- irregular galaxy
- Milky Way Galaxy
- open cluster
- spiral arm
- spiral galaxy
- star cluster
- star system

Introduction

Where do you live? Sure you live in a house or apartment, on a street, in a town or city, in a state or province, and in a country. You may not think to mention that you live on planet Earth in the solar system (as if there is no other), which is in the Milky Way Galaxy. Our galaxy is just one of many billions of galaxies in the universe. These galaxies are incomprehensible distances from each other and from Earth.

Star Systems and Star Clusters

Although constellations have stars that usually only appear to be close together, stars may be found in the same portion of space. Stars that are grouped closely together are called **star systems**. Larger groups of hundreds or thousands of stars are called **star clusters**.

Star Systems

Although the star humans know best is a single star, many stars—in fact, more than half of the bright stars in our galaxy—are star systems. A system of two stars orbiting each other is a **binary star**. A system with more than two stars orbiting each other is a multiple star system. The stars in a binary or multiple star system are often so close together that they appear as one and only through a telescope can the pair be distinguished.

An animation of a solar system like ours but with two suns was created by NASA: http://www.spitzer.caltech.edu/video-audio/852-ssc2007-05v1-Two-Suns-Raise-Family-of-Planetary-Bodies-

Star Clusters

Star clusters are divided into two main types, **open clusters** and **globular clusters**. Open clusters are groups of up to a few thousand stars that are loosely held together by gravity. The Pleiades, shown in **Figure** 3.10, is an open cluster that is also called the Seven Sisters.

FIGURE 3.10
In the Pleiades, seven stars can be seen without a telescope, but the cluster has close to a thousand stars.

Open clusters tend to be blue in color and often contain glowing gas and dust. Why do you think that open clusters have these features? Open clusters are made of young stars that formed from the same nebula. The stars may eventually be pulled apart by gravitational attraction to other objects.

Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. **Figure** 3.11 shows an example of a globular cluster. Globular clusters have a definite, spherical shape and contain mostly reddish stars. The stars are closer together, closer to the center of the cluster. Globular clusters don't have much dust in them —the dust has already formed into stars.

Check out http://seds.org/messier/cluster.html and http://hubblesite.org/newscenter/archive/releases/star-cluster/ for more information about star clusters.

Types of Galaxies

Galaxies are the biggest groups of stars and can contain anywhere from a few million stars to many billions of stars. Every star that is visible in the night sky is part of the Milky Way Galaxy. To the naked eye the closest major galaxy

FIGURE 3.11
M80 is a large globular cluster containing hundreds of thousands of stars. Note that the cluster is spherical and contains mostly red stars.

—the Andromeda Galaxy, shown in **Figure** 3.12 —looks like only a dim, fuzzy spot. But that fuzzy spot contains one trillion stars – 1,000,000,000,000 stars!

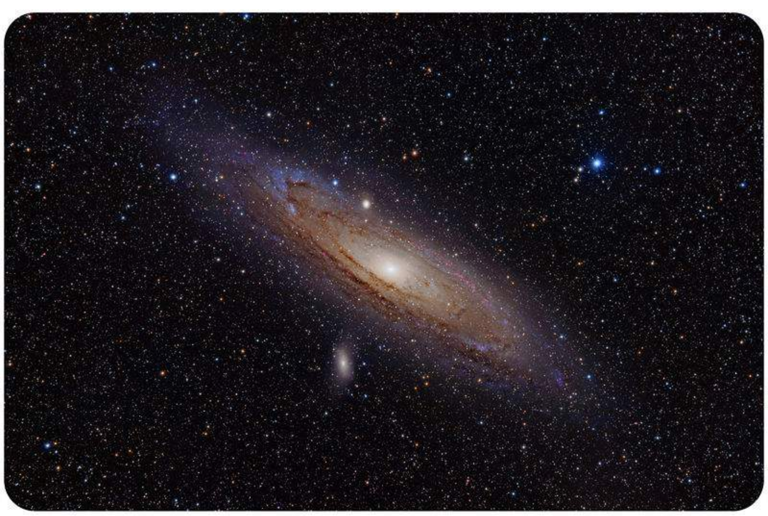

FIGURE 3.12
The Andromeda Galaxy is a large spiral galaxy similar to the Milky Way.

Galaxies are divided into three types according to shape: spiral galaxies, elliptical galaxies, and irregular galaxies.

Spiral Galaxies

Spiral galaxies spin, so they appear as a rotating disk of stars and dust, with a bulge in the middle, like the Sombrero Galaxy shown in **Figure** 3.13. Several arms spiral outward in the Pinwheel Galaxy (seen in **Figure** 3.13) and are appropriately called **spiral arms**. Spiral galaxies have lots of gas and dust and lots of young stars.

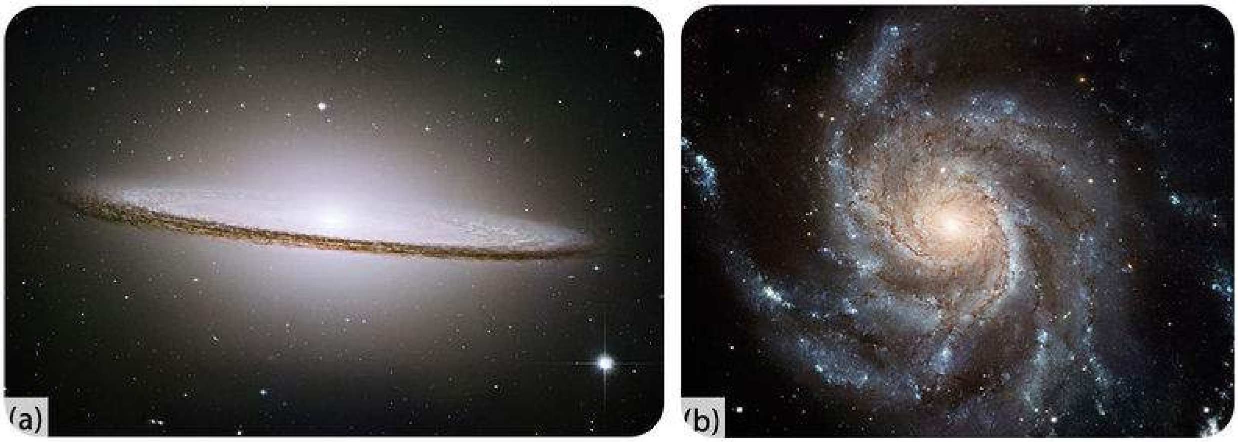

FIGURE 3.13

(a) The Sombrero Galaxy is a spiral galaxy that we see from the side so the disk and central bulge are visible. (b) The Pinwheel Galaxy is a spiral galaxy that we see face-on so we can see the spiral arms. Because they contain lots of young stars, spiral arms tend to be blue.

Elliptical Galaxies

Figure 3.14 shows a typical egg-shaped **elliptical galaxy**. The smallest elliptical galaxies are as small as some globular clusters. Giant elliptical galaxies, on the other hand, can contain over a trillion stars. Elliptical galaxies are reddish to yellowish in color because they contain mostly old stars.

Most elliptical galaxies contain very little gas and dust because the gas and dust has already formed into stars. However, some elliptical galaxies, such as the one shown in **Figure** 3.15, contain lots of dust. Why might some elliptical galaxies contain dust?

Irregular Galaxies and Dwarf Galaxies

Is the galaxy in **Figure** 3.16 a spiral galaxy or an elliptical galaxy? It is neither one! Galaxies that are not clearly elliptical galaxies or spiral galaxies are **irregular galaxies**. How might an irregular galaxy form? Most irregular galaxies were once spiral or elliptical galaxies that were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy.

Dwarf galaxies are small galaxies containing only a few million to a few billion stars. Dwarf galaxies are the most common type in the universe. However, because they are relatively small and dim, we don't see as many dwarf galaxies from Earth. Most dwarf galaxies are irregular in shape. However, there are also dwarf elliptical galaxies and dwarf spiral galaxies.

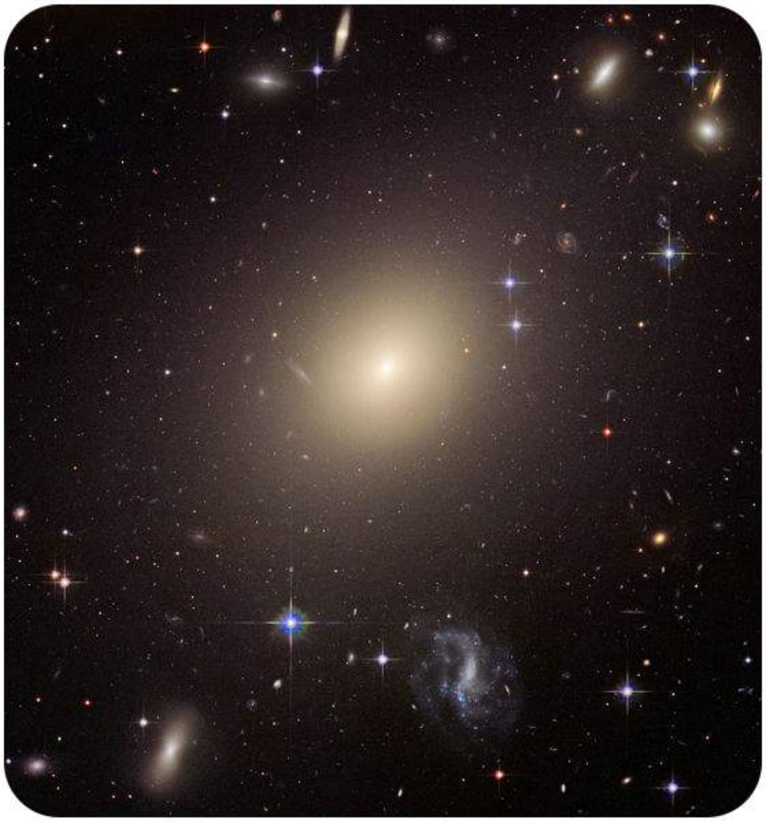

FIGURE 3.14
The large, reddish-yellow object in the middle of this figure is a typical elliptical galaxy. What other types of galaxies can you find in the figure?

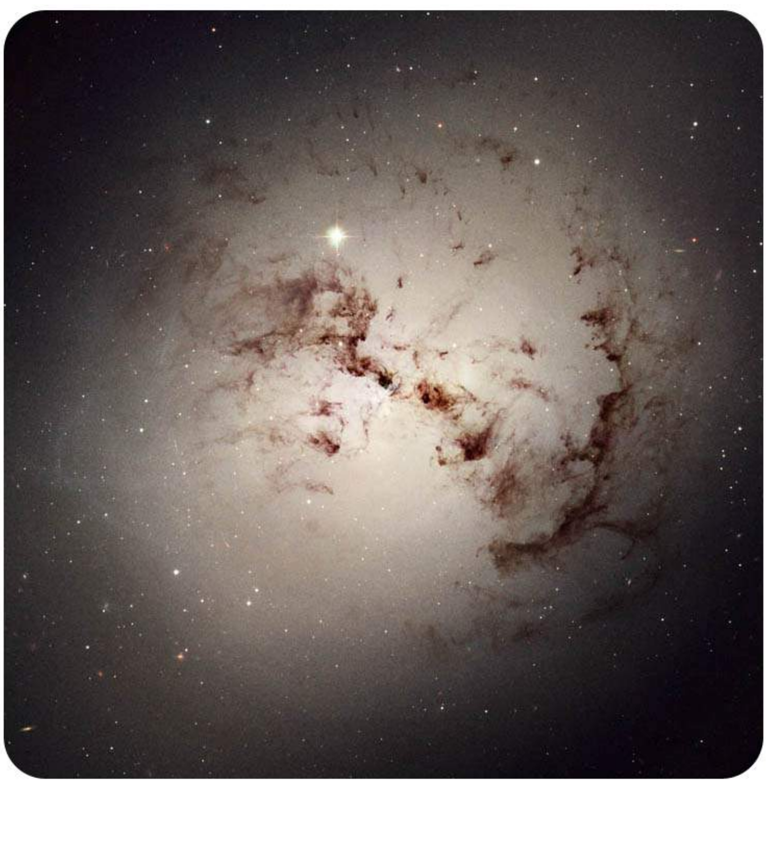

FIGURE 3.15
Astronomers believe that these dusty elliptical galaxies form when two galaxies of similar size collide.

FIGURE 3.16
This galaxy, called NGC 1427A, has neither a spiral nor an elliptical shape.

Look back at the picture of the elliptical galaxy. In the figure, you can see two dwarf elliptical galaxies that are companions to the Andromeda Galaxy. One is a bright sphere to the left of center, and the other is a long ellipse below and to the right of center. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Images from the Hubble Space Telescope are seen in this video: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop .

The Milky Way Galaxy

On a dark, clear night, you will see a milky band of light stretching across the sky, as in **Figure** 3.17 . This band is the disk of a galaxy, the **Milky Way Galaxy**, which is our galaxy. The Milky Way is made of millions of stars along with a lot of gas and dust.

Shape and Size

Although it is difficult to know what the shape of the Milky Way Galaxy is because we are inside of it, astronomers have identified it as a typical spiral galaxy containing about 100 billion to 400 billion stars (**Figure** 3.18).

Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy's gas, dust, young stars, and open clusters are in the disk. What evidence do astronomers find that lets them know that the Milky Way is a spiral galaxy?

1. The shape of the galaxy as we see it (**Figure** 3.19).

2. The velocities of stars and gas in the galaxy show a rotational motion.

3. The gases, color, and dust are typical of spiral galaxies.

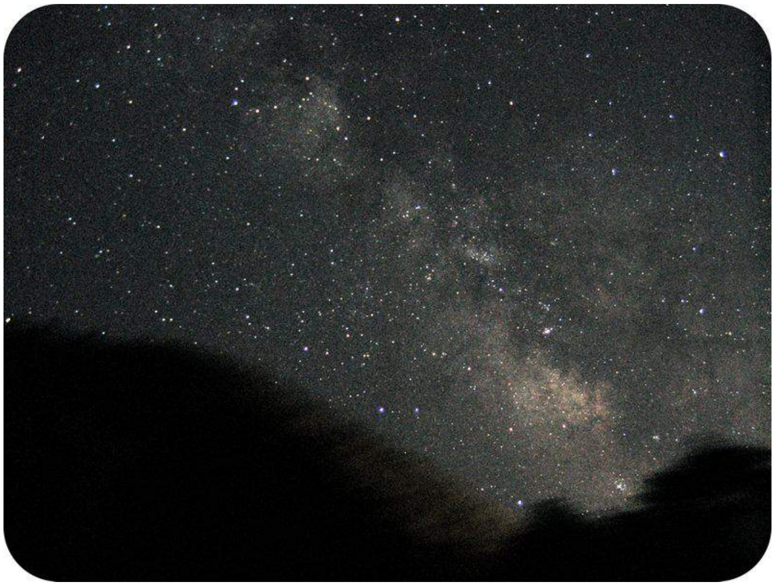

FIGURE 3.17
The Milky Way Galaxy looks different than other galaxies because we are looking along the main disk from within the galaxy.

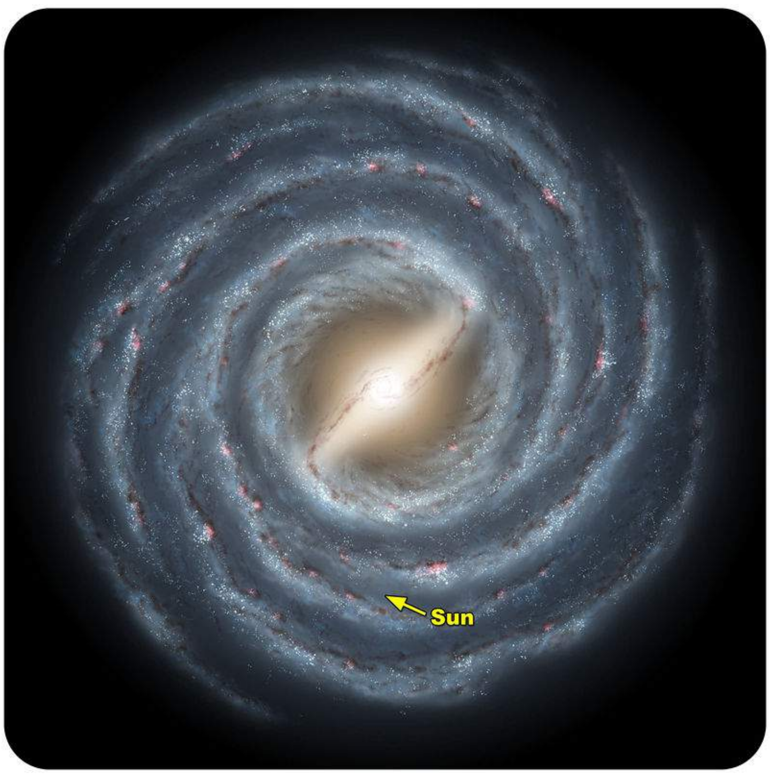

FIGURE 3.18
An artist's rendition of what astronomers think the Milky Way Galaxy would look like seen from above. The Sun is located approximately where the arrow points.

The central bulge is about 12,000 to 16,000 light-years wide and 6,000 to 10,000 light-years thick. The central bulge contains mostly older stars and globular clusters. Some recent evidence suggests the bulge might not be spherical, but is instead shaped like a bar. The bar might be as long as 27,000 light-years long. The disk and bulge are surrounded by a faint, spherical halo, which also contains old stars and globular clusters. Astronomers have discovered that there is a gigantic black hole at the center of the galaxy.

The Milky Way Galaxy is a big place. If our solar system were the size of your fist, the Galaxy's disk would still be

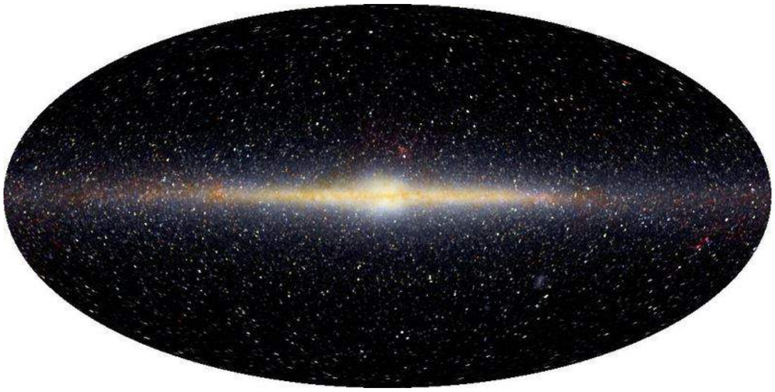

FIGURE 3.19
An infrared image of the Milky Way shows the long thin line of stars and the central bulge typical of spiral galaxies.

wider than the entire United States!

A video closeup of the Milky Way Galaxy is seen here: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTopjjj .

Where We Are

Our solar system, including the Sun, Earth, and all the other planets, is within one of the spiral arms in the disk of the Milky Way Galaxy. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are about 26,000 light-years from the center of the galaxy, a little more than halfway out from the center of the galaxy to the edge.

Just as Earth orbits the Sun, the Sun and solar system orbit the center of the Galaxy. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago. Astronomers have recently discovered that at the center of the Milky Way, and most other galaxies, is a supermassive black hole, although a black hole cannot be seen.

This video describes the solar system in which we live. It is located in an outer edge of the Milky Way galaxy, which spans 100,000 light years **(2a)**: http://www.youtube.com/watch?v=0Rt7FevNiRc (5:10).

MEDIA
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The Universe contains many billions of stars and there are many billions of galaxies. Our home, the Milky Way galaxy, is only one **(2a, 2b)**: http://www.youtube.com/watch?v=eRJvB3hM7K0&feature=related (5:59).

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Lesson Summary

- Many stars are in systems of two or more stars.
- Open clusters are groups of young stars loosely held together by gravity.
- Globular clusters are spherical groups of old stars held tightly together by gravity.
- Galaxies are collections of millions to many billions of stars.
- Spiral galaxies have a rotating disk of stars and dust, a bulge in the middle, and several arms spiraling out from the center. The disk and arms contain many young, blue stars.
- Typical elliptical galaxies are egg-shaped, reddish, and contain mostly old stars.
- Galaxies that are not elliptical or spiral galaxies are called irregular galaxies. These galaxies were probably deformed by other galaxies.
- The Milky Way Galaxy is a typical spiral galaxy. Our solar system is in a spiral arm of the Milky Way Galaxy, a little more than halfway from the center to the edge of the disk.

Review Questions

1. What is a binary star?
2. Compare globular clusters with open clusters.
3. Name the three main types of galaxies.
4. List three main features of a spiral galaxy.
5. Suppose you see a round galaxy that is reddish in color and contains very little dust. What kind of galaxy is it?
6. What galaxy do we live in, and what kind of galaxy is it?
7. What is the evidence that the galaxy we live in is this type of galaxy?
8. Describe the location of our solar system in our galaxy.
9. What are all the contents of the Milky Way revolving around?

Further Reading / Supplemental Links

- Variety of astronomy news: http://www.space.com
- More about galaxies: http://stardate.org/resources/btss/galaxies/

Points to Consider

- Objects in the universe tend to be grouped together. What forces or factors do you think cause objects to form and stay in groups?
- Some people used to call galaxies "island universes." Are they really universes?
- Can you think of anything, either an object or a group of objects, that is bigger than a galaxy?

3.6 Stars

Lesson Objectives

- Define constellation.
- Describe the flow of energy in a star.
- Classify stars based on their properties.
- Outline the life cycle of a star.
- Use light-years as a unit of distance.

Essential Knowledge

1. Differentiate the life paths of low mass and high mass stars. 2. Evaluate the future life path of the Sun. 3. Compare low mass stars and high mass stars and their positions on the H-R Diagram.

Vocabulary

- absolute magnitude
- apparent magnitude
- black hole
- magnitude
- main sequence star
- neutron star
- nuclear fusion reaction
- parallax
- red giant
- star
- supernova
- white dwarf

Introduction

When you look at the sky on a clear night, you can see dozens, perhaps even hundreds, of tiny points of light. Almost every one of these points of light is a **star**, a giant ball of glowing gas at a very, very high temperature. Stars differ in size, temperature, and age, but they all appear to be made up of the same elements and to behave according to the same principles

Constellations

People of many different cultures, including the Greeks, identified patterns of stars in the sky. We call these patterns constellations. **Figure** 3.20 shows one of the most easily recognized constellations.

Why do the patterns in constellations and in groups or clusters of stars, called **asterisms**, stay the same night after night? Although the stars move across the sky, they stay in the same patterns. This is because the apparent nightly motion of the stars is actually caused by the rotation of Earth on its axis. The patterns also shift in the sky with the

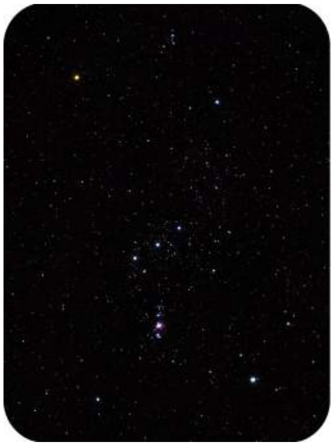


FIGURE 3.20
The ancient Greeks thought this group of stars looked like a hunter, so they named it Orion after their mythical hunter. The line of three stars at the center is "Orion's Belt".

seasons as Earth revolves around the Sun. As a result, people in a particular location can see different constellations in the winter than in the summer. For example, in the Northern Hemisphere Orion is a prominent constellation in the winter sky, but not in the summer sky. This is the annual traverse of the constellations.

Apparent Versus Real Distances and Magnitude.

Although the stars in a constellation appear close together as we see them in our night sky, they are not at all close together out in space. In the constellation Orion, the stars visible to the naked eye are at distances ranging from just 26 light-years (which is relatively close to Earth) to several thousand light-years away. The distance a star appears to us on earth is called apparent distance. The real measured distance a star is from earth is called absolute distance. This same concept can be applied to brightness or **magnitude**. The **apparent magnitude** of a star is how bright the star is to us on earth. For example, our sun has the highest apparent magnitude in the night sky. The **absolute magnitude** is the actual measured brightness of a star. The only difference between the absolute and apparent brightness or magnitude of a star is the star's distance from earth.

Star Power

The Sun is Earth's major source of energy, yet the planet only receives a small portion of its energy and the Sun is just an ordinary star. Many stars produce much more energy than the Sun. The energy source for all stars is nuclear fusion.

Nuclear Fusion

Stars are made mostly of hydrogen and helium, which are packed so densely in a star that in the star's center the pressure is great enough to initiate nuclear fusion reactions. In a **nuclear fusion reaction**, the nuclei of two atoms combine to create a new atom. Most commonly, in the core of a star, two hydrogen atoms fuse to become a helium atom. Although nuclear fusion reactions require a lot of energy to get started, once they are going they produce enormous amounts of energy (**Figure** 3.21).

In a star, the energy from fusion reactions in the core pushes outward to balance the inward pull of gravity. This energy moves outward through the layers of the star until it finally reaches the star's outer surface. The outer layer of the star glows brightly, sending the energy out into space as electromagnetic radiation, including visible light, heat, ultraviolet light, and radio waves (**Figure** 3.22).

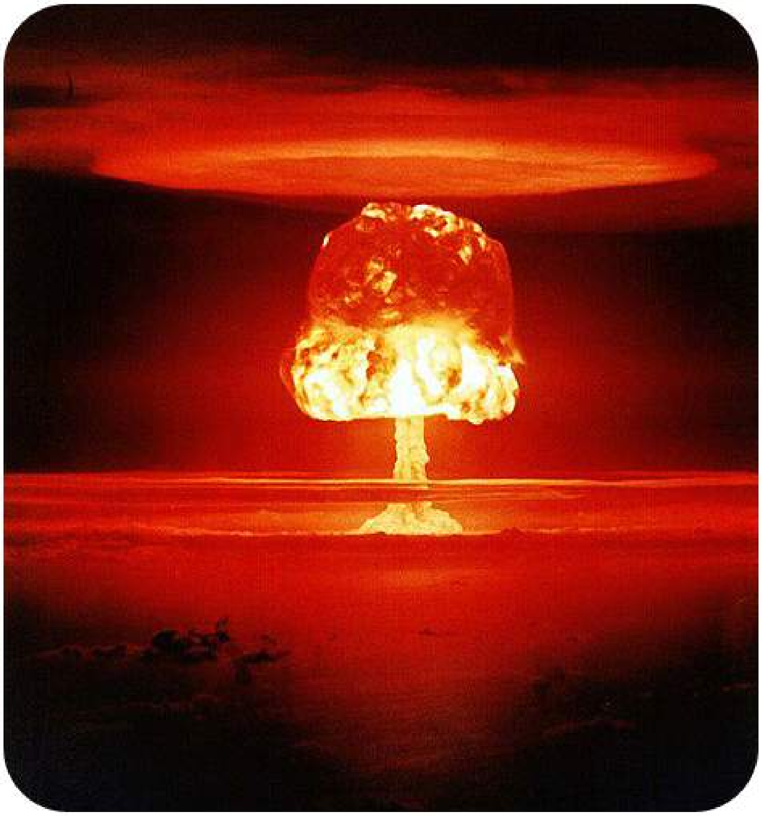


FIGURE 3.21
A thermonuclear bomb is an uncontrolled fusion reaction in which enormous amounts of energy are released.

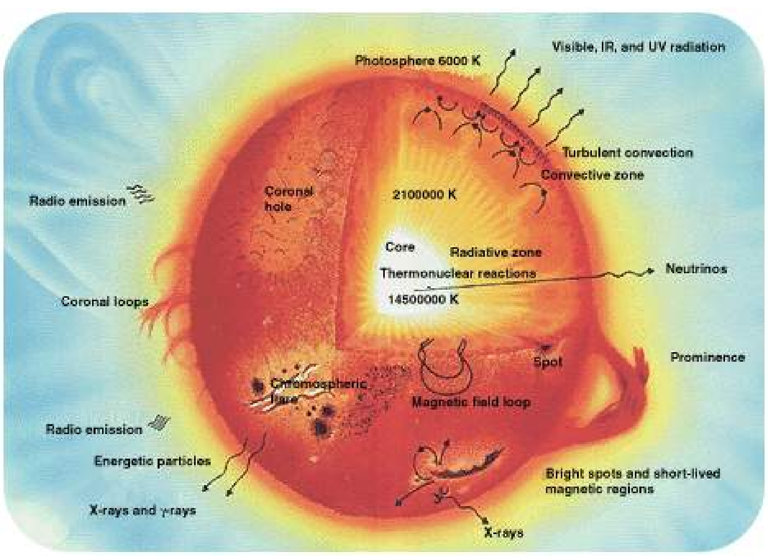
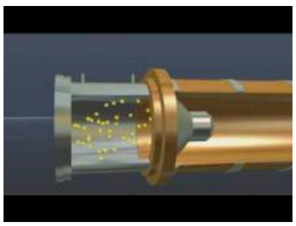


FIGURE 3.22
A diagram of a star like the Sun.

In particle accelerators, subatomic particles are propelled until they have attained almost the same amount of energy as found in the core of a star (**Figure** 3.23). When these particles collide head-on, new particles are created. This process simulates the nuclear fusion that takes place in the cores of stars. The process also simulates the conditions that allowed for the first helium atom to be produced from the collision of two hydrogen atoms in the first few minutes of the universe.

FIGURE 3.23
The SLAC National Accelerator Lab in California can propel particles a straight 2 mi (3.2 km).

The CERN Particle Accelerator presented in this video is the world's largest and most powerful particle accelerator and can boost subatomic particles to energy levels that simulate conditions in the stars and in the early history of the universe before stars formed **(2e)**: http://www.youtube.com/watch?v=sxAxV7g3yf8 (6:16).



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How Stars Are Classified

The many different colors of stars reflect the star's temperature. In Orion (as shown above) the bright, red star in the upper left named Betelgeuse (pronounced BET-ul-juice) is not as hot than the blue star in the lower right named Rigel.

Color and Temperature

Think about how the color of a piece of metal changes with temperature. A coil of an electric stove will start out black but with added heat will start to glow a dull red. With more heat the coil turns a brighter red, then orange. At extremely high temperatures the coil will turn yellow-white, or even blue-white (it's hard to imagine a stove coil getting that hot). A star's color is also determined by the temperature of the star's surface. Relatively cool stars are red, warmer stars are orange or yellow, and extremely hot stars are blue or blue-white (**Figure** 3.24).

Classifying Stars by Color

Color is the most common way to classify stars. **Table** 3.1 shows the classification system. The class of a star is given by a letter. Each letter corresponds to a color, and also to a range of temperatures. Note that these letters don't match the color names; they are left over from an older system that is no longer used.

TABLE 3.1: **Classification of Stars By Color and Temperature**

Class	Color	Temperature Range	Sample Star
O	Blue	30,000 K or more	Zeta Ophiuchi
B	Blue-white	10,000–30,000 K	Rigel
A	White	7,500–10,000 K	Altair
F	Yellowish-white	6,000–7,500 K	Procyon A
G	Yellow	5,500–6,000 K	Sun
K	Orange	3,500–5,000 K	Epsilon Indi

TABLE 3.1: (continued)

Class	Color	Temperature Range	Sample Star
M	Red	2,000–3,500 K	Betelgeuse, Proxima Centauri

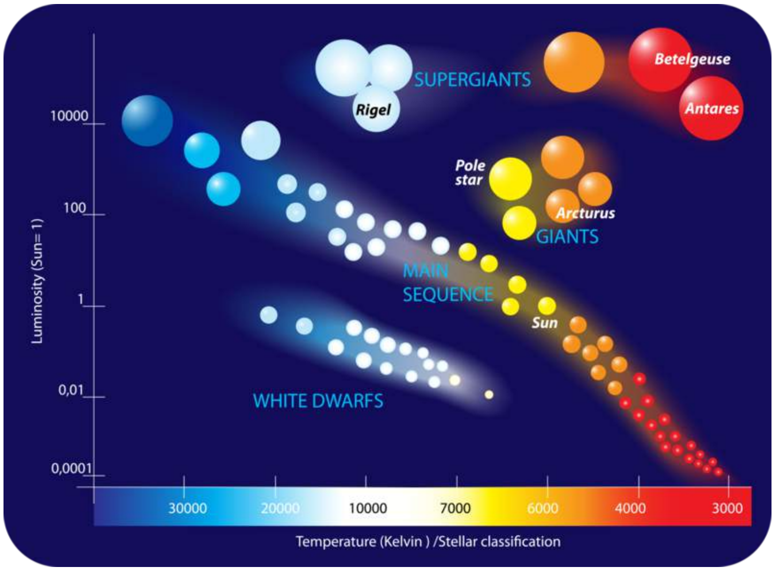


FIGURE 3.24

A Hertzsprung-Russell diagram shows the brightness and color of main sequence stars. The brightness is indicated by luminosity and is higher up the y-axis. The temperature is given in degrees Kelvin and is higher on the left side of the x-axis. How does our Sun fare in terms of brightness and color compared with other stars?

(*Sources*: http://en.wikipedia.org/wiki/Stellar_classification; http://en.wikipedia.org/wiki/Star, License: GNU-FDL)

For most stars, surface temperature is also related to size. Bigger stars produce more energy, so their surfaces are hotter. These stars tend toward bluish white. Smaller stars produce less energy. Their surfaces are less hot and so they tend to be yellowish.

Before reading, Lifetime of Stars, please compete the "Properties of Stars" lab found in the Resources Section.

Lifetime of Stars

Stars have a life cycle that is expressed similarly to the life cycle of a living creature: they are born, grow, change over time, and eventually die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars is because of data gathered from visual, radio, and X-ray telescopes.

Star Formation

As discussed in the Solar System chapter, stars are born in clouds of gas and dust called nebulas, like the one shown in **Figure** 3.25.

For more on star formation, check out http://www.spacetelescope.org/science/formation_of_stars.html and http://hurricanes.nasa.gov/universe/science/stars.html .

The Main Sequence

For most of a star's life, nuclear fusion in the core produces helium from hydrogen. A star in this stage is a **main sequence** star. This term comes from the Hertzsprung-Russell diagram shown above. For stars on the main sequence, temperature is directly related to brightness. A star is on the main sequence as long as it is able to balance the inward force of gravity with the outward force of nuclear fusion in its core. The more massive a star, the more it must

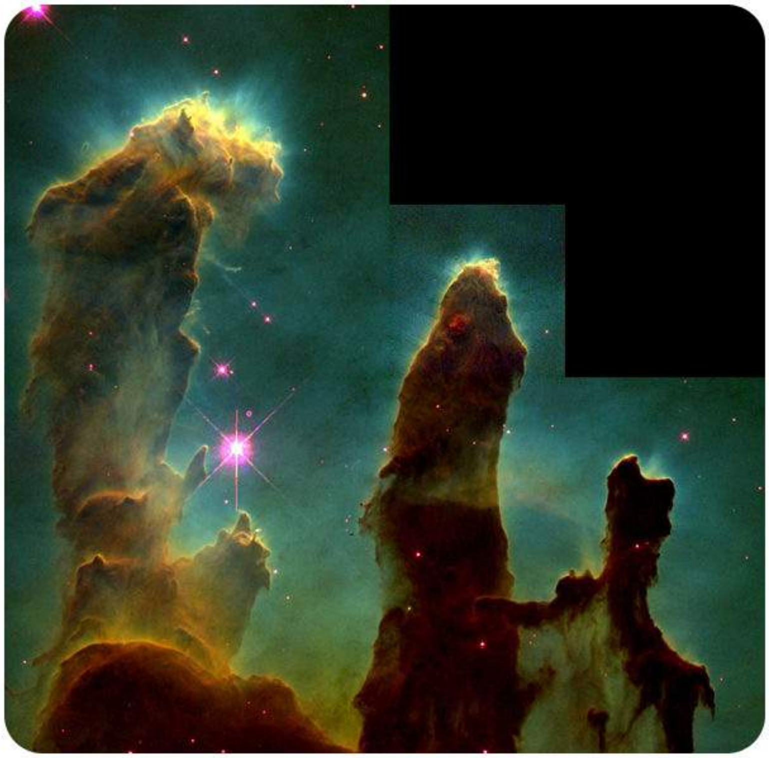


FIGURE 3.25
The Pillars of Creation within the Eagle Nebula are where gas and dust come together as a stellar nursery.

burn hydrogen fuel to prevent gravitational collapse. Because they burn more fuel, more massive stars have higher temperatures. Massive stars also run out of hydrogen sooner than smaller stars do.

Our Sun has been a main sequence star for about 5 billion years and will continue on the main sequence for about 5 billion more years (**Figure** 3.26). Very large stars may be on the main sequence for only 10 million years. Very small stars may last tens to hundreds of billions of years.

The fate of the Sun and inner planets is explored in this video: http://www.space.com/common/media/video/player.php?videoRef=mm32_SunDeath .

Red Giants and White Dwarfs

As a star begins to use up its hydrogen, it fuses helium atoms together into heavier atoms such as carbon. A blue giant star has exhausted its hydrogen fuel and is a transitional phase. When the light elements are mostly used up the star can no longer resist gravity and it starts to collapse inward. The outer layers of the star grow outward and cool. The larger, cooler star turns red in color and so is called a **red giant**.

Eventually, a red giant burns up all of the helium in its core. What happens next depends on how massive the star is. A typical star, such as the Sun, stops fusion completely. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth, called a **white dwarf** (**Figure** 3.27). A white dwarf will ultimately fade out.

Supergiants and Supernovas

A star that runs out of helium will end its life much more dramatically. When very massive stars leave the main sequence, they become red supergiants (**Figure** 3.28).

FIGURE 3.26
Our Sun is a medium-sized star in about the middle of its main sequence life.

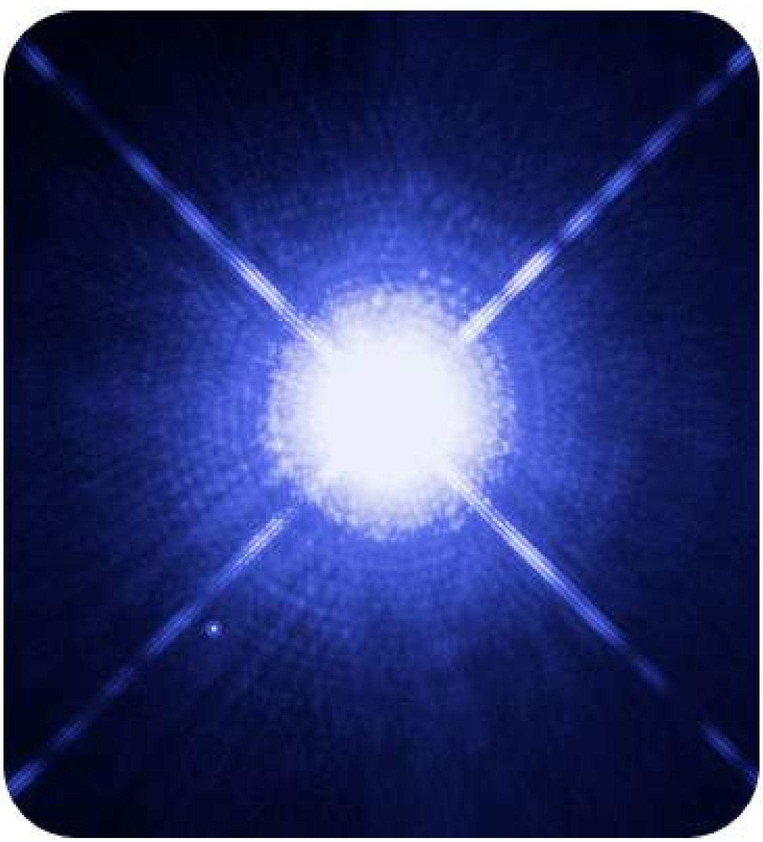


FIGURE 3.27
Sirius, the brightest star in the sky, is actually a binary star system. Sirius A is on the main sequence. Sirius B, the tiny dot on the lower left, is a white dwarf.

FIGURE 3.28
The red star Betelgeuse in Orion is a red supergiant.

Unlike a red giant, when all the helium in a red supergiant is gone, fusion continues. Lighter atoms fuse into heavier atoms up to iron atoms. Creating elements heavier than iron through fusion uses more energy than it produces so stars do not ordinarily form any heavier elements. When there are no more elements for the star to fuse, the core succumbs to gravity and collapses, creating a violent explosion called a **supernova** (**Figure** 3.29). A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver, and uranium. A supernova can shine as brightly as an entire galaxy for a short time. All elements with an atomic number greater than that of lithium were formed by nuclear fusion in stars.

An animation of the Crab Supernova is seen here: http://www.youtube.com/watch?v=0J8srN24pSQ&feature=fvw .

This video looks at the origin of the universe, star formation, and the formation of the chemical elements in supernovas **(2c)**: http://www.youtube.com/watch?v=8AKXpBeddu0&feature=related (8:30).

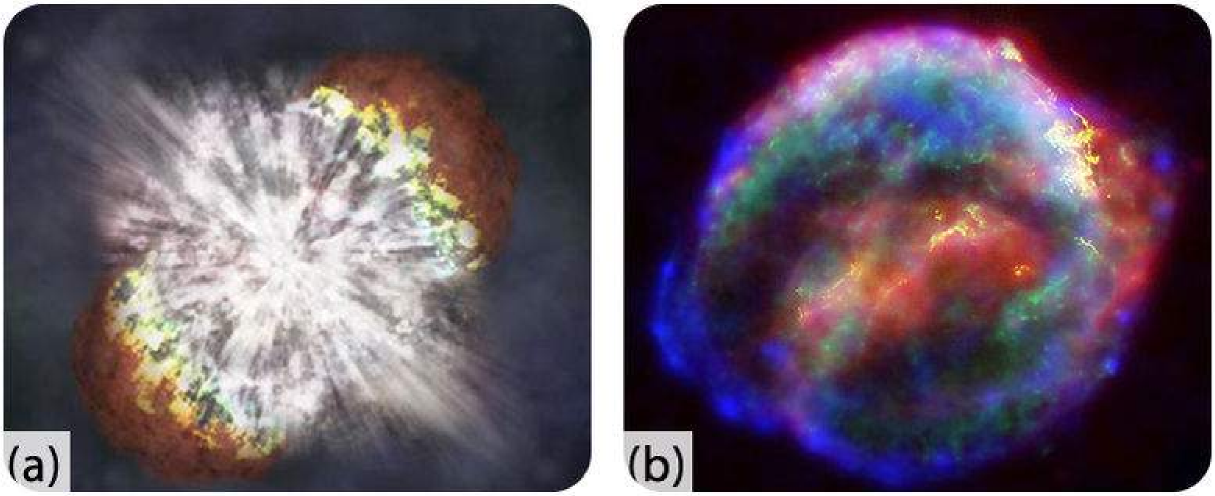
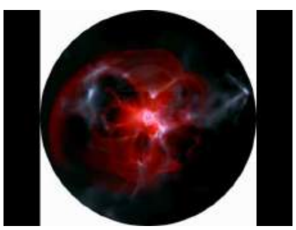


FIGURE 3.29

(a) NASA's Chandra X-ray observatory captured the brightest stellar explosion so far, 100 times more energetic than a typical supernova. (b) This false-color image of the supernova remnant SN 1604 was observed as a supernova in the Milky Way galaxy. At its peak it was brighter than all other stars and planets, except Venus, in the night sky.



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Neutron Stars and Black Holes

After a supernova explosion, the leftover material in the core is extremely dense. If the core is less than about four times the mass of the Sun, the star becomes a **neutron star** (**Figure** 3.30). A neutron star is made almost entirely of neutrons, relatively large particles that have no electrical charge.

If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses into a **black hole**. Black holes are so dense that not even light can escape their gravity. With no light, a black hole cannot be observed directly. But a black hole can be identified by the effect that it has on objects around it, and by radiation that leaks out around its edges.

How to make a black hole: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop .

A video about black holes is seen on Space.com: http://www.space.com/common/media/video/player.php?videoRef=black_holes .

A Star's Life Cycle video from Discovery Channel describes how stars are born, age and die **(2f)**: http://www.youtu

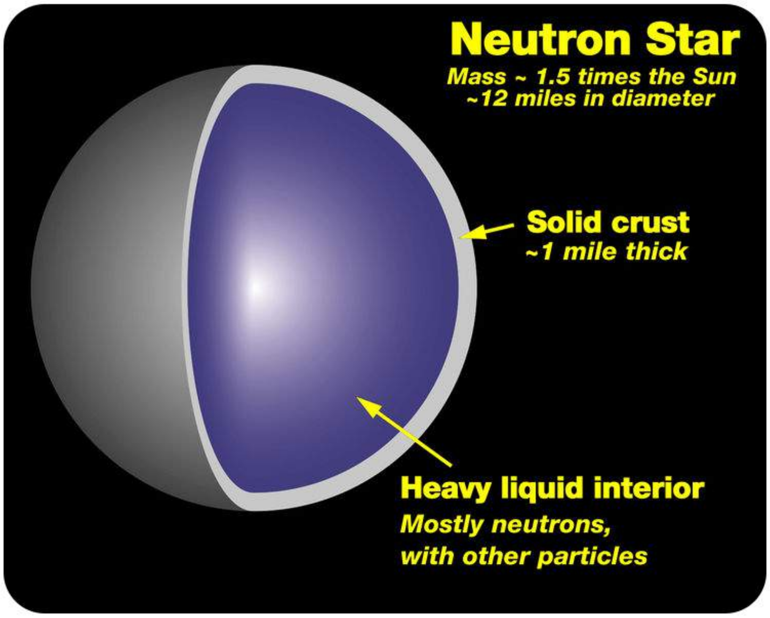

FIGURE 3.30
After a supernova, the remaining core may end up as a neutron star. A neutron star is more massive than the Sun, but only a few kilometers in diameter.

be.com/watch?v=H8Jz6FU5D1A (3:11).

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A video of neutron stars is available at: http://www.youtube.com/watch?v=VMnLVkV_ovc (4:24).

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Measuring Star Distances

How can you measure the distance of an object that is too far away to measure? Now what if you don't know the size of the object or the size or distance of any other objects like it? That would be very difficult, but that is the problem facing astronomers when they try to measure the distances to stars.

Parallax

Distances to stars that are relatively close to us can be measured using **parallax**. Parallax is an apparent shift in position that takes place when the position of the observer changes.

To see an example of parallax, try holding your finger about 1 foot (30 cm) in front of your eyes. Now, while focusing on your finger, close one eye and then the other. Alternate back and forth between eyes, and pay attention to how your finger appears to move. The shift in position of your finger is an example of parallax. Now try moving your finger closer to your eyes, and repeat the experiment. Do you notice any difference? The closer your finger is to your eyes, the greater the position changes because of parallax.

As **Figure** 3.31 shows, astronomers use this same principle to measure the distance to stars. Instead of a finger, they focus on a star, and instead of switching back and forth between eyes, they switch between the biggest possible differences in observing position. To do this, an astronomer first looks at the star from one position and notes where the star is relative to more distant stars. Now where will the astronomer go to make an observation the greatest possible distance from the first observation? In six months, after Earth moves from one side of its orbit around the Sun to the other side, the astronomer looks at the star again. This time parallax causes the star to appear in a different position relative to more distant stars. From the size of this shift, astronomers can calculate the distance to the star.

For more about parallax, visit http://starchild.gsfc.nasa.gov/docs/StarChild/questions/parallax.html .

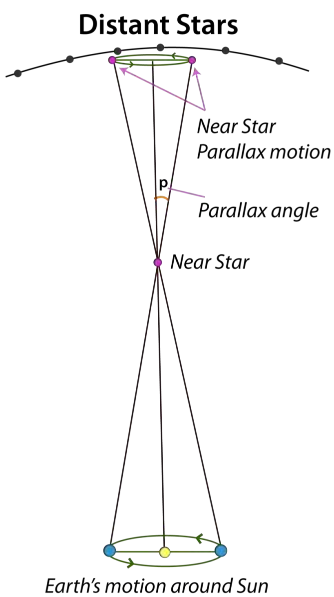


FIGURE 3.31

Parallax is used to measure the distance to stars that are relatively nearby.

A parallax exercise is seen here: http://www.astro.ubc.ca/~scharein/a311/Sim/new-parallax/Parallax.html .

Other Methods

Even with the most precise instruments available, parallax is too small to measure the distance to stars that are more than a few hundred light years away. For these more distant stars, astronomers must use more indirect methods of determining distance. Most of these methods involve determining how bright the star they are looking at really is. For example, if the star has properties similar to the Sun, then it should be about as bright as the Sun. The astronomer compares the observed brightness to the expected brightness.

Lesson Summary

- Constellations and asterisms are apparent patterns of stars in the sky.
- Stars in the same constellation are often not close to each other in space.
- A star generates energy by nuclear fusion reactions in its core.

- The color of a star is determined by its surface temperature.
- Stars are classified by color and temperature: O (blue), B (bluish white), A (white), F (yellowish white), G (yellow), K (orange), and M (red), from hottest to coolest.
- Stars form from nebulas. Gravity causes stars to collapse until nuclear fusion begins.
- Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
- Typical, Sun-like stars expand into red giants, then fade out as white dwarfs.
- Very large stars expand into red supergiants, explode in supernovas, and end up as neutron stars or black holes.
- Parallax is an apparent shift in an object's position when the position of the observer changes. Astronomers use parallax to measure the distance to

relatively nearby stars.

Review Questions

1. What distinguishes a nebula and a star?

2. What kind of reactions provide a star with energy?

3. Stars are extremely massive. Why don't they collapse under the weight of their own gravity?

4. Which has a higher surface temperature: a blue star or a red star?

5. List the seven main classes of stars, from hottest to coolest.

6. What is the main characteristic of a main sequence star?

7. What kind of star will the Sun be after it leaves the main sequence?

8. Suppose a large star explodes in a supernova, leaving a core that is 10 times the mass of the Sun. What would happen to the core of the star?

9. Since black holes are black, how do astronomers know that they exist?

10. What is a light year?

11. Why don't astronomers use parallax to measure the distance to stars that are very far away?

Further Reading / Supplemental Links

- Myths and history of constellations: http://www.ianridpath.com/startales/contents.htm
- NASA World Book, Stars: http://www.nasa.gov/worldbook/star_worldbook.html
- NASA, parts of a star: http://imagine.gsfc.nasa.gov/docs/science/know_l1/stars.html

Points to Consider

- Although stars may appear to be close together in constellations, they are usually not close together out in space. Can you think of any groups of astronomical objects that are relatively close together in space?
- Most nebulas contain more mass than a single star. If a large nebula collapsed into several different stars, what would the result be like?

3.7 Study of Space by the Electromagnetic Spectrum

- Describe the electromagnetic spectrum.
- Explain how astronomers use radiation to tell them about the Universe.

How do scientists learn about space?

Many scientists can touch the materials they study. Most can do experiments to test those materials. Biologists can collect cells, seeds, or sea urchins to study in the laboratory. Physicists can test the strength of metal or smash atoms into each other. Geologists can chip away at rocks and test their chemistry. What can astronomers use to study space? Light and other electromagnetic waves, of course. This is the Andromeda Galaxy as it appeared 2.5 million years ago. Why is the light so old?

Electromagnetic Spectrum

Earth is just a tiny speck in the Universe. Our planet is surrounded by lots of space. Light travels across empty space. Light is the visible part of the **electromagnetic spectrum**. Astronomers use the light and other energy that comes to us to gather information about the Universe.

The Speed of Light

In space, light travels at about 300,000,000 meters per second (670,000,000 miles per hour). How fast is that? A beam of light could travel from New York to Los Angeles and back again nearly 40 times in just one second. Even at that amazing rate, objects in space are so far away that it takes a lot of time for their light to reach us. Even light from the nearest star, our sun, takes about eight minutes to reach Earth.

Light-Years

We need a really big unit to measure distances out in space because distances between stars are so great. A **light-year**, 9.5 trillion kilometers (5.9 trillion miles), is the distance that light travels in one year. That's a long way! Out in space, it's actually a pretty short distance.

Proxima Centauri is the closest star to us after the Sun. This near neighbor is 4.22 light-years away. That means the light from Proxima Centauri takes 4.22 years to reach us. Our galaxy, the Milky Way Galaxy, is about 100,000 light-years across. So it takes light 100,000 years to travel from one side of the galaxy to the other! It turns out that even 100,000 light years is a short distance. The most distant galaxies we have detected are more than 13 billion light-years away. That's over a hundred-billion-trillion kilometers!

Looking Back in Time

When we look at stars and galaxies, we are seeing over great distances. More importantly, we are also seeing back in time. When we see a distant galaxy, we are actually seeing how the galaxy used to look. For example, the Whirlpool Galaxy is about 23 million light-years from Earth (**Figure** 3.32). When you see an image of the galaxy what are you seeing? You are seeing the galaxy as it was 23 million years ago!

FIGURE 3.32
The Whirlpool Galaxy as it looked 23 million years ago.

Since scientists can look back in time, they can better understand the Universe's history. Check out http://science.nasa.gov/headlines/y2002/08feb_gravlens.htm to see how this is true.

Electromagnetic Waves

Light is one type of **electromagnetic radiation**. Light is energy that travels in the form of an electromagnetic wave. Pictured below is a diagram of an electromagnetic wave (**Figure** 3.33). An electromagnetic (EM) wave has two parts: an electric field and a magnetic field. The electric and magnetic fields vibrate up and down, which makes the wave.

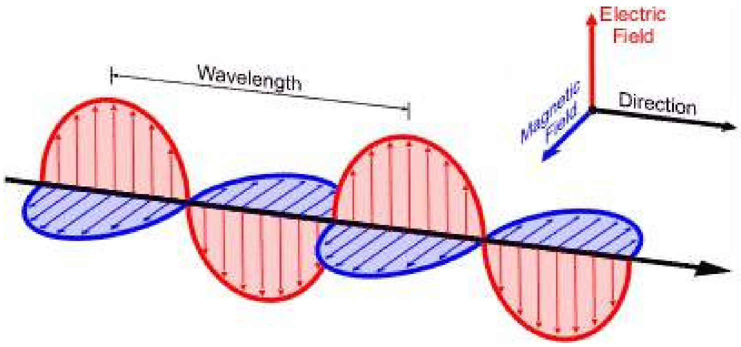


FIGURE 3.33
An electromagnetic wave has oscillating electric and magnetic fields.

The **wavelength** is the horizontal distance between two of the same points on the wave, like wave crest to wave crest. A wave's **frequency** measures the number of wavelengths that pass a given point every second. As wavelength increases, frequency decreases. This means that as wavelengths get shorter, more waves move past a particular spot in the same amount of time.

The Electromagnetic Spectrum

Visible light is the part of the electromagnetic spectrum (**Figure** 3.34) that humans can see. Visible light includes all the colors of the rainbow. Each color is determined by its wavelength. Visible light ranges from violet wavelengths of 400 nanometers (nm) through red at 700 nm.

Visible light is only a small part of the electromagnetic spectrum. There are parts of the electromagnetic spectrum that humans cannot see. This radiation exists all around you. You just can't see it! Every star, including our Sun, emits radiation of many wavelengths. Astronomers can learn a lot from studying the details of the spectrum of radiation from a star.

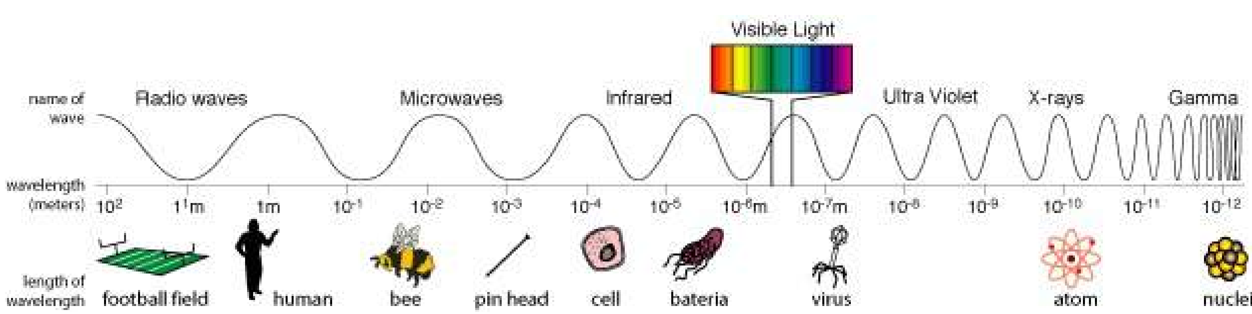


FIGURE 3.34
The electromagnetic spectrum from radio waves to gamma rays.

Many extremely interesting objects can't be seen with the unaided eye. Astronomers use telescopes to see objects at wavelengths all across the electromagnetic spectrum. Some very hot stars emit light primarily at ultraviolet wavelengths. There are extremely hot objects that emit X-rays and even gamma rays. Some very cool stars shine mostly in the infrared light wavelengths. Radio waves come from the faintest, most distant objects.

To learn more about stars' spectra, visit http://www.colorado.edu/physics/PhysicsInitiative/Physics2000/quantumzon e/ .

Vocabulary

- **electromagnetic radiation**: Energy transmitted through space as a wave.
- **electromagnetic spectrum**: Full range of electromagnetic radiation.
- **frequency**: Number of wavelengths that pass a given point every second.
- **light-year**: Distance that light travels in one year; 5.9 trillion miles, 9.5 trillion kilometers.
- **visible light**: Portion of energy in the electromagnetic spectrum that is visible to humans.
- **wavelength**: Horizontal distance from wave crest to wave crest, or wave trough to wave trough.

Summary

- Electromagnetic radiation is energy transmitted as waves with different wavelengths. This makes up the electromagnetic spectrum.
- Light travels very fast but still takes a long time to get across space. A light year is the distance light can travel in one year.
- From longest wavelengths to shortest wavelengths the electromagnetic spectrum is: radio waves, microwaves, infrared, visible light, ultra violet, x-rays, and gamma rays.

Practice

Use the resource below to answer the questions that follow.

- **The Electromagnetic Spectrum** at http://www.youtube.com/watch?v=cfXzwh3KadE (5:20)

MEDIA
Click image to the left for more content.

1. What is the electromagnetic spectrum?
2. What type of waves have the shortest wavelengths?
3. What type of waves have the longest wavelengths?
4. What do electromagnetic waves transmit?
5. Define wavelength.
6. Define frequency.
7. What type of waves have the lowest frequency?
8. What is the visible light region?
9. How is color produced?
10. What do scientists use the electromagnetic spectrum for?

Review

1. Why do astronomers use light years as a measure of distance?

2. In the electromagnetic spectrum, which wavelengths are shorter than visible light? Which are longer than visible light? Which are relatively cool? Which are relatively hot?
3. Why does light we see today tell us something about what happened earlier in the history of the Universe?

3.8 Fission and Fusion

Lesson Objectives

- Define fission and explain why energy is released during the fission process.
- Describe a nuclear chain reaction and how it is applied in both a fission bomb and in a nuclear power plant.
- Define fusion and explain the difficulty in using fusion as a controlled energy source.
- Explain how ionizing radiation is measured and how it is detected.
- Describe some uses of radiation in medicine and agriculture.

Vocabulary

- nuclear fission
- chain reaction
- critical mass
- nuclear fusion
- control rod
- moderator
- ionizing radiation
- roentgen
- rem
- Geiger counter
- scintillation counter
- film badge
- radioactive tracer

Check Your Understanding

Recalling Prior Knowledge

- What is nuclear binding energy and how does it relate to the stability of nuclei?
- Why do alpha particles need to be accelerated in order to collide with other nuclei but neutrons do not?

Common methods of energy production include the burning of fossil fuels, solar power, wind, and hydroelectric. Each has advantages and disadvantages. In this lesson, you will learn about nuclear fission and nuclear fusion, two processes that release tremendous amounts of energy but also present unique challenges.

Nuclear Fission

According to the graph of nuclear binding energy per nucleon in the lesson "Nuclear Radiation," the most stable nuclei are of intermediate mass. To become more stable, the heaviest nuclei are capable of splitting into smaller fragments. **Nuclear fission** *is a process in which a very heavy nucleus (mass >200) splits into smaller nuclei of intermediate mass*. Because the smaller nuclei are more stable, the fission process releases tremendous amounts of energy. Nuclear fission may occur spontaneously or may occur as result of bombardment. When uranium-235 is hit with a slow-moving neutron, it absorbs it and temporarily becomes the very unstable uranium-236. This nucleus splits into two medium-mass nuclei while also emitting more neutrons. The mass of the products is less than the mass of the reactants, with the lost mass being converted to energy.

Nuclear Chain Reaction

Because the fission process produces more neutrons, a chain reaction can result. A **chain reaction** *is a reaction in which the material that starts the reaction is also one of the products and can start another reaction*. **Figure** 3.35 shows a nuclear chain reaction for the fission of uranium-235.

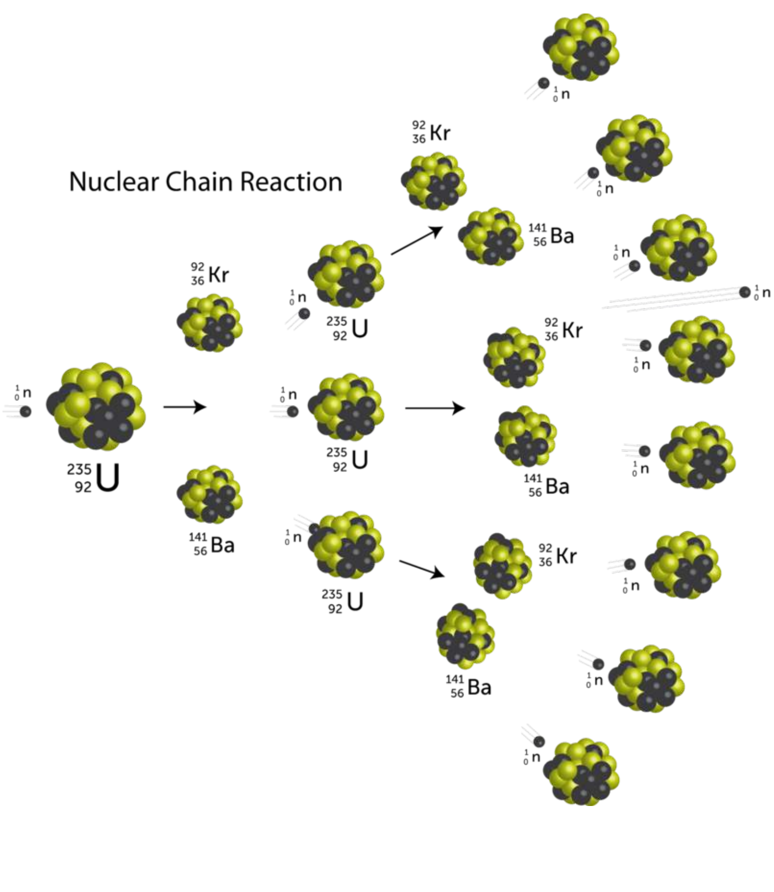


FIGURE 3.35
The nuclear chain reaction is a series of fission processes that sustains itself due to the continuous production of neutrons in each reaction.

The original uranium-235 nucleus absorbs a neutron, splits into a krypton-92 nucleus and a barium-141 nucleus, and releases three more neutrons upon splitting.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{92}_{36}\text{Kr} + ^{141}_{56}\text{Ba} + 3\,^{1}_{0}\text{n}$$

Those three neutrons are then able to cause the fission of three more uranium-235 nuclei, each of which release more neutrons, and so on. The chain reaction continues until all of the uranium-235 nuclei have been split or until the released neutrons escape the sample without striking any more nuclei. If the size of the original sample of uranium-235 is sufficiently small, too many neutrons escape without striking other nuclei and the chain reaction quickly ceases. The **critical mass** *is the minimum amount of fissionable material needed to sustain a chain reaction*. Atomic bombs and nuclear reactors are two ways to harness the large energy released during nuclear fission.

Atomic Bomb

In an atomic bomb, or fission bomb, the nuclear chain reaction is designed to be uncontrolled, releasing huge amounts of energy in a short amount of time. A schematic for one type of fission bomb is shown in **Figure** 3.36. A critical mass of fissionable plutonium is contained within the bomb, but not at a sufficient density. Conventional explosives are used to compress the plutonium, causing it to go critical and trigger a nuclear explosion.

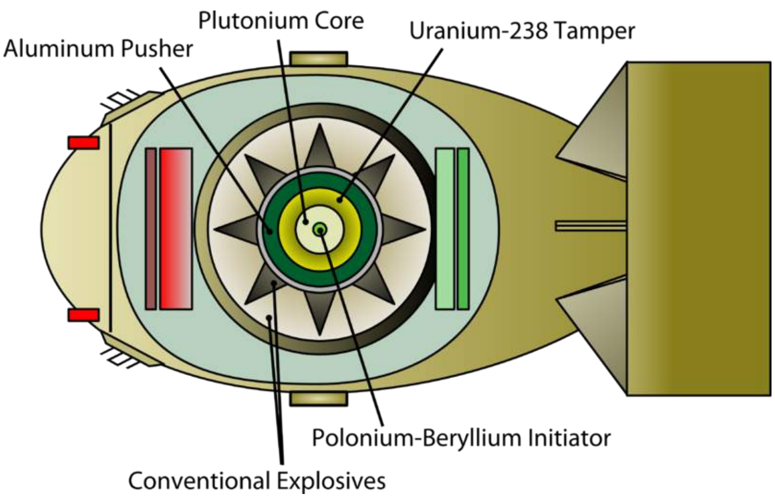


FIGURE 3.36
An atomic bomb uses a conventional explosive to bring together a critical mass of fissionable material, which then explodes because of the chain reaction and releases a large amount of energy.

Nuclear Power Plant

A nuclear power plant (**Figure** 3.37) uses a controlled fission reaction to produce large amounts of heat, which is then used to generate electrical energy.

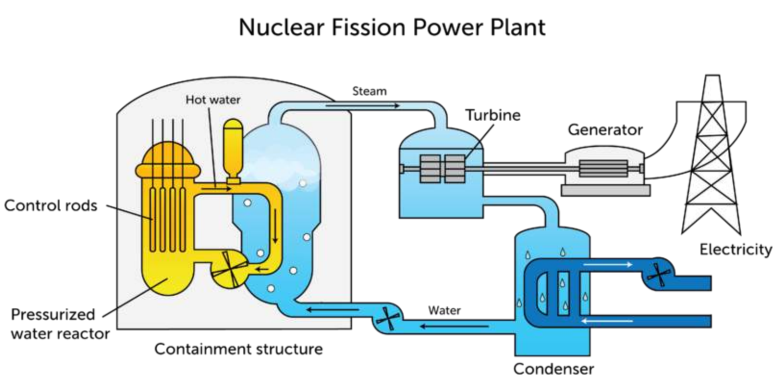


FIGURE 3.37
A nuclear reactor harnesses the energy of nuclear fission to generate electricity.

Uranium-235, the usual fissionable material in a nuclear reactor, is first packaged into fuel rods. In order to keep the chain reaction from proceeding unchecked, moveable control rods are placed in between the fuel rods. **Control**

rods, *limit the amount of available neutrons by absorbing some of them and preventing the reaction from proceeding too rapidly*. Common control rod materials include alloys with various amounts of silver, indium, cadmium, or boron. A **moderator** *is a material that slows down high-speed neutrons*. This is beneficial because slow-moving neutrons are more efficient at splitting nuclei. Water is often used as a moderator. The heat released by the fission reaction is absorbed by constantly circulating coolant water. The coolant water releases its heat to a steam generator, which turns a turbine and generates electricity. The core of the reactor is surrounded by a containment structure that absorbs radiation.

Controversy abounds over the use of nuclear power. An advantage of nuclear power over the burning of fossil fuels is that it does not emit carbon dioxide or various other conventional pollutants. However, the smaller nuclei produced in the fission process are themselves radioactive and must be disposed of or contained in a safe manner. Containment of this nuclear waste is a challenging problem, because the half-lives of the waste products can often be thousands of years. Spent fuel rods are typically stored temporarily on site in large pools of water to cool them before being transported to permanent storage facilities where the waste will be kept forever.

Another risk of nuclear power is that an accident at a nuclear power plant is life-threatening and very harmful to the environment. On April 26, 1986, an accident occurred at the Chernobyl Nuclear Power Plant in Ukraine. Thousands were killed either from the initial effects of the explosion or from radiation-induced cancers in subsequent years. Note that this was not a nuclear explosion, simply a conventional explosion that unfortunately spread radioactive materials into the surrounding environment. Because the fuel rods used in nuclear reactors are not as enriched with radioactive nuclei as the materials used in an atomic bomb, an accidental release of the massive destruction associated with a runaway nuclear reaction is not a major risk factor at nuclear power plants.

Nuclear Fusion

The lightest nuclei are also not as stable as nuclei of intermediate mass. **Nuclear fusion** *is a process in which light-mass nuclei combine to form a heavier and more stable nucleus*. Fusion produces even more energy than fission. In the sun and other stars, four hydrogen nuclei combine at extremely high temperatures and pressures to produce a helium nucleus. The concurrent loss of mass is converted into extraordinary amounts of energy (**Figure** 3.38).

Fusion is even more appealing than fission as an energy source because no radioactive waste is produced and the only reactant needed is hydrogen. However, fusion reactions only occur at very high temperatures –in excess of 40,000,000°C. No known materials can withstand such temperatures, so there is currently no feasible way to harness nuclear fusion for energy production, although research is ongoing.

Uses of Radiation

As we saw earlier, different types of radiation vary in their abilities to penetrate through matter. Alpha particles have very low penetrating ability and are stopped by skin and clothing. Beta particles have a penetrating ability that is about 100 times that of alpha particles. Gamma rays have very high penetrating ability, and great care must be taken to avoid overexposure to gamma rays.

Exposure and Detection

Radiation emitted by radioisotopes is called ionizing radiation. **Ionizing radiation** *is radiation that has enough energy to knock electrons off the atoms of a bombarded substance and produce ions*. The **roentgen** *is a unit that measures nuclear radiation and is equal to the amount of radiation that produces* 2×10^9 *ion pairs when it passes through 1* cm^3 *of air*. The primary concern is that ionizing radiation can do damage to living tissues. Radiation

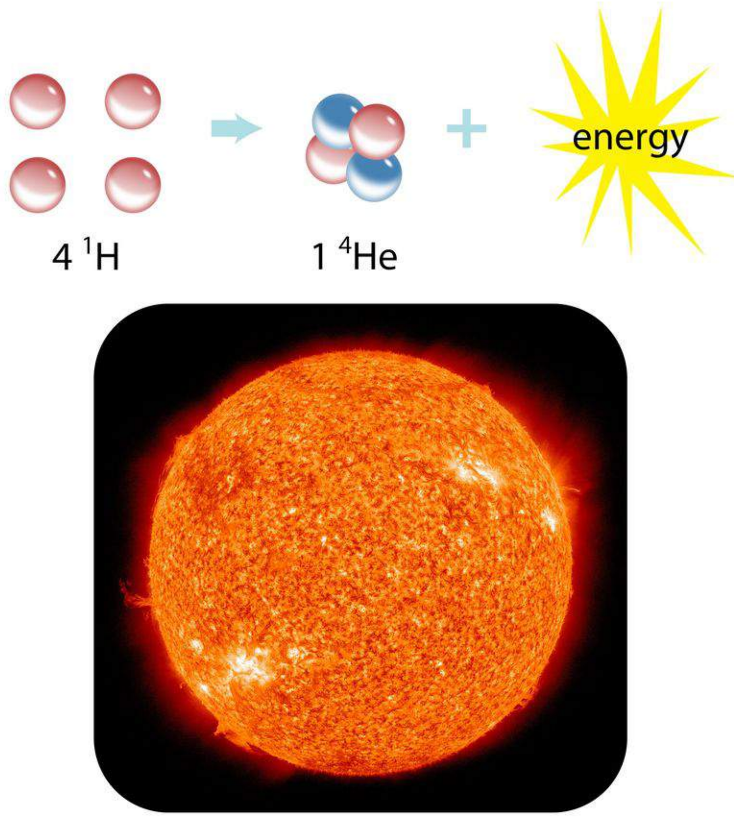


FIGURE 3.38

Nuclear fusion takes place when small nuclei combine to make larger ones. The enormous amounts of energy produced by fusion powers our sun and other stars.

damage is measured in rems, which stands for roentgen equivalent man. A **rem** *is the amount of ionizing radiation that does as much damage to human tissue as is done by 1 roentgen of high-voltage x-rays*. Tissue damage from ionizing radiation can cause genetic mutations due to interactions between the radiation and DNA, which can lead to cancer.

You are constantly being bombarded with background radiation from space and from geologic sources that vary depending on where you live. Average exposure is estimated to be about 0.1 rem per year. The maximum permissible dose of radiation exposure for people in the general population is 0.5 rem per year. Some people are naturally at higher risk because of their occupations, so reliable instruments to detect radiation exposure have been developed. A **Geiger counter** *is a device that uses a gas-filled metal tube to detect radiation* (**Figure** 3.39). When the gas is exposed to ionizing radiation, it conducts a current, and the Geiger counter registers this as audible clicks. The frequency of the clicks corresponds to the intensity of the radiation.

A **scintillation counter** *is a device that uses a phosphor-coated surface to detect radiation by the emission of bright bursts of light*. Workers who are at risk of exposure to radiation wear small portable film badges. A **film badge** *consists of several layers of photographic film that can measure the amount of radiation to which the wearer has been exposed*. Film badges are removed and analyzed at periodic intervals to ensure that the person does not become overexposed to radiation on a cumulative basis.

Medicine and Agriculture

Radioactive nuclides, such as cobalt-60, are frequently used in medicine to treat certain types of cancers. The faster growing cancer cells are exposed to the radiation and are more susceptible to damage than healthy cells. Thus, the cells in the cancerous area are killed by the exposure to high-energy radiation. Radiation treatment is risky because some healthy cells are also killed, and cells at the center of a cancerous tumor can become resistant to the radiation.

FIGURE 3.39
A Geiger counter is used to detect radiation.

Radioactive tracers *are radioactive atoms that are incorporated into substances so that the movement of these substances can be tracked by a radiation detector*. Tracers are used in the diagnosis of cancer and other diseases. For example, iodine-131 is used to detect problems with a person's thyroid. A patient first ingests a small amount of iodine-131. About two hours later, the iodine uptake by the thyroid is determined by a radiation scan of the patient's throat.The scanned image of a thyroid gland shows where iodine-131 has been absorbed and allows doctors to identify thyroid disorders. In a similar way, technetium-99 is used to detect brain tumors and liver disorders, and phosphorus-32 is used to detect skin cancer.

Radioactive tracers can be used in agriculture to test the effectiveness of various fertilizers. The fertilizer is enriched with a radioisotope, and the uptake of the fertilizer by the plant can be monitored by measuring the emitted radiation levels. Nuclear radiation is also used to prolong the shelf life of produce by killing bacteria and insects that would otherwise cause the food to spoil faster.

Lesson Summary

- Nuclear fission involves the splitting of large nuclei into nuclei of intermediate size. A chain reaction is self-sustaining and is used in an uncontrolled fashion in an atomic bomb.
- Nuclear power plants use controlled fission to generate electricity from the large amounts of heat produced.
- Nuclear fusion involves combining of small nuclei into larger ones, a process that releases considerably more energy than fission. Fusion powers our sun and other stars but cannot currently be harnessed directly to generate electricity.
- Ionizing radiation is capable of doing cellular damage and is detected by a Geiger counter, scintillation counter, or film badge.
- Radiation is used for various cancer treatments, as a tracer to study other processes, and as a way to prolong the shelf-life of food.

Lesson Review Questions

Reviewing Concepts

1. Explain the difference between nuclear fission and nuclear fusion.
2. What is a nuclear chain reaction, and how is it related to the concept of a critical mass?
3. What is the function of the conventional explosive in an atomic bomb?
4. Describe the purposes of control rods and moderators in a nuclear power plant.
5. Why is fusion not used to generate electrical power?
6. Why are x-rays and the radiation emitted by radioisotopes called ionizing radiation?
7. Describe two applications of radioisotopes in medicine.
8. Explain why irradiation of food helps it to last longer.

Problems

9. Explain why fusion reactions release more energy than fission reactions. (*Hint*: Use the nuclear binding energy per nucleon graph from the lesson "Nuclear Radiation.")
10. Fill in the unknown nuclides for the fission and fusion reactions shown below.
    a. ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{144}_{55}\text{Cs} + \_\_\_\_\_ + 2{}^{1}_{0}\text{n}$
    b. ${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow + \_\_\_\_\_ + {}^{1}_{0}\text{n}$

Further Reading / Supplemental Links

- Nuclear Fission, (http://www.kentchemistry.com/links/Nuclear/fission.htm
- Nuclear Fusion, (http://www.kentchemistry.com/links/Nuclear/fusion.htm
- Nuclear Power Plants, (http://www.kentchemistry.com/links/Nuclear/NuclearPP.htm
- Uses of Radioisotopes, (http://www.kentchemistry.com/links/Nuclear/radioisotopes.htm

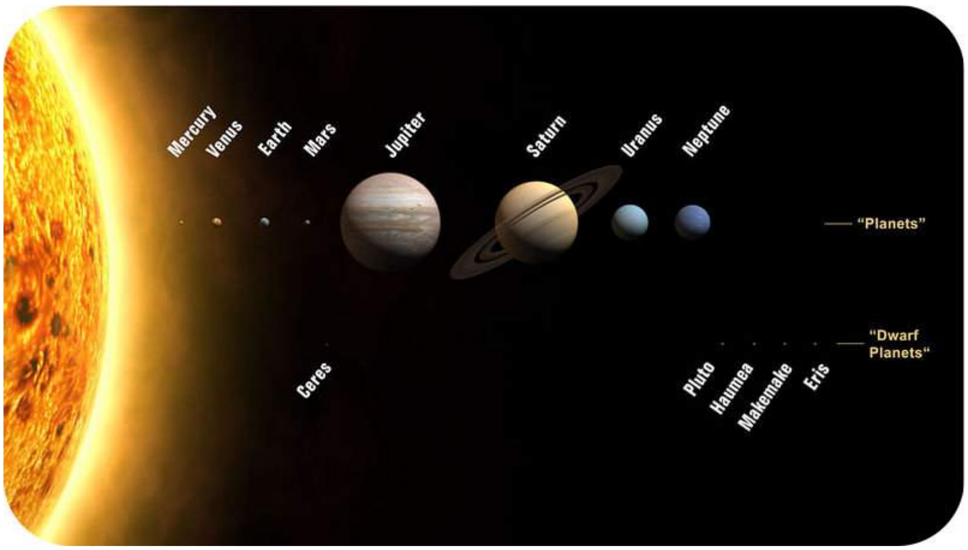
Points to Consider

Fission and fusion are promising as energy sources, but they are not without difficulties and controversy.

- Do the advantages of nuclear power justify the risk of accidents and the problems associated with the disposal of nuclear waste?
- What methods are being investigated as a way to use controlled nuclear fusion as an energy source?

3.9 Planets of the Solar System

- Define astronomical unit.
- Identify the solar system's eight planets and their characteristics, including size and length of orbit relative to Earth.



Who is in the Sun's family?

The family includes the Sun, its eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), and the five known dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris). In the image above, relative sizes of the Sun, planets, and dwarf planets and their positions relative to each other are correct, but the relative distances are not.

Eight Planets

Since the time of Copernicus, Kepler, and Galileo, we have learned a lot more about our solar system. Astronomers have discovered two more planets (Uranus and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects.

Although the Sun is just an average star compared to other stars, it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! **Table** 3.2 gives data on the sizes of the Sun and planets relative to Earth.

TABLE 3.2: Sizes of Solar System Objects Relative to Earth

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth's mass	1.00 Earth's diameter

TABLE 3.2: (continued)

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter
Neptune	17.2 Earth's mass	3.81 Earth's diameter

Orbits and Rotations

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km, or 93 million miles. **Table** 3.3 shows the distances to the planets (the average radius of orbits) in AU. The table also shows how long it takes each planet to spin on its axis (the length of a day) and how long it takes each planet to complete an orbit (the length of a year); in particular, notice how slowly Venus rotates relative to Earth.

TABLE 3.3: Distances to the Planets and Properties of Orbits Relative to Earth's Orbit

Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Mercury	0.39 AU	56.84 days	0.24 years
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

Here is a website that illustrates both the sizes of the planets, and the distance between them: http://www.scalesolarsystem.66ghz.com/#sun .

Summary

- The planets of the solar system, with increasing distance from the Sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The five known dwarf planets are Ceres, Pluto, Makemake, Haumea, and Eris.
- Solar system distances are measured as multiples of the distance between Earth and Sun, which is defined as one astronomical unit (AU).
- All planets and dwarf planets orbit the Sun and rotate on their axes.

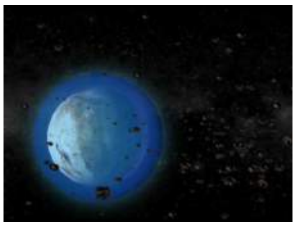
Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

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



MEDIA
Click image to the left for more content.

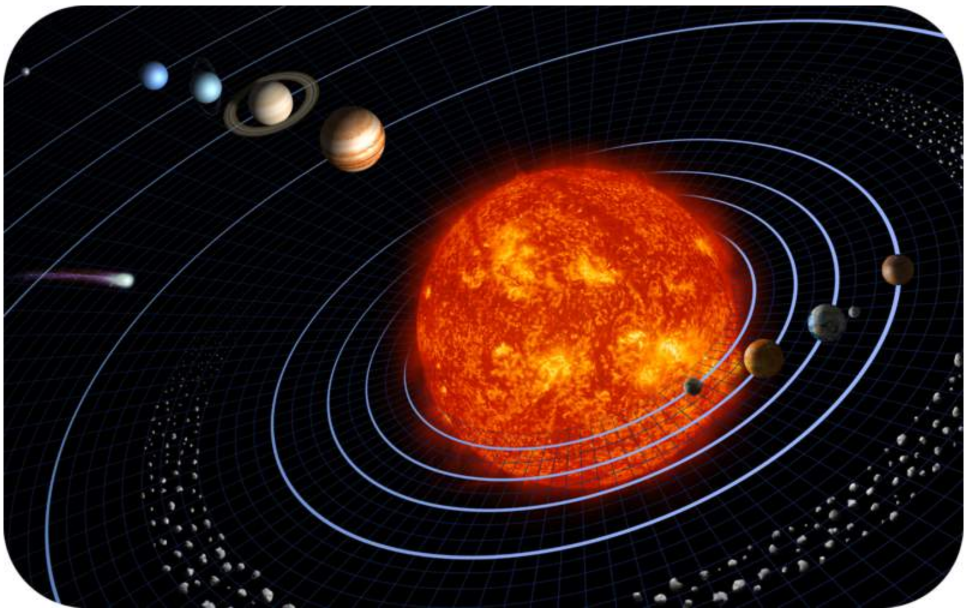
1. How old is our solar system?
2. How did the planets form?
3. What are the two main regions of the solar system?
4. List the inner planets.
5. List the outer planets.
6. What are the requirements to be a planet?
7. Why was Pluto demoted?
8. What is the Kuiper Belt?
9. What are found in the Kuiper Belt?
10. What is the scattered disk?
11. What is the heliosphere?

Review

1. Why does the number of dwarf planets recognized by astronomers in the solar system periodically increase?
2. What is the order of planets and dwarf planets by distance from the Sun?
3. What is an astronomical unit? Why is this unit used to measure distances in the solar system?

3.10 Planet Orbits in the Solar System

- Describe the size and shape of planetary orbits.



"Accordingly, since nothing prevents the earth from moving...

...I suggest that we should now consider also whether several motions suit it, so that it can be regarded as one of the planets. For, it is not the center of all the revolutions." - Nicolaus Copernicus

The Size and Shape of Orbits

Figure 3.40 shows the relative sizes of the orbits of the planets, asteroid belt, and Kuiper belt. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next. The orbits of the planets are not circular but slightly elliptical, with the Sun located at one of the foci (see opening image).

While studying the solar system, Johannes Kepler discovered the relationship between the time it takes a planet to make one complete orbit around the Sun, its "orbital period," and the distance from the Sun to the planet. If the orbital period of a planet is known, then it is possible to determine the planet's distance from the Sun. This is how astronomers without modern telescopes could determine the distances to other planets within the solar system.

How old are you on Earth? How old would you be if you lived on Jupiter? How many days is it until your birthday on Earth? How many days until your birthday if you lived on Saturn?

Scaling the solar system creates a scale to measure all objects in solar system: http://www.youtube.com/watch?v=-6szEDHMxP4 (4:44).

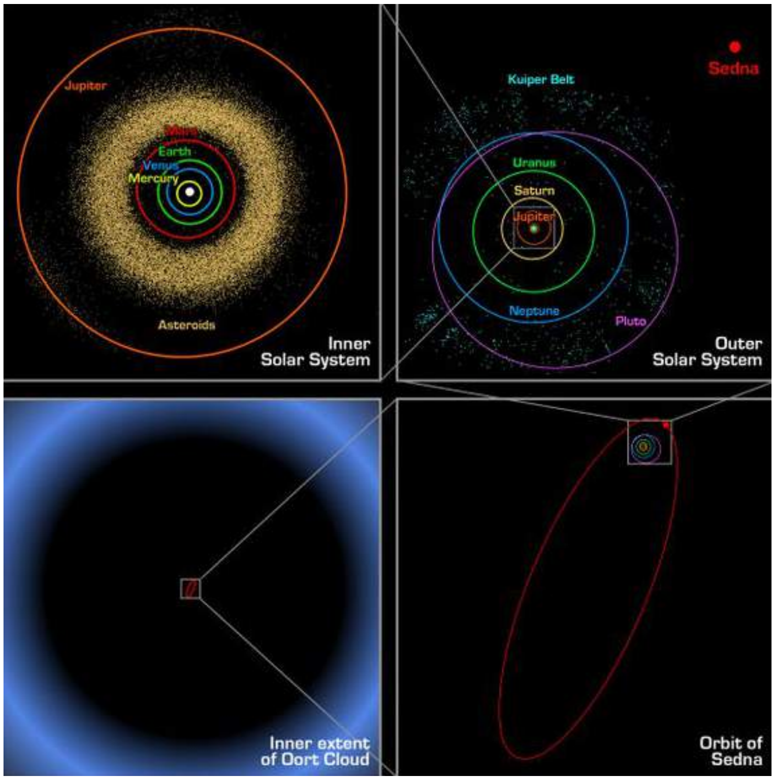


FIGURE 3.40
The relative sizes of the orbits of planets in the solar system. The inner solar system and asteroid belt is on the upper left. The upper right shows the outer planets and the Kuiper belt.

MEDIA
Click image to the left for more content.

Summary

- The eight planets orbit the Sun along slightly elliptical paths, with Sun located at one of the foci.
- Kepler discovered that by using a planet's orbital period, it is possible to determine its distance from the Sun.
- The farther the planets are from the Sun, the greater their distance from each other.

Practice

Use this resource to answer the questions that follow.

http://www.classzone.com/books/earth_science/terc/content/visualizations/es2701/es2701page01.cfm?chapter_no=visualization

1. What does this animation show?
2. Describe what you see in this animation.
3. How long would it take to travel the solar system on today's fastest spacecraft?
4. How long would the trip take at the speed of light?

5. How fast is this animation?

Review

1. When you look at the diagram of planet orbits, which planet doesn't fit the criteria of a planet?
2. How can a planet's orbital period be used to determine a its distance from the Sun?
3. Why would your age be different on a different planet?

3.11 Gravity in the Solar System

- Define Newton's Universal Law of Gravitation.
- Explain the influence of gravity on the relative positions of Earth to the Sun and the Moon.

"I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses." - Isaac Newton, in *Philosophiae Naturalis Principia Mathematica*, 1687.

The Role of Gravity

Isaac Newton first described gravity as the force that causes objects to fall to the ground and also the force that keeps the Moon circling Earth instead of flying off into space in a straight line. Newton defined the Universal Law of Gravitation, which states that a force of attraction, called **gravity**, exists between all objects in the universe (**Figure** 3.41). The strength of the gravitational force depends on how much mass the objects have and how far apart they are from each other. The greater the objects' mass, the greater the force of attraction; in addition, the greater the distance between objects, the smaller the force of attraction.

The distance between the Sun and each of its planets is very large, but the Sun and each of the planets are also very large. Gravity keeps each planet orbiting the Sun because the star and its planets are very large objects. The force of gravity also holds moons in orbit around planets.

BigThink video: Who was the greatest physicist in history? According to Neal deGrasse Tyson, it was Sir Isaac Newton: http://bigthink.com/ideas/13154 .

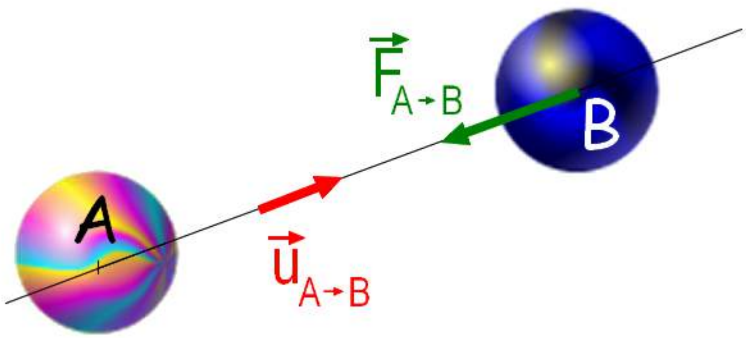


FIGURE 3.41
The force of gravity exists between all objects in the universe; the strength of the force depends on the mass of the objects and the distance between them.

Summary

- Newton developed the Universal Law of Gravitation, which recognizes the gravitational attraction between objects.
- All objects have a force of attraction between them that is proportional to their mass and distance from each other.
- Gravity keeps the planets orbiting the Sun because they are very large, just as gravity keeps satellites orbiting the planets.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=Jk5E-CrE1zg

MEDIA
Click image to the left for more content.

1. How long have the Earth and Moon existed?
2. What evidence shows that the Moon's gravity affects the Earth?
3. What does Newton's law of gravitation state?
4. What happens as mass increases?
5. What happens as distance increases?

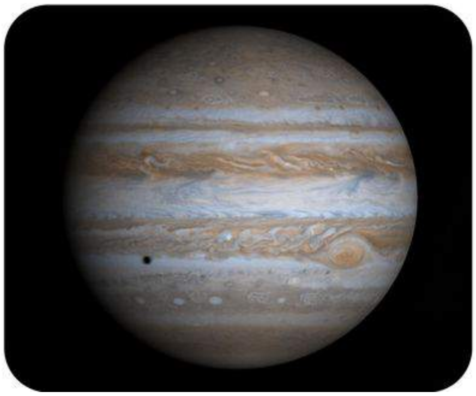
Review

1. Why is the gravitational attraction of the Moon to Earth greater than the attraction of Earth to Sun?
2. Why doesn't the Moon fly off into space? Why does an apple fall to the ground rather than orbiting Earth at a distance?

3. What is the Universal Law of Gravitation?

3.12 Revolutions of Earth

- Describe Earth's revolution around the Sun.



What kind of revolution are we talking about?

Copernicus caused a revolution. He said that Earth revolved around the Sun. With his telescope, Galileo found a lot of evidence for this. He could see moons orbiting Jupiter. If moons can orbit Jupiter, surely Earth can orbit the Sun. Yes? In the two images above, you can see Jupiter at two different times, showing moons in different places.

Earth's Revolution

Earth orbits a star. That star is our Sun. One **revolution** around the Sun takes 365.24 days. That is equal to one year. Earth stays in orbit around the Sun because of the Sun's gravity (**Figure** 3.42).

Earth's orbit is not a circle. It is a bit elliptical. So as we travel around the Sun, sometimes we are a little farther away from the Sun. Sometimes we are closer to the Sun.

Students sometimes think the slightly oval shape of our orbit causes Earth's seasons. That's not true! The seasons are due to the tilt of Earth's axis, as discussed in the previous concept.

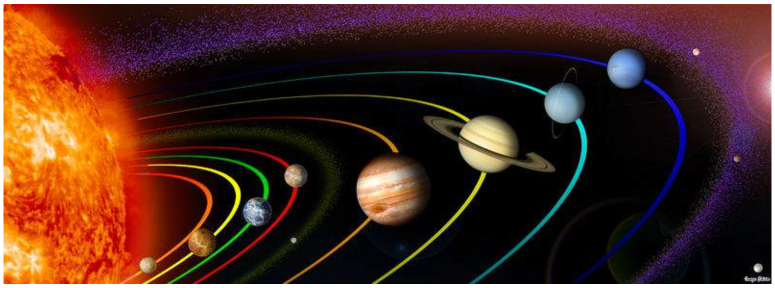


FIGURE 3.42
Earth and the other planets in the solar system make elliptical orbits around the Sun. The ellipses in this image are highly exaggerated.

The distance between the Earth and the Sun is about 93 million miles, or 150 million kilometers. Earth revolves around the Sun at an average speed of about 27 kilometers (17 miles) per second. Mercury and Venus are closer to the Sun, so they take shorter times to make one orbit. Mercury takes only about 88 Earth days to make one trip around the Sun. All of the other planets take longer amounts of time. The exact amount depends on the planet's distance from the Sun. Saturn takes more than 29 Earth years to make one revolution around the Sun. How old would you be if you were on Jupiter?

Vocabulary

- **revolution**: Earth's movement around the Sun in an orbital path.

Summary

- Earth's orbit around the Sun is somewhat elliptical.
- Earth's seasons are not caused by the shape of its orbit.
- Earth and the other planets of the solar system revolve around the Sun.

Practice

Use the resource below to answer the questions that follow.

- **How Earth Orbits Around the Sun** at

http://www.teachertube.com/viewVideo.php?video_id=6913

1. What is in the center of the solar system?
2. How long does an orbit around the Sun take?
3. Why does it look like Sun is moving around Earth?
4. What is the shape of Earth's orbit around the Sun?

Review

1. How long does it take for Earth to make one revolution around the Sun?
2. Is Earth farther from the Sun in the winter and closer in the summer? Explain.
3. Describe Earth's orbit around the Sun. Describe the orbits of the other planets.

3.13 Rotation of Earth

- Describe Earth's rotation on its axis.

What would you do if you were in Paris?

Take a view from the top of the Eiffel Tower? March up the stairs to eye the gargoyles at Notre Dame? Nibble on coffee and croissants in a sidewalk cafe? Visit Foucault's Pendulum in the Pantheon? Yes! When in Paris, don't forget to go to the Pantheon and visit this testament to Earth's rotation.

Foucault's Pendulum

In 1851, a French scientist named Léon Foucault took an iron sphere and hung it from a wire. He pulled the sphere to one side and then released it, as a pendulum. Although a pendulum set in motion should not change its motion, Foucault observed that his pendulum did seem to change direction relative to the circle below. Foucault concluded that Earth was moving underneath the pendulum. People at that time already knew that Earth rotated on its axis, but Foucault's experiment was nice confirmation.

FIGURE 3.43
Foucault's Pendulum is at the Pantheon in Paris, France.

Earth's Rotation

Imagine a line passing through the center of Earth that goes through both the North Pole and the South Pole. This imaginary line is called an **axis**. Earth spins around its axis, just as a top spins around its spindle. This spinning movement is called Earth's **rotation**.

An observer in space will see that Earth requires 23 hours, 59 minutes, and 4 seconds to make one complete rotation on its axis. But because Earth moves around the Sun at the same time that it is rotating, the planet must turn just a little bit more to reach the same place relative to the Sun. Hence the length of a day on Earth is actually 24 hours.

At the Equator, the Earth rotates at a speed of about 1,700 km per hour, but at the poles the movement speed is nearly nothing.

Day-Night Cycle

Earth rotates once on its axis about every 24 hours. To an observer looking down at the North Pole, the rotation appears counterclockwise. From nearly all points on Earth, the Sun appears to move across the sky from east to west each day. Of course, the Sun is not moving from east to west at all; Earth is rotating. The Moon and stars also seem to rise in the east and set in the west.

Earth's rotation means that there is a cycle of daylight and darkness approximately every 24 hours, the length of a day. Different places experience sunset and sunrise at different times and the amount of daylight and darkness also differs by location.

Shadows are areas where an object obstructs a light source so that darkness takes on the form of the object. On Earth, a shadow can be cast by the Sun, Moon, or (rarely) Mercury or Venus.

Summary

- Foucault's pendulum shows that Earth moves beneath a swinging pendulum.
- Earth rotates on its axis every 24 hours.
- Earth rotates so that the Sun, Moon, and stars appear to travel from east to west each day.

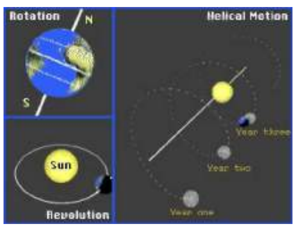
Interactive Practice

Use these resources to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. Why does the Earth spin?
2. Why has the Earth's spin slowed?
3. What will eventually happen to the Moon?



MEDIA

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4. How long does it take for the Earth to complete a rotation?
5. What direction is the Earth rotating?

Review

1. How does Foucault's pendulum show that Earth rotates on its axis?
2. Why do the Sun, Moon, and stars appear to rise in the east and set in the west each day?
3. Why does the Equator travel at a speed of 1,700 km per hour and the poles not travel at all?

3.14 The Precession of the Earth's Axis

What does this motion tell us about the Earth's motion in space? If you ever had a spinning top, you know that its axis tends to stay lined up in the same direction — usually, vertically (left figure), though in space any direction qualifies.

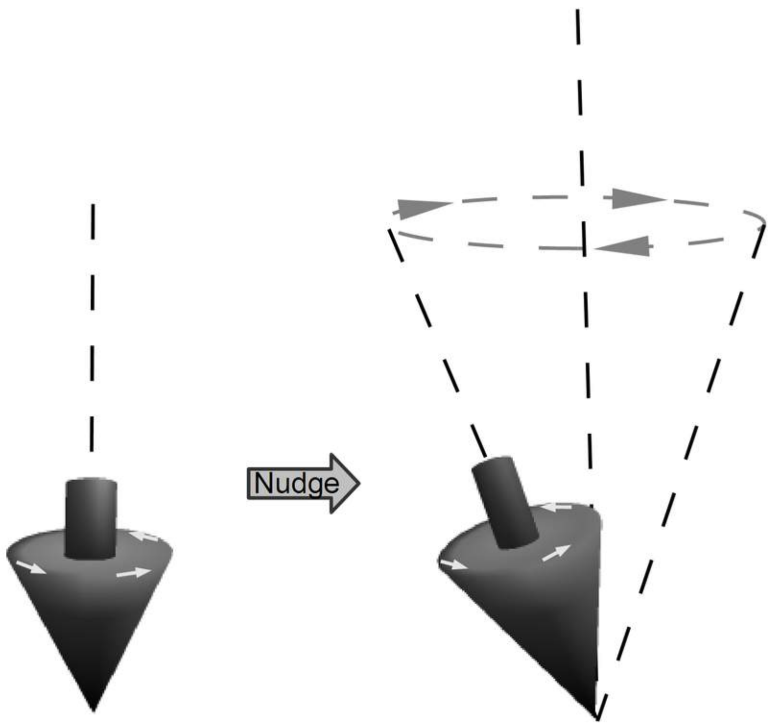


FIGURE 3.44
Precession of a spinning top: the spin axis traces the surface of a cone.

Give it a nudge, however, and the axis will start to gyrate wildly around the vertical, its motion tracing a cone (right figure). The spinning Earth moves like that, too, though the time scale is much slower — each spin lasts a day, and each gyration around the cone takes 26 000 years. The axis of the cone is perpendicular to the plane of the ecliptic.

The cause of the precession is the equatorial bulge of the Earth, caused by the centrifugal force of the Earth's rotation (the centrifugal force is discussed in a later section). That rotation changes the Earth from a perfect sphere to a slightly flattened one, thicker across the equator. The attraction of the Moon and Sun on the bulge is then the "nudge" which makes the Earth precess.

Through each 26 000-year cycle, the direction in the sky to which the axis points goes around a big circle, the radius of which covers an angle of about 23.50. The pole star to which the axis points now (within about one degree) used to be distant from the pole, and will be so again in a few thousand years (for your information, the closest approach is in 2017). Indeed, the "pole star" used by ancient Greek sailors was a different one, not nearly as close to the pole.

Because of the discovery mady by Hipparchus, the word "precession" itself no longer means "shift forward" but is now applied to any motion of a spin axis around a cone–for instance, the precession of a gyroscope in an airplane's instrument, or the precession of a spinning satellite in space.

Precession of a spinning scientific payload (also known as its "coning" — from "cone" — or its "nutation") is

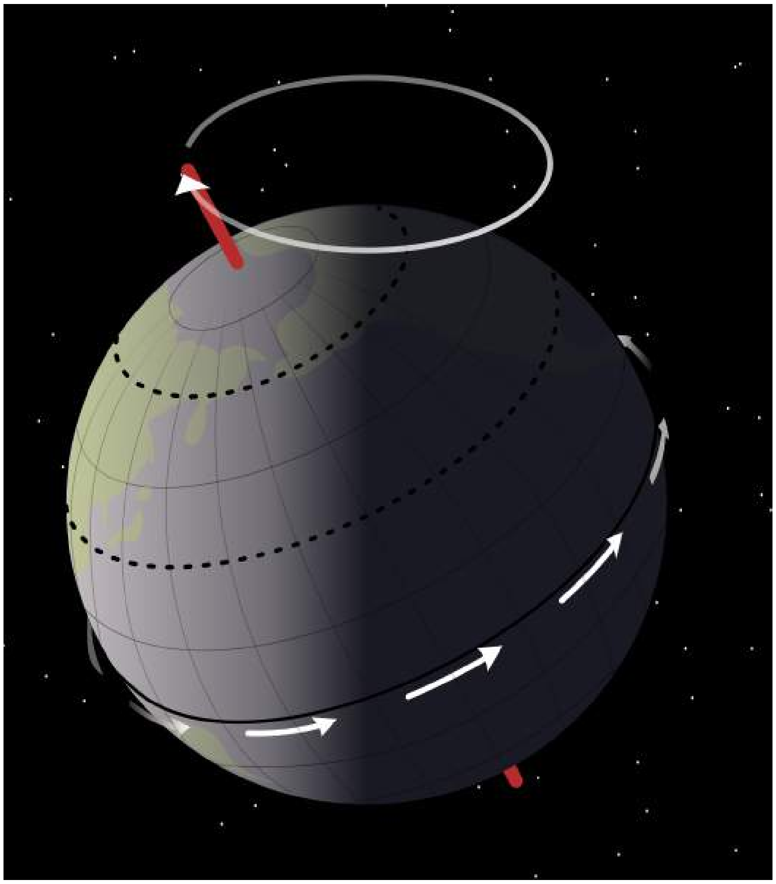


FIGURE 3.45

Precession of the Earth's axis.

an unwelcome feature, because it complicates the tracking of its instruments. To eliminate it, such satellites use "nutation dampers," small tubes partially filled with mercury. If the satellite spins as it was designed to do, the mercury merely flows to the part of the tube most distant from the spin axis, and stays there. However, if the axis of rotation precesses, the mercury sloshes back and forth in the tube. Its friction then consumes energy, and since the source of the sloshing is the precession of the spin axis, that precession (very gradually) loses energy and dies down.

Note: In the section on the calendar, we saw that the Earth's rotation is slowed down very gradually by the tides, raised by the gravity of the Moon. That process is a bit similar to the action of nutation dampers: the energy of the tides is "lost"–that is, converted to heat–when the waves caused by tides break up on the seashore, and that loss is ultimately taken away from the rotational motion (**not** the precession) of the Earth.

3.15 Seasons

- Explain why seasons occur.

Do you like the seasons?

Do you live in a place with well-defined seasons? Do you appreciate the change of the seasons, from cold and dark to hot and bright, over the months? In other words, are you happy that Earth's axis is tilted?

Earth's Seasons

A common misconception is that the Sun is closer to Earth in the summer and farther away from it during the winter. Instead, the seasons are caused by the 23.5^o tilt of Earth's axis of rotation relative to its plane of orbit around the Sun (**Figure** 3.46). **Solstice** refers to the position of the Sun when it is closest to one of the poles. At summer solstice, June 21 or 22, Earth's axis points toward the Sun and so the Sun is directly overhead at its furthest north point of the year, the Tropic of Cancer (23.5^o N).

During the summer, areas north of the Equator experience longer days and shorter nights. In the Southern Hemisphere, the Sun is as far away as it will be and so it is their winter. Locations will have longer nights and shorter days. The opposite occurs on winter solstice, which begins on December 21. More about seasons can be found in the Atmospheric Processes chapter.

Solar Radiation on Earth

Different parts of the Earth receive different amounts of solar radiation. Which part of the planet receives the most solar radiation? The Sun's rays strike the surface most directly at the Equator.

Different areas also receive different amounts of sunlight in different seasons. What causes the seasons? The seasons are caused by the direction Earth's axis is pointing relative to the Sun.

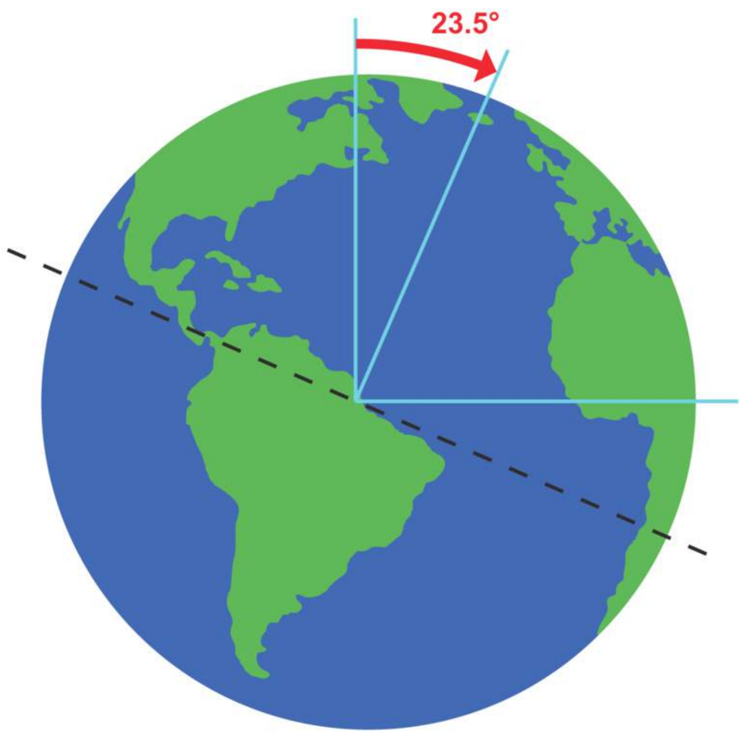


FIGURE 3.46
The Earth's tilt on its axis leads to one hemisphere facing the Sun more than the other hemisphere and gives rise to seasons.

The Earth revolves around the Sun once each year and spins on its axis of rotation once each day. This axis of rotation is tilted 23.5^o relative to its plane of orbit around the Sun. The axis of rotation is pointed toward Polaris, the North Star. As the Earth orbits the Sun, the tilt of Earth's axis stays lined up with the North Star.

Northern Hemisphere Summer

The North Pole is tilted towards the Sun and the Sun's rays strike the Northern Hemisphere more directly in summer (**Figure** 3.47). At the summer solstice, June 21 or 22, the Sun's rays hit the Earth most directly along the Tropic of Cancer (23.5^oN); that is, the angle of incidence of the Sun's rays there is zero (the angle of incidence is the deviation in the angle of an incoming ray from straight on). When it is summer solstice in the Northern Hemisphere, it is winter solstice in the Southern Hemisphere.

Northern Hemisphere Winter

Winter solstice for the Northern Hemisphere happens on December 21 or 22. The tilt of Earth's axis points away from the Sun (**Figure** 3.48). Light from the Sun is spread out over a larger area, so that area isn't heated as much. With fewer daylight hours in winter, there is also less time for the Sun to warm the area. When it is winter in the Northern Hemisphere, it is summer in the Southern Hemisphere.

An animation of the seasons from the University of Illinois is seen here: http://projects.astro.illinois.edu/data/Seasons/seasons.html . Notice the area of solar radiation, or insolation, in the lower right of the screen.

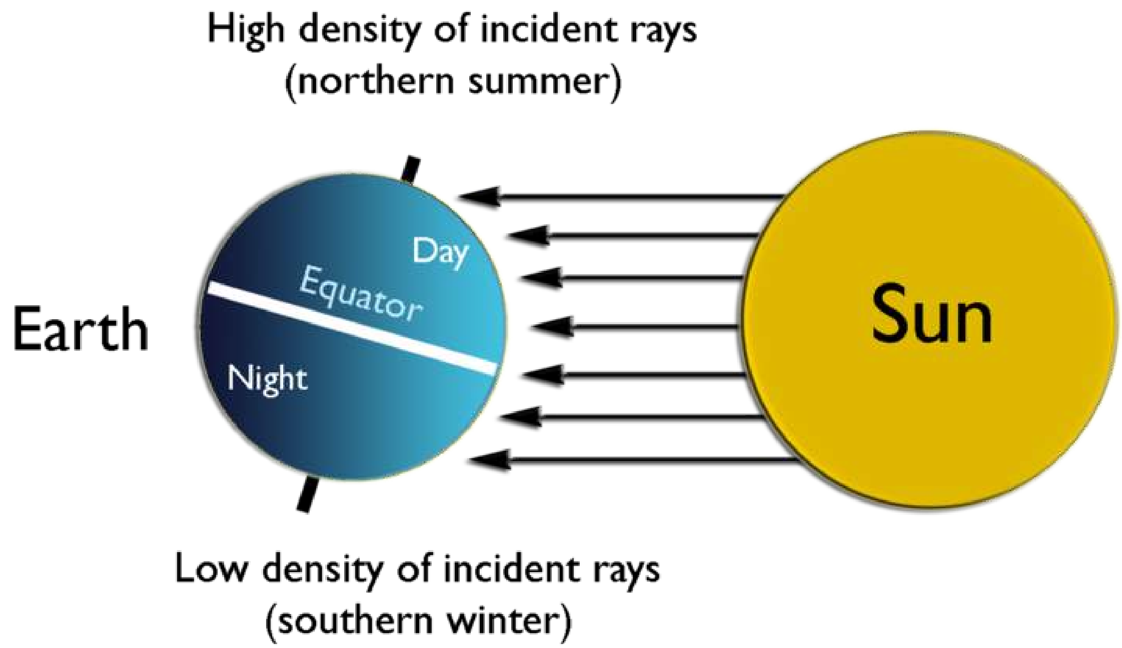


FIGURE 3.47
Summer solstice in the Northern Hemisphere.

Equinox

Halfway between the two solstices, the Sun's rays shine most directly at the Equator, called an **equinox** (**Figure** 3.49). The daylight and nighttime hours are exactly equal on an equinox. The autumnal equinox happens on September 22 or 23 and the vernal, or spring, equinox happens March 21 or 22 in the Northern Hemisphere.

Summary

- In the Northern Hemisphere, at summer solstice the Sun is closest to the north pole (around June 22) and at winter solstice, the Sun is closest to the south pole (around December 22). In the Southern Hemisphere, the names are changed.
- Over the course of a year, the amount of solar energy received by the Equator is greater than the amount received elsewhere.
- At equinox the Sun is directly over the Equator; autumnal equinox is around September 22 and spring equinox is around March 22 in the Northern Hemisphere.

Practice

Use these resources to answer the questions that follow.

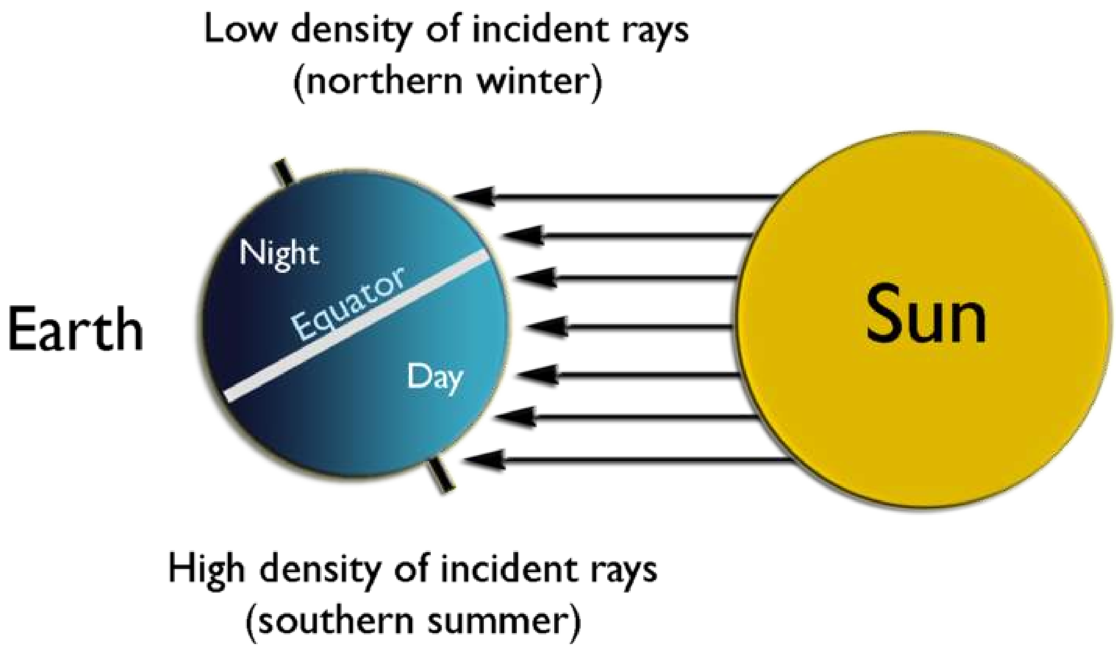
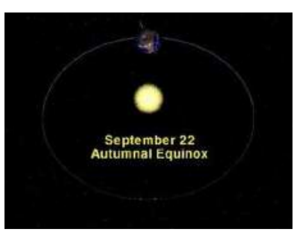


FIGURE 3.48
In Southern Hemisphere summer, the Sun's rays directly strike the Tropic of Capricorn (23.5^{o}S). Sunlight is spread across a large area near the South Pole. No sunlight reaches the North Pole.



MEDIA
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1. What causes Earth's seasons?
2. What is the longest day of the year in the Northern Hemisphere?
3. What occurs at the equinoxes?
4. What happens during the winter solstice?
5. When is summer in the Southern Hemisphere?

http://www.learner.org/jnorth/tm/mclass/eclipticsimulator.swf

6. Place the observer on the Tropic of Capricorn and run the animation. When does the observer get the most direct sunlight (90 degree angle)?

7. Place the observer in the Arctic Circle and run the simulation. Explain what occurs for the observer over the year.

8. Place the observer close to your present latitude and run the simulation. Explain what the observer experiences over a year.

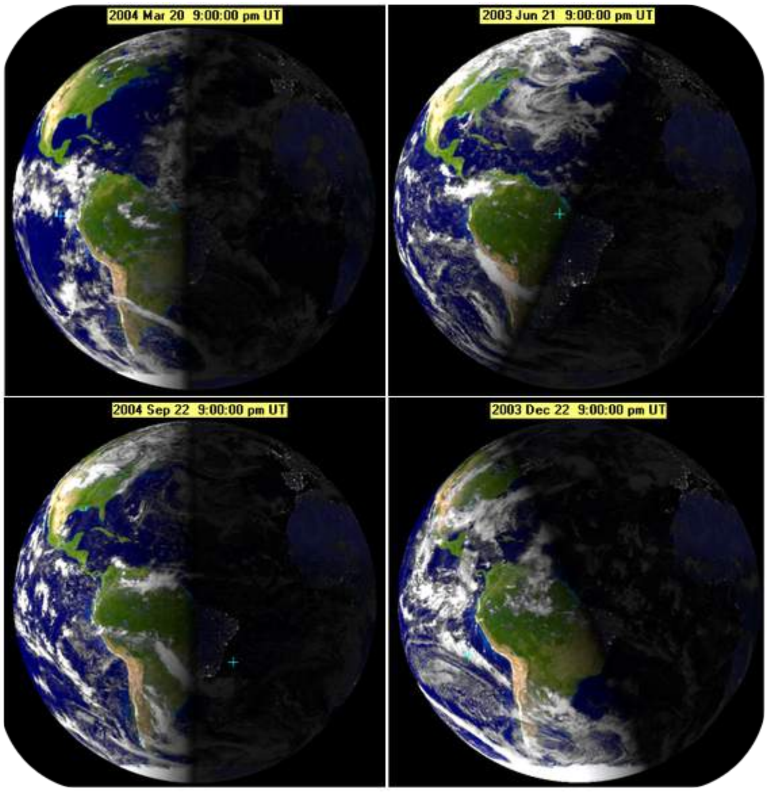


FIGURE 3.49
Where sunlight reaches on spring equinox, summer solstice, vernal equinox, and winter solstice. The time is 9:00 p.m. Universal Time, at Greenwich, England.

Review

1. At summer solstice in the Northern Hemisphere, what is the date and where is the Sun? What is happening in the Southern Hemisphere at that time?

2. Since the Sun is up for months during the summer at the north pole, why is it that the Equator actually gets the most solar radiation over the course of a year?

3. What are equinoxes and when do they come?

3.16 Earth's Shape

- Describe Earth's shape and explain how Earth's shape is related to its mass.

Before spacecraft, how did people know that Earth is spherical?

The ancient Greeks knew that Earth was round by observing the arc shape of the shadow on the Moon during a lunar eclipse. Was there other evidence of Earth's roundness available to people before spacecraft gave us a bird's eye view?

Earth's Shape

Earth is a sphere or, more correctly, an oblate spheroid, which is a sphere that is a bit squished down at the poles and bulges a bit at the Equator. To be more technical, the minor axis (the diameter through the poles) is smaller than the major axis (the diameter through the Equator). Half of the sphere is a **hemisphere**. North of the Equator is the northern hemisphere and south of the Equator is the southern hemisphere. Eastern and western hemispheres are also designated.

What evidence is there that Earth is spherical? What evidence was there before spaceships and satellites?

Try to design an experiment involving a ship and the ocean to show Earth is round. If you are standing on the shore and a ship is going out to sea, the ship gets smaller as it moves further away from you. The ship's bottom also starts to disappear as the vessel goes around the arc of the planet (**Figure** 3.50). There are many other ways that early scientists and mariners knew that Earth was not flat. Here is a summary of some: http://www.physlink.com/education/askexperts/ae535.cfm .

The Sun and the other planets of the solar system are also spherical. Larger satellites, those that have enough mass for their gravitational attraction to have made them round, are spherical as well.

Summary

- Ancient Greeks knew that Earth was round because of the shadow the planet cast on the Moon during a lunar eclipse.
- A boat does not get smaller with distance but sinks below the horizon - more evidence for Earth's roundness.
- Earth is divided into hemispheres: northern, southern, eastern, and western.

FIGURE 3.50
Earth's curvature is noticeable when objects at a distance are below the arc.

Interactive Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What was the first photo of Earth? What did it prove?
2. Why are bodies in space round?
3. How did the planets form?
4. What is the only shape in nature that looks the same from all directions?
5. Why are there odd-shaped objects in space?

Review

1. Describe where you live in terms of hemispheres.
2. If you met up with someone who claimed that Earth is flat, what evidence would you present to them that their assertion is not true?
3. What evidence do you have that our planet is flat? Which of these ideas do you believe and why?

3.17 Earth as a Magnet

- Describe how Earth is a magnet.
- Distinguish between Earth's geographic and magnetic poles.
- Describe the magnetosphere.

Did you ever use a compass like the one in this picture? Even if you've never used a compass, you probably know that the needle of a compass always points north. That's because a compass needle is magnetized, so it is attracted by a magnet.

Q: What magnet attracts a compass needle?

A: A compass needle is attracted by magnet Earth. It always points north because Earth acts as a giant magnet.

Earth's Magnetic Poles

Imagine a huge bar magnet passing through Earth's axis, as in the **Figure** 3.51. This is a good representation of Earth as a magnet. Like a bar magnet, Earth has north and south magnetic poles. A **magnetic pole** is the north or south end of a magnet, where the magnet exerts the most force.

Two North Poles

Although the needle of a compass always points north, it doesn't point to Earth's north geographic pole. Find the north geographic pole in the **Figure** 3.52. As you can see, it is located at 90° north latitude. Where does a compass

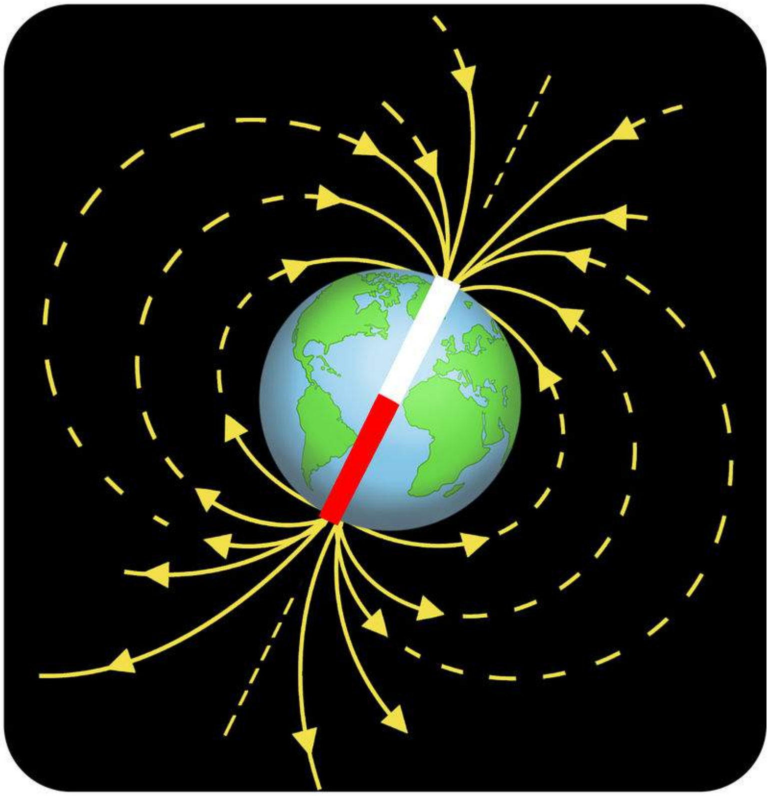


FIGURE 3.51

needle point instead? It points to Earth's north magnetic pole, which is located at about 80° north latitude. Earth also has two south poles: a south geographic pole and a south magnetic pole.

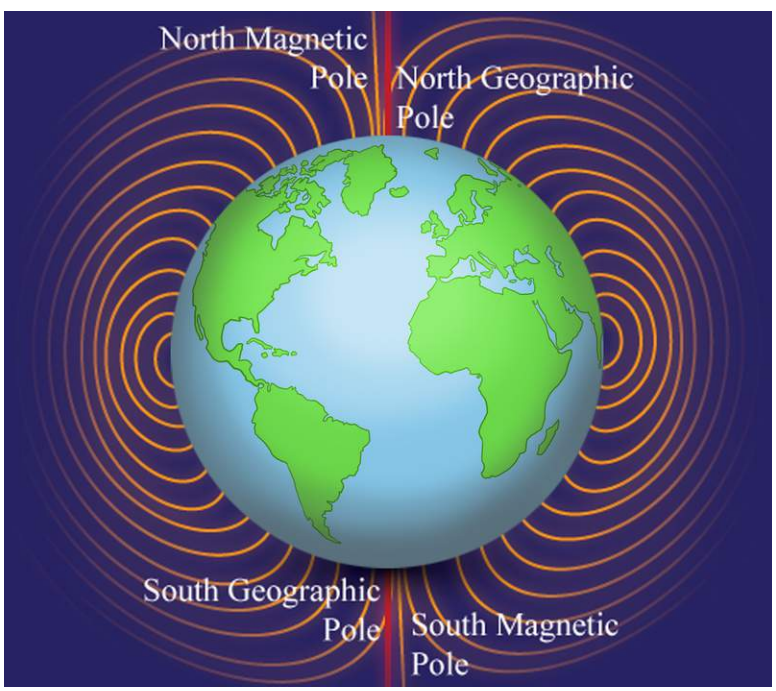


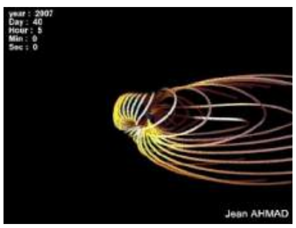
FIGURE 3.52

Q: The north end of a compass needle points toward Earth's north magnetic pole. The like poles of two magnets repel each other, and the opposite poles attract. So why doesn't the north end of a compass needle point to Earth's south magnetic pole instead?

A: The answer may surprise you. The compass needle actually does point to the south pole of magnet Earth. However, it is called the north magnetic pole because it is close to the north geographic pole. This naming convention was adopted a long time ago to avoid confusion.

Earth's Magnetic Field

Like all magnets, Earth has a magnetic field. Earth's magnetic field is called the **magnetosphere**. You can see a model of the magnetosphere in the **Figure** 3.53. It is a huge region that extends outward from Earth in all directions. Earth exerts magnetic force over the entire field, but the force is strongest at the poles, where lines of force converge. For an animated model of the magnetosphere, watch this video: http://www.youtube.com/watch?v=5SXgOWYyn84 .



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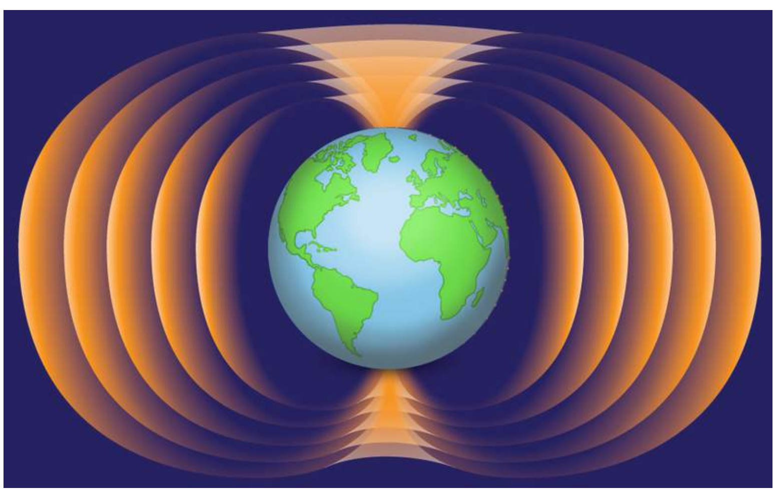

FIGURE 3.53

Summary

- Earth acts as a giant magnet with magnetic poles and a magnetic field over which it exerts magnetic force.
- Earth has north and south magnetic poles like a bar magnet. Earth's magnetic poles are not the same as the geographic poles.
- Earth's magnetic field is called the magnetosphere. It is strongest at the poles.

Vocabulary

- **magnetic pole**: North or south end of a magnet where the magnet exerts the most force.

- **magnetosphere**: Region surrounding Earth that is affected by Earth's magnetic force; name for Earth's magnetic field.

Practice

At the following URL, use the simulation to explore Earth's magnetic field. Then write a paragraph to describe your observations. http://www.windows2universe.org/physical_science/magnetism/earth_magnet_dipole_interactive.html

Review

1. How does Earth act as a bar magnet?
2. The compass in a car shows that the car is moving north. Does this mean that the car is moving toward 90° north latitude? Why or why not?
3. Describe the magnetosphere.

3.18 Moon

- Describe the characteristics of Earth's Moon.

That's one small step for [a] man, one giant leap for mankind. —Neil Armstrong

On July 20, 1969, hundreds of millions of people all over the world witnessed something incredible. Never before had a human being walked on a planetary body other than Earth. But on that day, Neil Armstrong and Buzz Aldrin walked on the Moon. The footprints the men left behind are the first signs of life ever on the Moon. Scientists have learned a great deal about the Moon from the Apollo missions and from rovers and satellites sent to the Moon for study.

Lunar Characteristics

The Moon is Earth's only natural satellite, a body that moves around a larger body in space. The Moon orbits Earth for the same reason Earth orbits the Sun —gravity. The Moon is 3,476 km in diameter, about one-fourth the size of Earth. The satellite is also not as dense as the Earth; gravity on the Moon is only one-sixth as strong as it is on Earth. An astronaut can jump six times as high on the Moon as on Earth!

The Moon makes one complete orbit around the Earth every 27.3 days. The Moon also rotates on its axis once every 27.3 days. Do you know what this means? The same side of the Moon always faces Earth, so that side of the Moon is what we always see in the night sky (**Figure** 3.54). The Moon makes no light of its own, but instead only reflects light from the Sun.

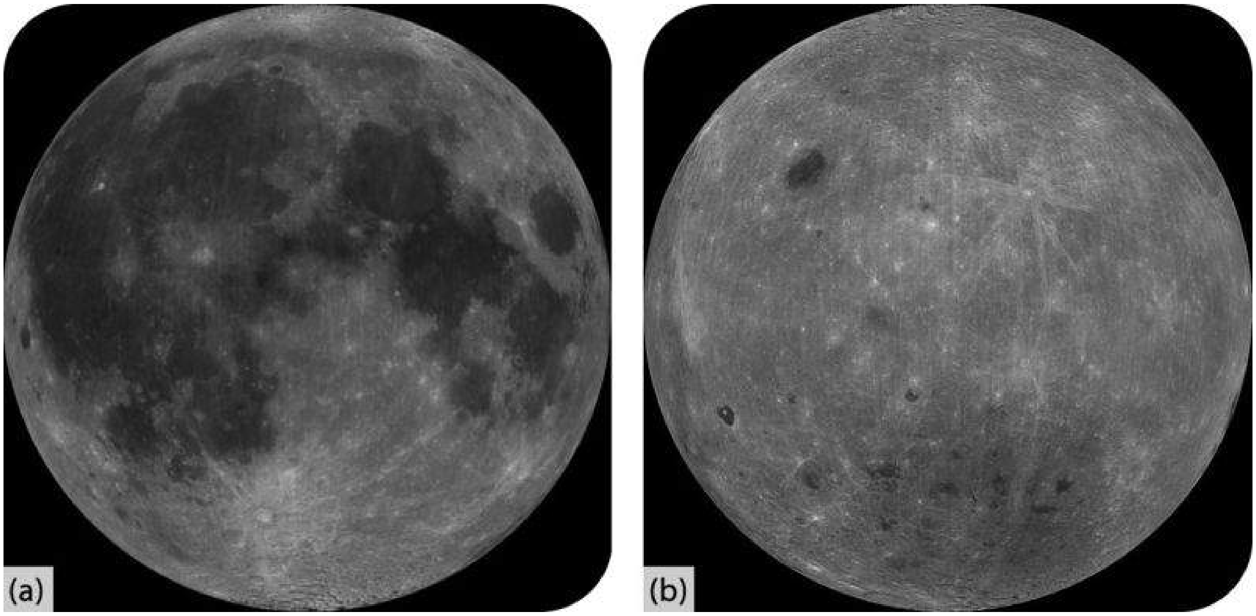

FIGURE 3.54

(a) The near side of the Moon faces Earth continually. It has a thinner crust with many more maria (flat areas of basaltic rock). (b) The far side of the Moon has only been seen by spacecraft. It has a thicker crust and far fewer maria (flat areas of basaltic rock).

The Lunar Surface

The Moon has no atmosphere. Since an atmosphere moderates temperature, the Moon's average surface temperature during the day is approximately 225°F, but drops to -243°F at night. The coldest temperatures, around -397°F, occur in craters in the permanently shaded south polar basin. These are among the coldest temperatures recorded in the entire solar system.

Earth's landscape is extremely varied, with mountains, valleys, plains and hills. This landscape is always changing as plate tectonics builds new features and weathering and erosion destroys them. The landscape of the Moon is very different. With no plate tectonics, features are not built. With no atmosphere, features are not destroyed. Still, the Moon has a unique surface. **Lunar** surface features include the bowl-shaped **craters** that are caused by meteorite impacts (**Figure** 3.55). If Earth did not have plate tectonics or erosion, its surface would also be covered with meteorite craters.

Even from Earth, the Moon has visible dark areas and light areas. The dark areas are called **maria**, which means "seas" because that's what the ancients thought they were. In fact, the maria are not water but solid, flat areas of basaltic lava. From about 3.0 to 3.5 billion years ago the Moon was continually bombarded by meteorites. Some of these meteorites were so large that they broke through the Moon's newly formed surface. Then, magma flowed out and filled the craters. Scientists estimate volcanic activity on the Moon ceased about 1.2 billion years ago, but most occurred long before that.

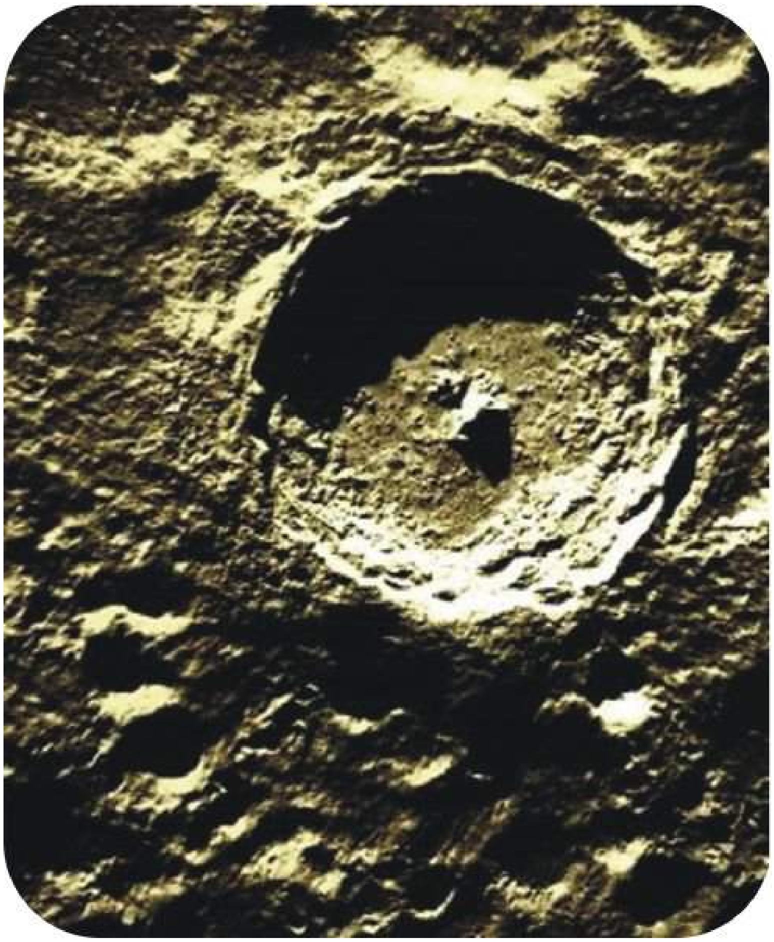

FIGURE 3.55
A crater on the surface of the Moon.

The lighter parts of the Moon are called **terrae** or highlands (**Figure** 3.56). The terrae are higher than the maria and include several high mountain ranges. The terrae are the light silicate minerals that precipitated out of the ancient magma ocean and formed the early lunar crust.

There are no lakes, rivers, or even small puddles anywhere to be found on the Moon's surface, but water in the form of ice has been found in the extremely cold craters and bound up in the lunar soil. Despite the possible presence of water, the lack of an atmosphere and the extreme temperatures make it no surprise to scientists that the Moon has absolutely no evidence of life.

Life from Earth has visited the Moon and there are footprints of astronauts on the lunar surface. With no wind, rain, or living thing to disturb them, these footprints will remain as long as the Moon exists. Only an impact with a meteorite could destroy them.

Interior of the Moon

Like Earth, the Moon has a distinct crust, mantle, and core. What is known about the Moon's interior was determined from the analysis of rock samples gathered by astronauts and from unmanned spacecraft sent to the Moon (**Figure** 3.57).

- The Moon's small core, 600 to 800 kilometers in diameter, is mostly iron with some sulfur and nickel.

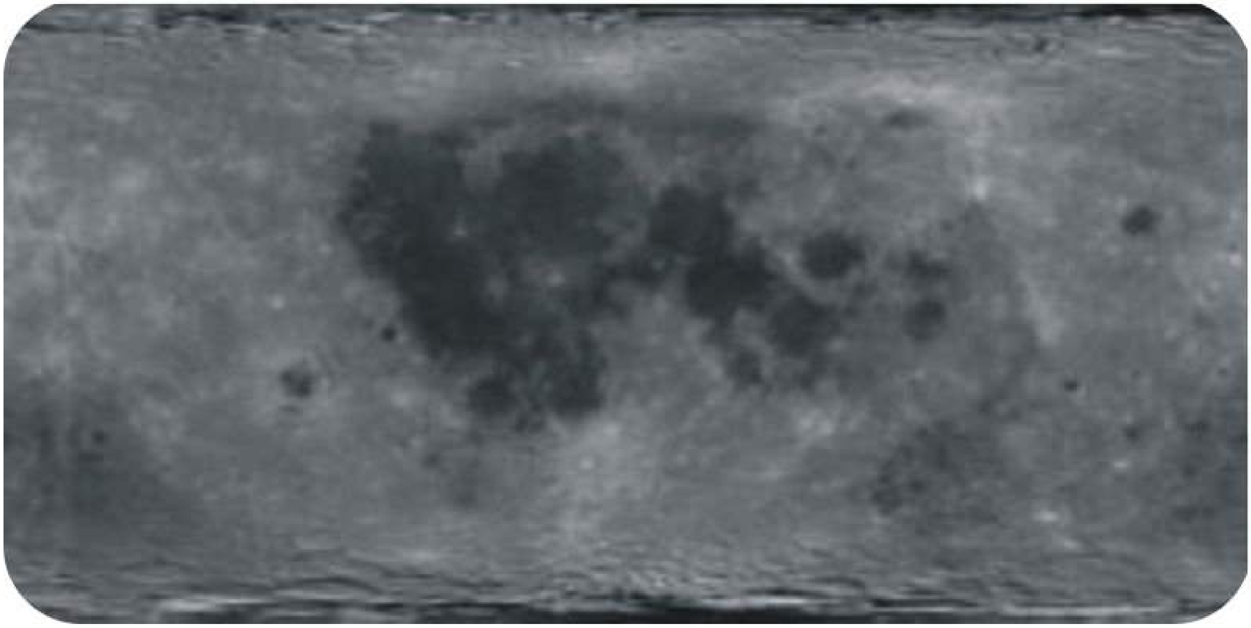

FIGURE 3.56
A close-up of the Moon, showing maria (the dark areas) and terrae (the light areas); maria covers around 16% of the Moon's surface, mostly on the side of the Moon we see.

FIGURE 3.57
The Moon's internal structure shows a small metallic core (yellow), a primitive mantle (orange), a depleted mantle (blue), and a crust (gray).

- The mantle is composed of the minerals olivine and orthopyroxene. Analysis of Moon rocks indicates that there may also be high levels of iron and titanium in the lunar mantle.
- The crust is composed of igneous rock rich in the elements oxygen, silicon, magnesium, and aluminum. The crust is about 60 km thick on the near side of the Moon and about 100 km thick on the far side.

LCROSS crashed into the Moon in May 2009. This QUEST video describes the mission. After watching, look up the mission to see what they found!

Watch it at http://science.kqed.org/quest/video/nasa-ames-rocket-to-the-moon/ .

MEDIA
Click image to the left for more content.

Summary

- The Moon revolves around Earth as they orbit the Sun; the same side of Moon always faces Earth.
- The lunar surface has dark basalt maria and light highlands called terrae.
- The Moon has a crust, mantle, and core, but no water or atmosphere.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is the Moon?
2. How far is the Moon from the Earth?
3. What did Galileo prove about the Moon?
4. Where did the Moon come from?

5. What is happening to the Moon?
6. Why do we always see the same side of the Moon?
7. Describe the Moon's structure.
8. What are maria?
9. What are terra?
10. What created the craters on the Moon?
11. What is the gravity on the Moon?
12. What is in an eclipse?
13. What is a lunar eclipse?
14. What is a solar eclipse?
15. Why is the Moon unique?
16. Who was the first person the Moon?

For additional information go to: https://www.windows2universe.org/earth/moons_and_rings.html .

Review

1. Explain why one side of the Moon always faces toward Earth and the other side always faces away from Earth.
2. How did the Moon's terrae form?
3. What is significant about the Moon's core?

3.19 Formation of the Moon

- Moon's birth story accounts for its amazing features.

Why is this called the Genesis Rock?

The Genesis Rock was brought from the Moon to Earth by Apollo 15 astronauts. The rock is only 100 million years younger than the solar system and comes from the Moon's original crust.

How the Moon Formed

One of the most unique features of planet Earth is its large Moon. Unlike the only other natural satellites orbiting an inner planet, those of Mars, the Moon is not a captured asteroid. Understanding the Moon's birth and early history reveals a great deal about Earth's early days.

Features of the Moon

To determine how the Moon formed, scientists had to account for several lines of evidence:

- The Moon is large; not much smaller than the smallest planet, Mercury.

- Earth and Moon are very similar in composition.
- Moon's surface is 4.5 billion years old, about the same as the age of the solar system.
- For a body its size and distance from the Sun, the Moon has very little core; Earth has a fairly large core.
- The oxygen isotope ratios of Earth and Moon indicate that they originated in the same part of the solar system.
- Earth has a faster spin than it should have for a planet of its size and distance from the Sun.

Can you devise a "birth story" for the Moon that takes all of these bits of data into account?

Moon's Birth Story

Astronomers have carried out computer simulations that are consistent with these facts and have detailed a birth story for the Moon. A little more than 4.5 billion years ago, roughly 70 million years after Earth formed, planetary bodies were being pummeled by asteroids and planetoids of all kinds. Earth was struck by a Mars-sized asteroid (**Figure** 3.58).

FIGURE 3.58
An artist's depiction of the impact that produced the Moon.

The tremendous energy from the impact melted both bodies. The molten material mixed up. The dense metals remained on Earth but some of the molten, rocky material was flung into an orbit around Earth. It eventually accreted into a single body, the Moon. Since both planetary bodies were molten, material could differentiate out of the magma ocean into core, mantle, and crust as they cooled. Earth's fast spin is from energy imparted to it by the impact.

Moon Rocks

Lunar rocks reveal an enormous amount about Earth's early days. The Genesis Rock, with a date of 4.5 billion years, is only about 100 million years younger than the solar system (see opening image). The rock is a piece of the Moon's anorthosite crust, which was the original crust. Why do you think Moon rocks contain information that is not available from Earth's own materials?

More information about the Genesis Rock from NASA is found here: http://www.nasa.gov/mission_pages/LRO/news/image_release042310.html .

Can you find how all of the evidence presented in the bullet points above is present in the Moon's birth story?

Summary

- The scientific explanation for how the Moon formed must take into account its features, such as its large size, internal structure, chemical composition, and spin.
- Earth was struck by a giant asteroid that melted the planet and asteroid and flung material into orbit where it coalesced and cooled to become the Moon.
- Moon's original crust is anorthosite, a feldspar-rich, light rock.

Practice

Use this resource to answer the questions that follow.

http://www.space.com/9926-moon-life.html

1. What is the mass of the Moon?
2. Why is our Moon unique?
3. What is the Moon made of?
4. What created the Moon?
5. How did the Earth maintain its integrity?
6. Why were the tides important to life on Earth?

Review

1. Relay the story of how the Moon formed. Integrate as many of the Moon's features into the story as possible.
2. Why are Earth and Moon roughly the same age as the rest of the solar system?
3. Why do scientists learn a lot about the early Earth from their studies of the Moon?

3.20 Eclipses

- Describe the types of eclipses and explain why eclipses occur.

If science weren't around to tell you what it is, would an eclipse scare you?

Ancient people could not predict eclipses and didn't know when one would end or even that it would end. Rituals to persuade the Sun or Moon to return to its normal state were developed. And they worked! The heavens always return to normal after an eclipse.

Solar Eclipses

A **solar eclipse** occurs when the new Moon passes directly between the Earth and the Sun (**Figure** 3.59). This casts a shadow on the Earth and blocks Earth's view of the Sun.

A total solar eclipse occurs when the Moon's shadow completely blocks the Sun (**Figure** 3.60). When only a portion of the Sun is out of view, it is called a partial solar eclipse.

Solar eclipses are rare and usually only last a few minutes because the Moon casts only a small shadow (**Figure** 3.61).

A BBC video of a solar eclipse is seen here: http://www.youtube.com/watch?v=eOvWioz4PoQ .

As the Sun is covered by the Moon's shadow, it will actually get cooler outside. Birds may begin to sing, and stars will become visible in the sky. During a solar eclipse, the corona and solar prominences can be seen.

A solar eclipse occurs when the Moon passes between Earth and the Sun in such a way that the Sun is either partially or totally hidden from view. Some people, including some scientists, chase eclipses all over the world to learn or just observe this amazing phenomenon.

See more at http://www.kqed.org/quest/television/eclipse-chasers .

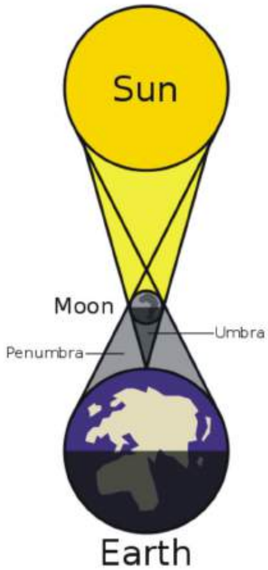

FIGURE 3.59

A solar eclipse, not to scale.

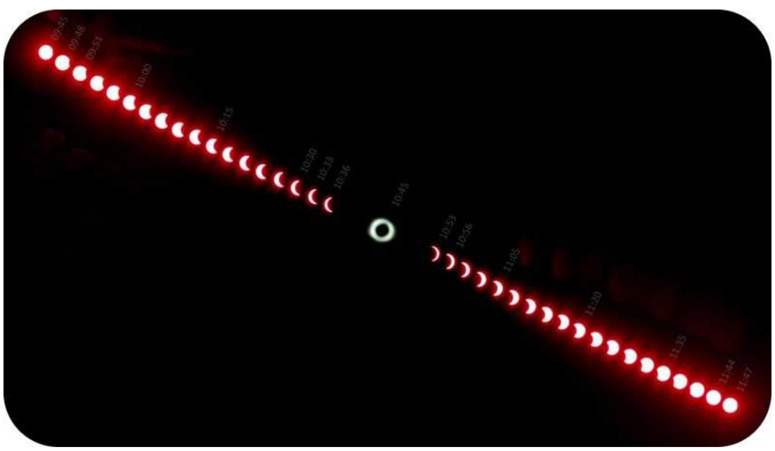

FIGURE 3.60

A solar eclipse shown as a series of photos.

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Lunar Eclipse

A **lunar eclipse** occurs when the full moon moves through Earth's shadow, which only happens when Earth is between the Moon and the Sun and all three are lined up in the same plane, called the ecliptic (**Figure** 3.62). In an eclipse, Earth's shadow has two distinct parts: the **umbra** and the **penumbra**. The umbra is the inner, cone-shaped part of the shadow, in which all of the light has been blocked. The penumbra is the outer part of Earth's shadow where only part of the light is blocked. In the penumbra, the light is dimmed but not totally absent.

FIGURE 3.61
The Moon's shadow in a solar eclipse covers a very small area.

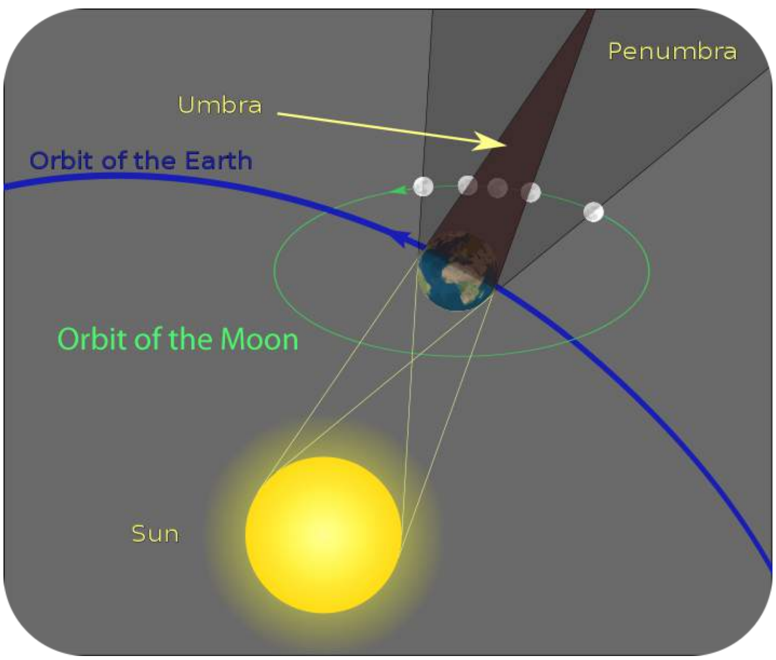

FIGURE 3.62
A lunar eclipse.

A total lunar eclipse occurs when the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. Earth's shadow is large enough that a lunar eclipse lasts for hours and can be seen by any part of Earth with a view of the Moon at the time of the eclipse (**Figure** 3.63). A lunar eclipse does not occur every month because Moon's orbit is inclined 5-degrees to Earth's orbit, so the two bodies are not in the same plane every month.

The Moon glows with a dull red coloring during a total lunar eclipse, which you can see in this video of a lunar eclipse over Hawaii: http://www.youtube.com/watch?v=2dk–lPAi04 .

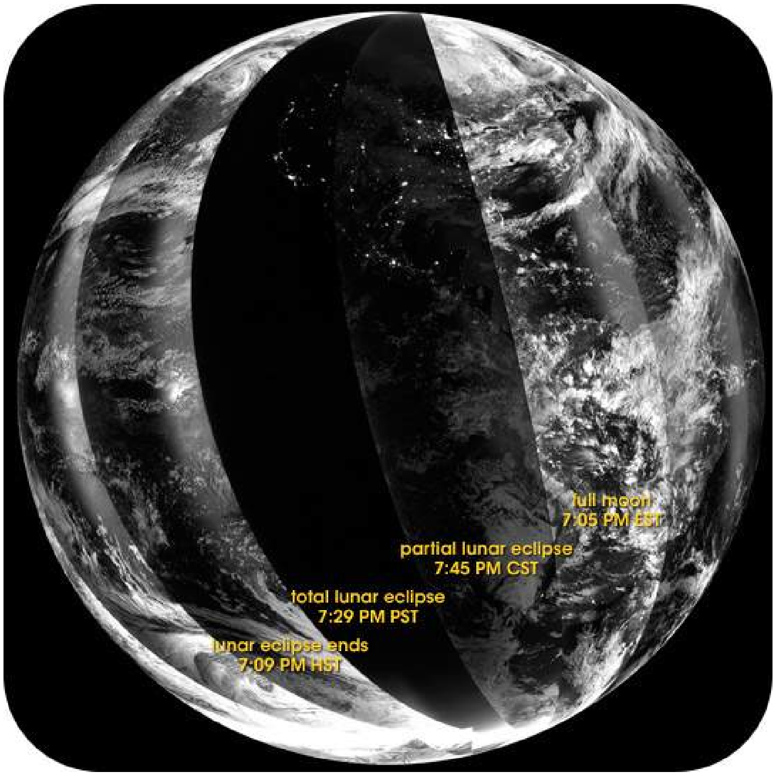

FIGURE 3.63
Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common.

Summary

- During a solar eclipse, the new Moon passes between Earth and Sun.
- During a lunar eclipse, the full Moon moves through Earth's shadow.
- The umbra is the part of the shadow in which light is completely blocked and the penumbra is the part of the shadow that is partially lit.

Practice

Use these resources to answer the questions that follow.

http://www.teachersdomain.org/asset/ess05_vid_totaleclipse/

1. Why do the Moon and Sun seem to be the same size from Earth?
2. What causes a solar eclipse?
3. What is first contact?
4. What can be seen at totality?
5. How often do solar eclipses occur?

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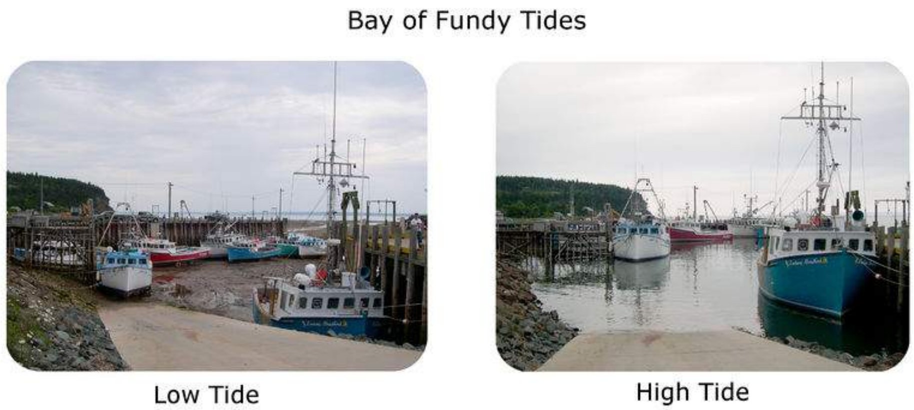
6. What are the phases of the Moon?
7. How often do lunar eclipses occur?
8. Describe a lunar eclipse.
9. What is the penumbra?
10. What is the umbra?
11. How long does a lunar eclipse last?

Review

1. What happens during a solar eclipse?
2. What happens during a lunar eclipse?
3. Why do we not see lunar eclipses every month?

3.21 Tides

- Define tides.
- Describe types of tides.
- Explain why tides occur.



How could a tide be so extreme?

These two photos show high tide (left) and low tide (right) at Bay of Fundy on the Gulf of Maine. The Bay of Fundy has the greatest tidal ranges on Earth at 38.4 feet. Why is this tidal range so extreme? Why aren't all tidal ranges so great? Tidal range depends on many factors, including the slope of the continental margin.

The Tides

Tides are the daily rise and fall of sea level at any given place. The pull of the Moon's gravity on Earth is the primary cause of tides and the pull of the Sun's gravity on Earth is the secondary cause (**Figure** 6.20). The Moon has a greater effect because, although it is much smaller than the Sun, it is much closer. The Moon's pull is about twice that of the Sun's.

To understand the tides it is easiest to start with the effect of the Moon on Earth. As the Moon revolves around our planet, its gravity pulls Earth toward it. The lithosphere is unable to move much, but the water is pulled by the gravity and a bulge is created. This bulge is the high tide beneath the Moon. On the other side of the Earth, a high tide is produced where the Moon's pull is weakest. These two water bulges on opposite sides of the Earth aligned with the Moon are the **high tides**. The places directly in between the high tides are **low tides**. As the Earth rotates beneath the Moon, a single spot will experience two high tides and two low tides approximately every day.

High tides occur about every 12 hours and 25 minutes. The reason is that the Moon takes 24 hours and 50 minutes to rotate once around the Earth, so the Moon is over the same location every 24 hours and 50 minutes. Since high tides occur twice a day, one arrives each 12 hours and 25 minutes. What is the time between a high tide and the next low tide?

The gravity of the Sun also pulls Earth's water towards it and causes its own tides. Because the Sun is so far away, its pull is smaller than the Moon's.

Some coastal areas do not follow this pattern at all. These coastal areas may have one high and one low tide per day or a different amount of time between two high tides. These differences are often because of local conditions, such as the shape of the coastline that the tide is entering.

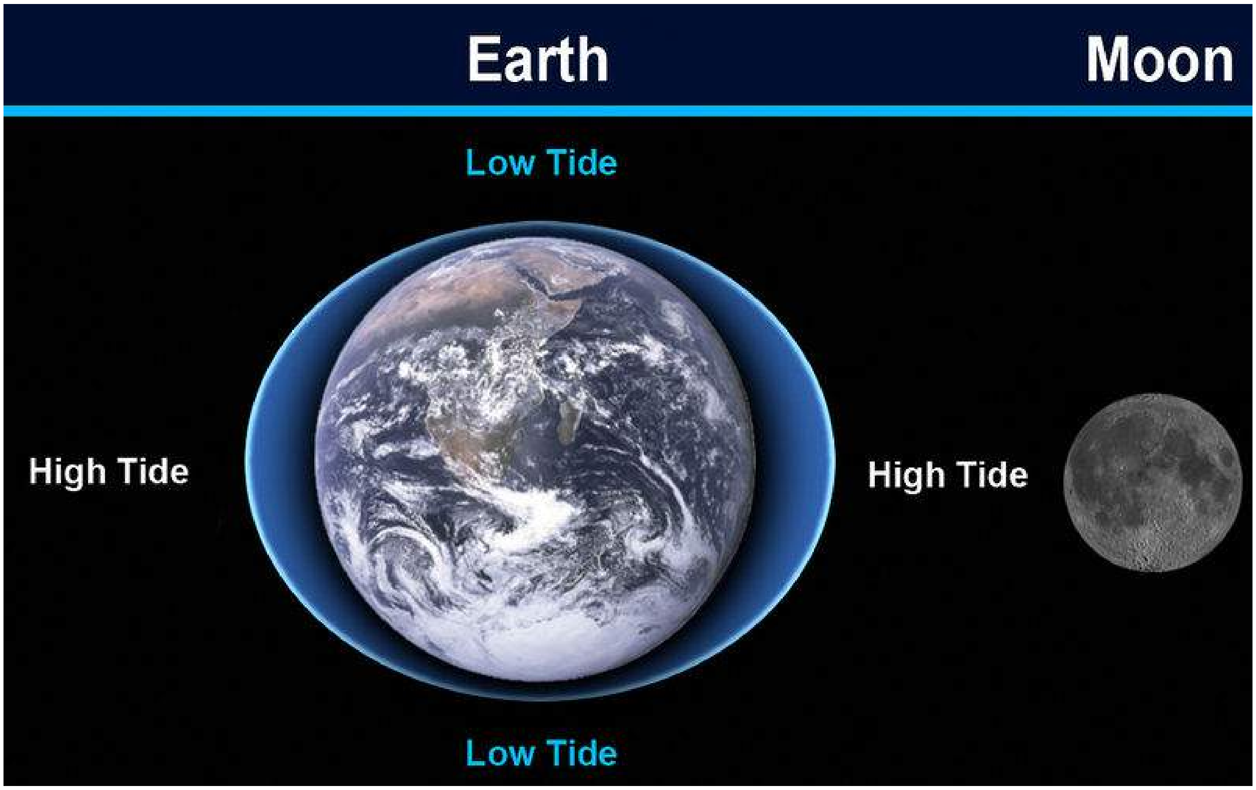


FIGURE 3.64
The gravitational attraction of the Moon to ocean water creates the high and low tides.

Tidal Range

The **tidal range** is the difference between the ocean level at high tide and the ocean level at low tide (**Figure** 6.21). The tidal range in a location depends on a number of factors, including the slope of the seafloor. Water appears to move a greater distance on a gentle slope than on a steep slope.

Monthly Tidal Patterns

If you look at the diagram of high and low tides on a circular Earth above, you'll see that tides are waves. So when the Sun and Moon are aligned, what do you expect the tides to look like?

Waves are additive, so when the gravitational pull of both bodies is in the same direction, the high tides are higher and the low tides lower than at other times through the month (**Figure** 6.22). These more extreme tides, with a greater tidal range, are called **spring tides**. Spring tides don't just occur in the spring; they occur whenever the Moon is in a new-moon or full-moon phase, about every 14 days.

Neap tides are tides that have the smallest tidal range, and they occur when the Earth, the Moon, and the Sun form a 90^o angle (**Figure** 6.23). They occur exactly halfway between the spring tides, when the Moon is at first or last quarter. How do the tides add up to create neap tides? The Moon's high tide occurs in the same place as the Sun's low tide and the Moon's low tide in the same place as the Sun's high tide. At neap tides, the tidal range is relatively small.

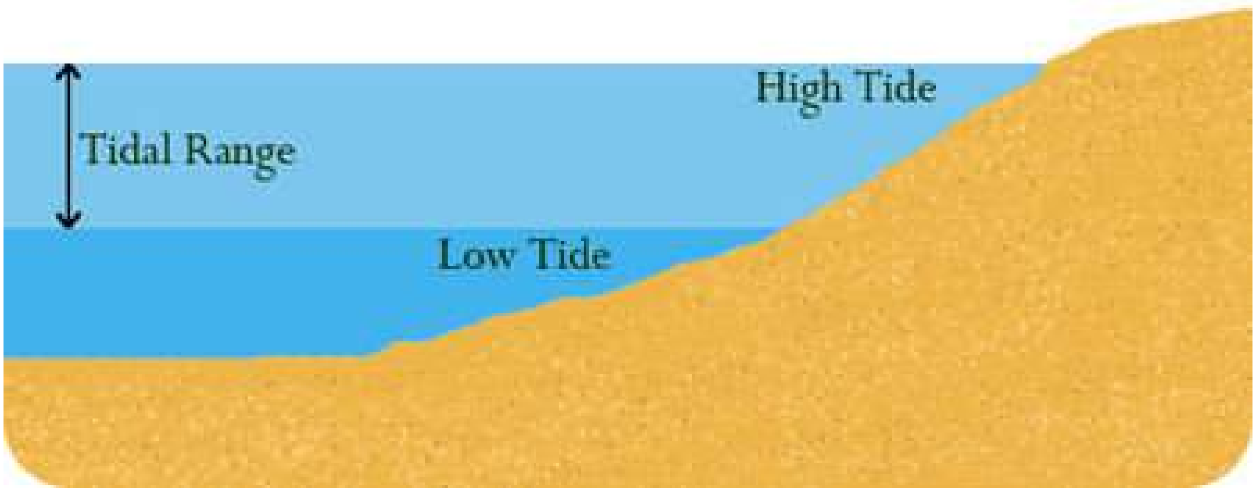


FIGURE 3.65
The tidal range is the difference between the ocean level at high tide and low tide.

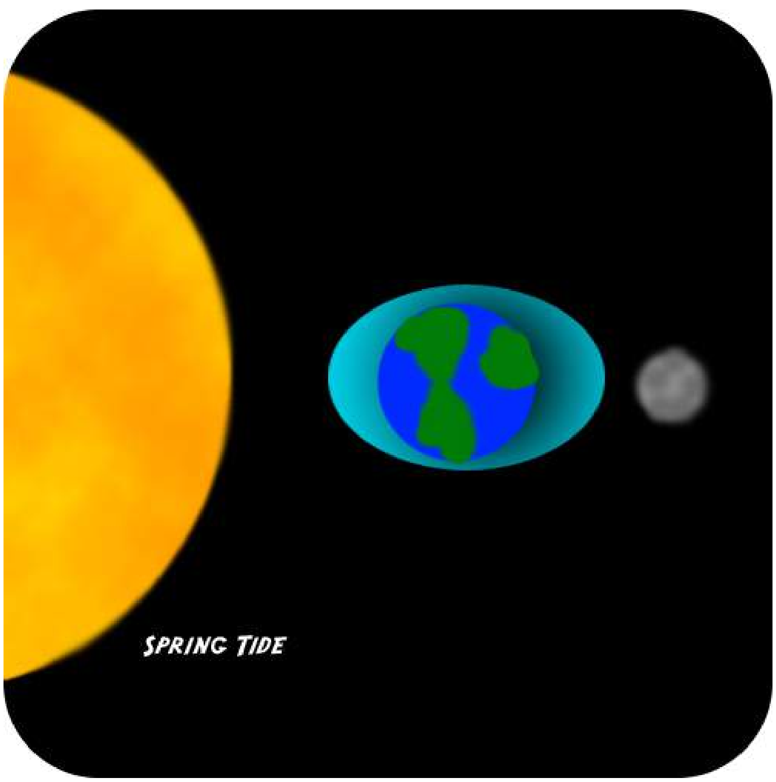


FIGURE 3.66
A spring tide occurs when the gravitational pull of both Moon and the Sun is in the same direction, making high tides higher and low tides lower and creating a large tidal range.

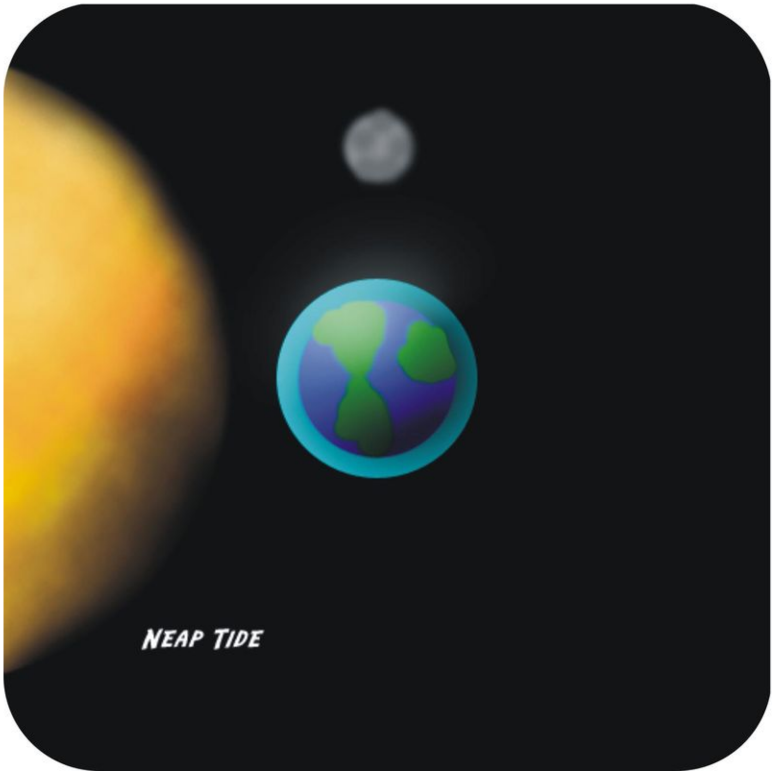


FIGURE 3.67
A neap tide occurs when the high tide of the Sun adds to the low tide of the Moon and vice versa, so the tidal range is relatively small.

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

A detailed animation of lunar tides is shown here: http://www.pbs.org/wgbh/nova/venice/tides.html .

Here is a link to see these tides in motion: http://oceanservice.noaa.gov/education/kits/tides/media/tide06a_450.gif .

A simple animation of spring and neap tides is found here: http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html .

Studying ocean tides' rhythmic movements helps scientists understand the ocean and the Sun/Moon/Earth system. This QUEST video explains how tides work, and visits the oldest continually operating tidal gauge in the Western Hemisphere.

Watch it at http://www.kqed.org/quest/television/science-on-the-spot-watching-the-tides .

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Summary

- The primary cause of tides is the gravitational attraction of the Moon, which causes two high and two low tides a day.
- When the Sun's and Moon's tides match, there are spring tides; when they are opposed, there are neap tides.
- The difference between the daily high and the daily low is the tidal range.

Practice

Use this resource to answer the questions that follow.

http://www.teachertube.com/viewVideo.php?video_id=655&title=The_Mystery_of_Earth_s_Tides

1. How often do tides occur?

2. What are tides?

3. What is a tidal bulge?

4. What causes tides?

5. How is the tidal bulge created?

Review

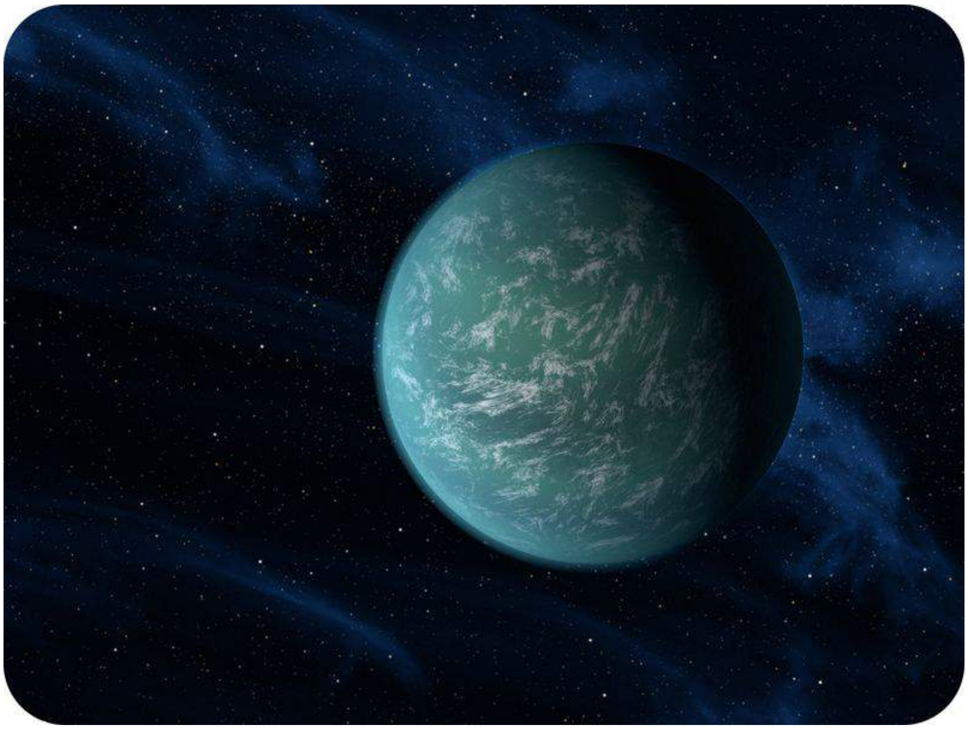
1. Using the terminology of waves, describe how the gravitational attraction of the Moon and Sun make a high tide and a low tide.

2. Describe the causes of spring and neap tides.

3. What are the possible reasons that the Bay of Fundy has such a large tidal range?

3.22 Exoplanets

- Define exoplanet.
- Explain how scientists locate exoplanets.



Is there life on other planets?

Newly discovered planet Kepler-22b is the habitable zone of a sun-like star. This means that the planet could have liquid water, which is necessary for life on Earth. Even though this is the most Earth-like planet yet, the chances that it harbors life are slim. But there are likely many more Earth-like planets in the universe.

Extrasolar Planets or Exoplanets

Since the early 1990s, astronomers have discovered other solar systems, with planets orbiting stars other than our own Sun. These are called "extrasolar planets" or simply **exoplanets** (see **Figure** 3.68). Exoplanets are not in our solar system, but are found in other solar systems.

Some extrasolar planets have been directly imaged, but most have been discovered by indirect methods. One technique involves detecting the very slight motion of a star periodically moving toward and away from us along our line-of-sight (also known as a star's "radial velocity"). This periodic motion can be attributed to the gravitational pull of a planet or, sometimes, another star orbiting the star.

An animation showing how the orbit of a smaller body, such as a planet or small star, can be identified by the effect it has on the orbit of a larger star is seen here from above: http://upload.wikimedia.org/wikipedia/commons/5/59/Orbit3.gif . This is in line with the plane of the system: http://en.wikipedia.org/wiki/File:Dopspec-inline.gif .

A planet may also be identified by measuring a star's brightness over time. A temporary, periodic decrease in light

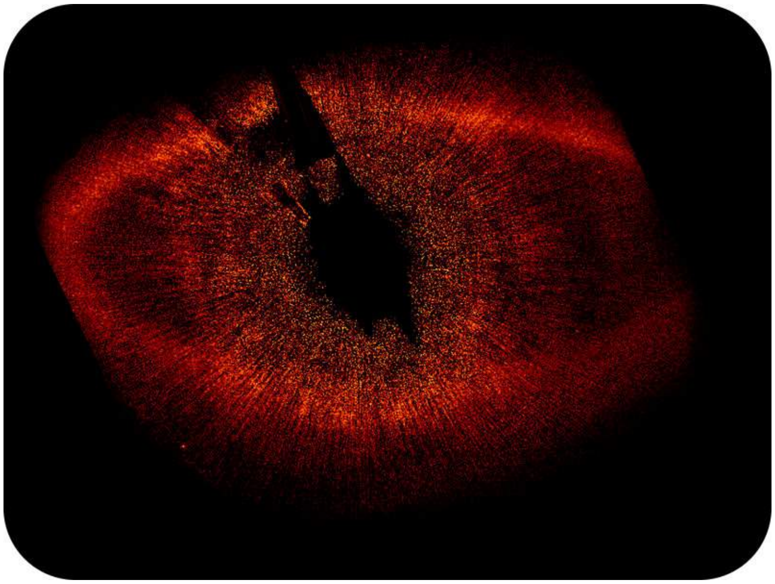
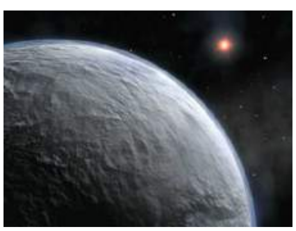


FIGURE 3.68
The extrasolar planet Fomalhaut is surrounded by a large disk of gas. The disk is not centered on the planet, suggesting that another planet may be pulling on the gas as well.

emitted from a star can occur when a planet crosses in front of, or "transits," the star it is orbiting, momentarily blocking out some of the starlight.

More than 700 extrasolar planets have been identified and confirmed and the rate of discovery is increasing rapidly.

Extrasolar Planet from the ESA discusses extrasolar planets and particularly a planetary system very similar to our solar system: http://www.youtube.com/watch?v=ouJahDONTWc (3:29).



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An introduction to extrasolar planets from NASA is available at: http://www.youtube.com/watch?v=oeeZCHDNTvQ (3:14).

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According to NASA, a statistical analysis shows that the Milky Way galaxy contains 100 million planets. That's a lot of exoplanets!

http://science.kqed.org/quest/audio/exoplanets/

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Hundreds of exoplanets have now been discovered. To learn something about how planet hunters find these balls of rock they usually can't even see, watch this QUEST video at http://www.kqed.org/quest/television/the-planet-hunters .

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Summary

- Now that scientists know how to identify extrasolar planets, the numbers of confirmed examples are increasing rapidly.
- An exoplanet may decrease a star's brightness as it passes in front of it.
- The gravitational pull of a planet may be detected in the slight motion of a star.

Practice

Use this resource to answer the questions that follow.

http://planetquest.jpl.nasa.gov/page/methods

1. How many total exoplanets have been found? How many have been confirmed?

2. What are the sizes of the exoplanets that have been found so far?

3. What are the challenges to finding exoplanets?

4. List the methods for detecting planets.

5. Why is direct imaging of exoplanets so difficult?

Review

1. What is an exoplanet?

2. Where are explanets located? How are exoplanets discovered?

3. Why are scientists so interested in exoplanets?

3.23 References

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48. CK-12 Foundation. Earth's axis is tilted. CC BY-NC 3.0
49. Sam McCabe. Summer solstice in the Northern Hemisphere. CC BY-NC 3.0
50. Sam McCabe. Summer solstice in the Southern Hemisphere. CC BY-NC 3.0
51. Tom Ruen, Full Sky Observatory. Pictures of Earth during the spring equinox, summer solstice, vernal equinox, and winter solstice. Public Domain
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54. Laura Guerin. Earth has two north poles, geographic north and magnetic north. CC BY-NC 3.0
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56. Courtesy of NASA. The near and far side of the Moon. Public Domain
57. Courtesy of NASA. A crater on the surface of the Moon. Public Domain
58. Courtesy of US Geological Survey. Maria and terrae cover the Moon. Public Domain
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60. Courtesy of NASA. An artist's depiction of the impact that produced the Moon. Public Domain
61. User:Fastfission/Wikimedia Commons. The moon's position during a solar eclipse. Public Domain
62. User:Kalan/Wikimedia Commons. A solar eclipse shown as a series of photos. CC BY 3.0

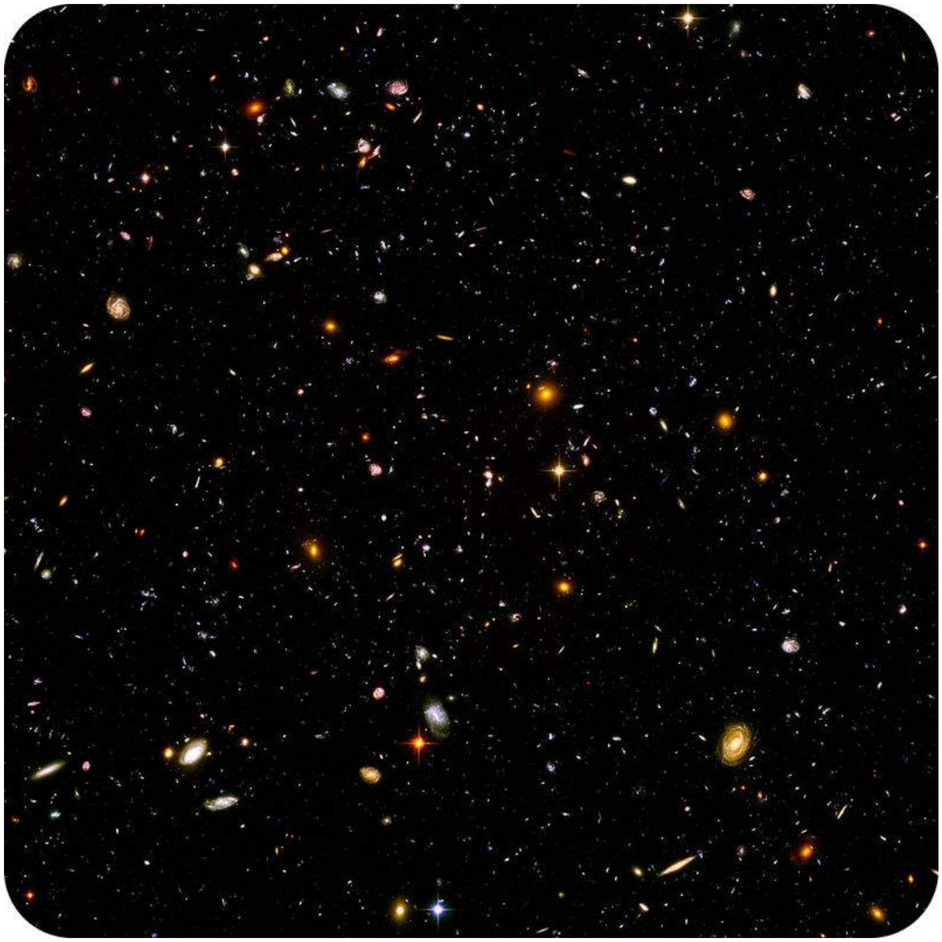
63. Courtesy of NASA. The Moon's shadow in a solar eclipse covers a very small area. Public Domain
64. User:Sagredo/Wikimedia Commons. The moon's position during a lunar eclipse. Public Domain
65. Courtesy of NOAA's National Geophysical Data Center. Parts of a lunar eclipse that can be seen on certain parts of Earth. Public Domain
66. Hana Zavadska, using Earth image courtesy of NASA, Moon image courtesy of NASA/GSFC/Arizona State University. Diagram of how the moon causes tides. CC BY-NC 3.0 (Earth and Moon: public domain)
67. User:Jared/Wikipedia. Diagram of the tidal range. Public Domain
68. User:BrianEd/Wikipedia. Diagram of a spring tide, when the Moon and Sun are aligned. Public Domain
69. User:BrianEd/Wikipedia. Diagram of a neap tide, when the Moon and Sun are opposed. Public Domain
70. Courtesy of NASA, ESA, and P Kalas. The extrasolar planet Fomalhaut is surrounded by a large disk of gas. Public Domain

Chapter 4 Structure of the Planet

Chapter Outline

4.1 Geologic Time Scale

- The geologic time scale allows scientists to refer to events in Earth history in relevant units.



To infinity and beyond!

We can picture deep space, but what does deep time look like? If you divided up the 4.6 billion years of Earth history into one calendar year, as is done at the end of this concept, you might get an idea.

The Geologic Time Scale

To be able to discuss Earth history, scientists needed some way to refer to the time periods in which events happened and organisms lived. With the information they collected from fossil evidence and using Steno's principles, they created a listing of rock layers from oldest to youngest. Then they divided Earth's history into blocks of time with each block separated by important events, such as the disappearance of a species of fossil from the rock record. Since many of the scientists who first assigned names to times in Earth's history were from Europe, they named the blocks of time from towns or other local places where the rock layers that represented that time were found.

From these blocks of time the scientists created the **geologic time scale** (**Figure** 4.1). In the geologic time scale the youngest ages are on the top and the oldest on the bottom. Why do you think that the more recent time periods are divided more finely? Do you think the divisions in the scale below are proportional to the amount of time each time period represented in Earth history?

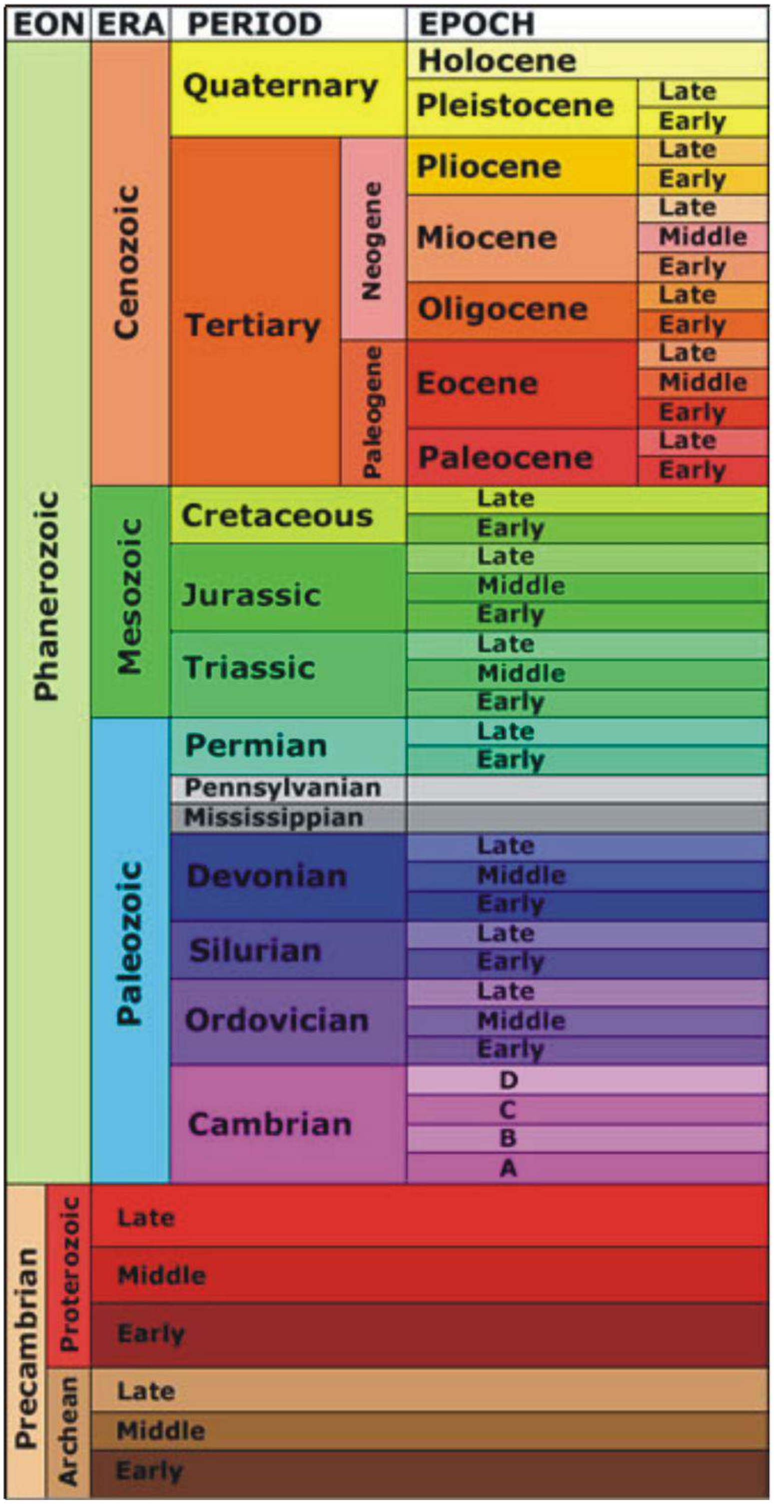


FIGURE 4.1
The geologic time scale is based on relative ages. No actual ages were placed on the original time scale.

In what eon, era, period and epoch do we now live? We live in the Holocene (sometimes called Recent) epoch, Quaternary period, Cenozoic era, and Phanerozoic eon.

Geologic Time Condensed to One Year

It's always fun to think about geologic time in a framework that we can more readily understand. Here are when some major events in Earth history would have occurred if all of earth history was condensed down to one calendar year.

January 1 12 am: Earth forms from the planetary nebula –4600 million years ago

February 25, 12:30 pm: The origin of life; the first cells –3900 million years ago

March 4, 3:39 pm: Oldest dated rocks –3800 million years ago

March 20, 1:33 pm: First stromatolite fossils –3600 million years ago

July 17, 9:54 pm: first fossil evidence of cells with nuclei –2100 million years ago

November 18, 5:11 pm: Cambrian Explosion –544 million years ago

December 1, 8:49 am: first insects –385 million years ago

December 2, 3:54 am: first land animals, amphibians –375 million years ago

December 5, 5:50 pm: first reptiles –330 million years ago

December 12, 12:09 pm: Permo-Triassic Extinction –245 million years ago

December 13, 8:37 pm: first dinosaurs –228 million years ago

December 14, 9:59 am: first mammals – 220 million years ago

December 22, 8:24 pm: first flowering plants –115 million years ago

December 26, 7:52 pm: Cretaceous-Tertiary Extinction –66 million years ago

December 26, 9:47 pm: first ancestors of dogs –64 million years ago

December 27, 5:25 am: widespread grasses –60 million years ago

December 27, 11:09 am: first ancestors of pigs and deer –57 million years ago

December 28, 9:31 pm: first monkeys –39 million years ago

December 31, 5:18 pm: oldest hominid –4 million years ago

December 31, 11:02 pm: oldest direct human ancestor –1 million years ago

December 31, 11:48 pm: first modern human –200,000 years ago

December 31, 11:59 pm: Revolutionary War –235 years ago

Source: http://www.timetoast.com/timelines/63215

See the video below for another analogy of geologic time:

MEDIA

Click image to the left for more content.

Summary

- The geologic time scale divides earth history into named units that are separated by major events in earth or life history.
- Naming time periods makes it easier to talk about them.
- Humans have been around for a miniscule portion of earth history.

Practice

Use this resource to answer the questions that follow.

Geologic Time - Introduction

http://www.youtube.com/watch?v=NFmdlRMO8II

MEDIA

Click image to the left for more content.

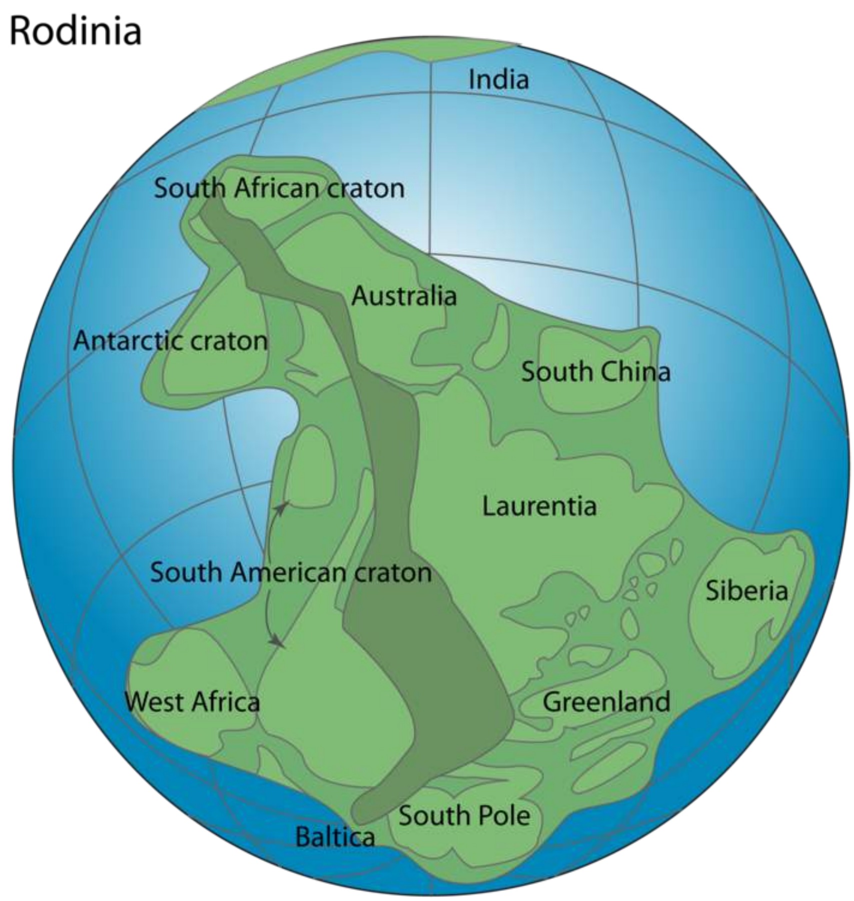
1. How old is the Earth?
2. What is stratigraphy?
3. What is an eon?
4. What do eras and periods represent?
5. What is the lower limit of the Proterozoic era?
6. What are isotopes?
7. Why are isotopes important to geologic time?

Review

1. Why do earth scientists need a geologic time scale?
2. Why are some units of the geologic time scale longer and some shorter?
3. How does the section that condenses all of geologic time into one year make you feel?

4.2 Plate Tectonics through Earth History

- Explain the relationship between plate tectonics theory and the existence of supercontinents such as Pangaea.



That map is sort of familiar, but what is it?

Wegener's persistent search for evidence that the continents had been joined paid off. Scientists who came after him developed an understanding of seafloor spreading, which was the mechanism for Wegener's continental drift. Geologists know that Wegener was right because the movements of continents explain so much about the geological activity we see.

The existence of Wegener's supercontinent Pangaea is completely accepted by geologists today. But did it all begin with Pangaea? Or were there other supercontinents that came before?

Plate Tectonics Theory

First, let's review plate tectonics theory. Plate tectonics theory explains why:

- Earth's geography has changed over time and continues to change today.
- some places are prone to earthquakes while others are not.

- certain regions may have deadly, mild, or no volcanic eruptions.
- mountain ranges are located where they are.
- many ore deposits are located where they are.
- living and fossil species are found where they are.

Plate tectonic motions affect Earth's rock cycle, climate, and the evolution of life.

Supercontinent Cycle

Remember that Wegener used the similarity of the mountains on the west and east sides of the Atlantic as evidence for his continental drift hypothesis. Those mountains rose at the convergent plate boundaries where the continents were smashing together to create Pangaea. As Pangaea came together about 300 million years ago, the continents were separated by an ocean where the Atlantic is now. The proto-Atlantic ocean shrank as the Pacific Ocean grew.

The Appalachian mountains of eastern North America formed at a convergent plate boundary as Pangaea came together (**Figure** 4.2). About 200 million years ago, the they were probably as high as the Himalayas, but they have been weathered and eroded significantly since the breakup of Pangaea.

FIGURE 4.2
The Appalachian Mountains in New Hampshire.

Pangaea has been breaking apart since about 250 million years ago. Divergent plate boundaries formed within the continents to cause them to rift apart. The continents are still moving apart, since the Pacific is shrinking as the Atlantic is growing. If the continents continue in their current directions, they will come together to create a supercontinent on the other side of the planet in around 200 million years.

If you go back before Pangaea there were earlier supercontinents, such as Rodinia, which existed 750 million to 1.1 billion years ago, and Columbia, at 1.5 to 1.8 billion years ago. This **supercontinent cycle** is responsible for most of the geologic features that we see and many more that are long gone (**Figure** 4.3).

This animation shows the movement of continents over the past 600 million years, beginning with the breakup of Rodinia: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_plate_reconstruction_blakey.html .

Summary

- Pangaea came together as a set of continent-continent convergent plate boundaries.
- Pangaea is still breaking up as the continents move apart. The Atlantic Ocean is getting bigger and the Pacific Ocean is getting smaller.

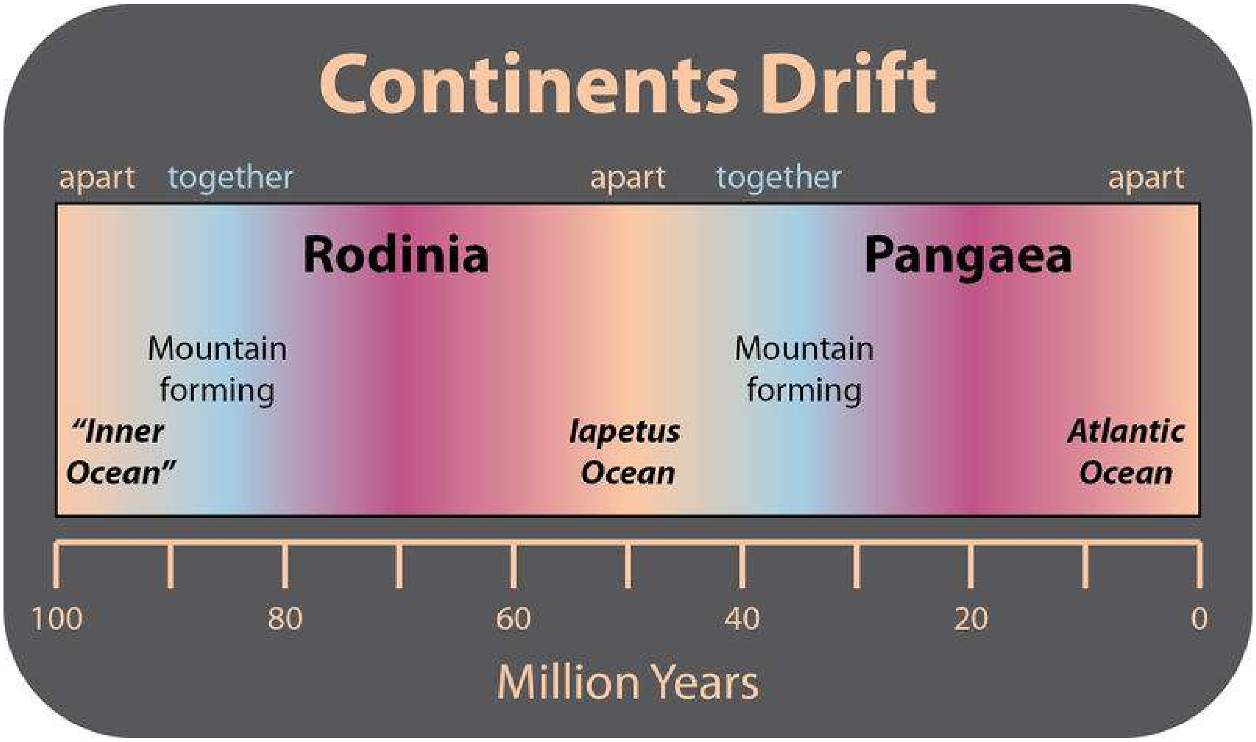


FIGURE 4.3

Scientists think that the creation and breakup of a supercontinent takes place about every 500 million years. The supercontinent before Pangaea was Rodinia. A new continent will form as the Pacific ocean disappears.

- Pangaea was not the first supercontinent and it won't be the last. The continents come together and break apart about every 500 million years in a process called the supercontinent (or Wilson) cycle.

Practice

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/drift.html

1. What did Alfred Wegener notice?
2. What did he discover from his research?
3. What did he call the original supercontinent?
4. What happened 200 million years ago?
5. What landmasses split up 135 million years ago?
6. List the events that occurred 65 million years ago.
7. When did Greenland separate from North America?
8. Explain the plate tectonics theory.

Review

1. Describe the plate tectonics processes that brought Pangaea together.
2. Describe the plate tectonics processes that split Pangaea up.
3. Why do scientists think that there will be another supercontinent in the future?

4.3 Wegener and the Continental Drift Hypothesis

- Define the continental drift hypothesis.
- Analyze why the continental drift hypothesis was not accepted by the majority of scientists in Wegener's day.

"Scientists still do not appear to understand sufficiently..."

"...that all earth sciences must contribute evidence toward unveiling the state of our planet in earlier times, and that the truth of the matter can only be reached by combing all this evidence. ... It is only by combing the information furnished by all the earth sciences that we can hope to determine 'truth' here, that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability. Further, we have to be prepared always for the possibility that each new discovery, no matter what science furnishes it, may modify the conclusions we draw." - Alfred L. Wegener, *The Origins of Continents and Oceans*, first published in 1915.

Wegener put together a tremendous amount of evidence that the continents had been joined. He advocated using scientific evidence to find the "truth." As his colleague, are you convinced? Let's explore.

Wegener's Continental Drift Hypothesis

Wegener put his idea and his evidence together in his book *The Origin of Continents and Oceans*, first published in 1915. New editions with additional evidence were published later in the decade. In his book he said that around 300 million years ago the continents had all been joined into a single landmass he called Pangaea, meaning "all earth" in ancient Greek. The supercontinent later broke apart and the continents having been moving into their current positions ever since. He called his hypothesis **continental drift**.

The Problem with the Hypothesis

Wegener's idea seemed so outlandish at the time that he was ridiculed by other scientists. What do you think the problem was? To his colleagues, his greatest problem was that he had no plausible mechanism for how the continents could move through the oceans. Based on his polar experiences, Wegener suggested that the continents were like icebreaking ships plowing through ice sheets. The continents moved by centrifugal and tidal forces. As Wegener's colleague, how would you go about showing whether these forces could move continents? What observations would you expect to see on these continents?

FIGURE 4.4
Alfred Wegener suggested that continental drift occurred as continents cut through the ocean floor, in the same way as this icebreaker plows through sea ice.

FIGURE 4.5
Early hypotheses proposed that centrifugal forces moved continents. This is the same force that moves the swings outward on a spinning carnival ride.

Scientists at the time calculated that centrifugal and tidal forces were too weak to move continents. When one scientist did calculations that assumed that these forces were strong enough to move continents, his result was that if Earth had such strong forces the planet would stop rotating in less than one year. In addition, scientists also thought that the continents that had been plowing through the ocean basins should be much more deformed than they are.

Wegener answered his question of whether Africa and South America had once been joined. But a hypothesis is rarely accepted without a mechanism to drive it. Are you going to support Wegener? A very few scientists did, since his hypothesis elegantly explained the similar fossils and rocks on opposite sides of the ocean, but most did not.

Mantle Convection

Wegener had many thoughts regarding what could be the driving force behind continental drift. Another of Wegener's colleagues, Arthur Holmes, elaborated on Wegener's idea that there is thermal convection in the mantle.

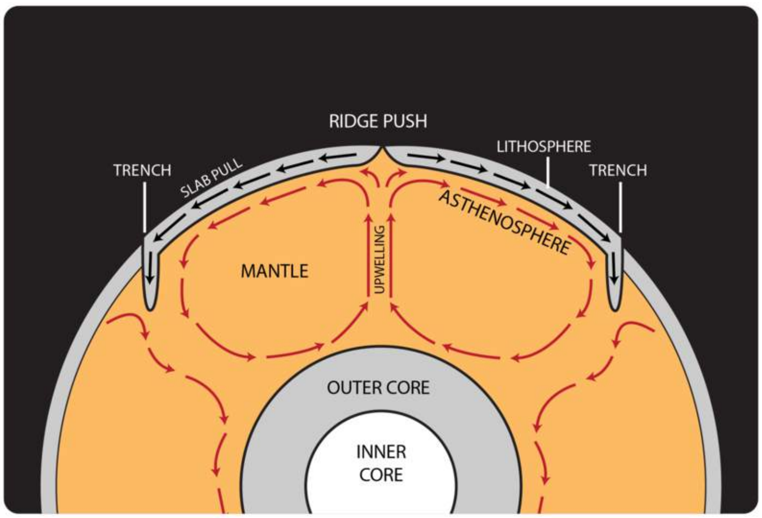


FIGURE 4.6
Thermal convection occurs as hot rock in the deep mantle rises towards the Earth's surface. This rock then spreads out and cools, sinking back towards the core, where it can be heated again. This circulation of rock through the mantle creates convection cells.

In a **convection cell**, material deep beneath the surface is heated so that its density is lowered and it rises. Near the surface it becomes cooler and denser, so it sinks. Holmes thought this could be like a conveyor belt. Where two adjacent convection cells rise to the surface, a continent could break apart with pieces moving in opposite directions. Although this sounds like a great idea, there was no real evidence for it, either.

Alfred Wegener died in 1930 on an expedition on the Greenland icecap. For the most part the continental drift idea was put to rest for a few decades, until technological advances presented even more evidence that the continents moved and gave scientists the tools to develop a mechanism for Wegener's drifting continents. Since you're on a virtual field trip, you get to go along with them as well.

Summary

- Alfred Wegener published his idea that the continents had been joined as a single landmass, which he called Pangaea, about 300 million years ago.
- Wegener's idea was mostly ridiculed, in part because Wegener could not develop a plausible mechanism for continents moving through oceanic crust.
- Calculations showed that his idea about centrifugal and tidal forces powering the continents could not be right.
- Wegener also thought about mantle convection an idea expanded on by Arthur Holmes as the driving force for continental drift. There was no evidence available to support the idea at the time.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=bVdrg5ZId1M

MEDIA
Click image to the left for more content.

1. What is uniformitarianism?
2. What did Wegener write about in his book?
3. What did Wegener think caused continental drift?
4. Give specific examples of the response to Wegener's continental drift theory.
5. What did scientists learn after the war?

Review

1. Describe the continental drift hypothesis.
2. Why did scientists reject Wegener's idea? What was needed for them to accept it?
3. Are there some ideas (hypotheses, theories) that have a great deal of evidence to support them, yet are not accepted by many people?

4.4 Earth History and Clues from Fossils

- Fossils are full of information about Earth's past and are essential for unraveling earth history.

Seashells at 20,000 feet!

On his voyage on the Beagle, Charles Darwin noticed many things besides just the Galapagos finches that made him famous. Another important discovery was shell beds high in the Andes Mountains. How did they get there? He determined that they must mean that mountains rise slowly above the ocean, an idea that was being championed at the time by Charles Lyell. If this is the case, Darwin reasoned, the mountains and Earth must be extremely old.

Clues from Fossils

Fossils are our best form of evidence about Earth history, including the history of life. Along with other geological evidence from rocks and structures, fossils even give us clues about past climates, the motions of plates, and other major geological events. Since the present is the key to the past, what we know about a type of organism that lives today can be applied to past environments.

History of Life on Earth

That life on Earth has changed over time is well illustrated by the fossil record. Fossils in relatively young rocks resemble animals and plants that are living today. In general, fossils in older rocks are less similar to modern organisms. We would know very little about the organisms that came before us if there were no fossils. Modern technology has allowed scientists to reconstruct images and learn about the biology of extinct animals like dinosaurs!

MEDIA
Click image to the left for more content.

Environment of Deposition

By knowing something about the type of organism the fossil was, geologists can determine whether the region was terrestrial (on land) or marine (underwater) or even if the water was shallow or deep. The rock may give clues to whether the rate of sedimentation was slow or rapid. The amount of wear and fragmentation of a fossil allows scientists to learn about what happened to the region after the organism died; for example, whether it was exposed to wave action.

Geologic History

The presence of marine organisms in a rock indicates that the region where the rock was deposited was once marine. Sometimes fossils of marine organisms are found on tall mountains indicating that rocks that formed on the seabed were uplifted.

Climate

By knowing something about the climate a type of organism lives in now, geologists can use fossils to decipher the climate at the time the fossil was deposited. For example, coal beds form in tropical environments but ancient coal beds are found in Antarctica. Geologists know that at that time the climate on the Antarctic continent was much warmer. Recall from the chapter Plate Tectonics that Wegener used the presence of coal beds in Antarctica as one of the lines of evidence for continental drift.

Index Fossils

An **index fossil** can be used to identify a specific period of time. Organisms that make good index fossils are distinctive, widespread, and lived briefly. Their presence in a rock layer can be used to identify rocks that were deposited at that period of time over a large area.

The fossil of a juvenile mammoth found near downtown San Jose California reveals an enormous amount about these majestic creatures: what they looked like, how they lived, and what the environment of the Bay Area was like so long ago.

Find out more at http://science.kqed.org/quest/video/science-on-the-spot-lupe-the-mammoth-comes-to-life/ .

MEDIA
Click image to the left for more content.

Summary

- Fossils tell a lot about the environment during the time they were deposited.
- Climate is one important thing that can be indicated by fossils since organisms have specific conditions in which they can live.
- An index fossil must be distinctive, widespread and short-lived so that it can identify a specific period of time.

Practice

Use this resource to answer the questions that follow.

Clues to the End - Permian Extinction

http://www.youtube.com/watch?v=eG8XyesAu74

MEDIA
Click image to the left for more content.

1. Why is the paleoecologist collecting samples?
2. What does he want to create from the fossil evidence?
3. How is this similar to forensic science?
4. Why is it important to understand insect feeding?
5. What has been discovered from these fossils?

Review

1. How does a single fossil or set of fossils help geologists to decipher the geological history of an area?
2. How is an index fossil used to identify a time period?
3. Why are the fossils of marine organisms sometimes found in rock units at the tops of high mountains? What evidence would you look for to determine if this reason is plausible?

4.5 Magnetic Evidence for Seafloor Spreading

- Explain how seafloor magnetism and the ages of seafloor rocks provide evidence of seafloor spreading.

What causes the strange stripes on the seafloor?

This pattern of stripes could represent what scientists see on the seafloor. Note that the stripes are symmetrical about the central dusky purple stripe. In the oceans, magnetic stripes are symmetrical about a mid-ocean ridge axis. What could cause this? What could it possibly mean?

Seafloor Magnetism

On our transit to the Mid-Atlantic ridge, we tow a magnetometer behind the ship. Shipboard magnetometers reveal the magnetic polarity of the rock beneath them. The practice of towing a magnetometer began during WWII when navy ships towed magnetometers to search for enemy submarines.

When scientists plotted the points of normal and reversed polarity on a seafloor map they made an astonishing discovery: the normal and reversed magnetic polarity of seafloor basalts creates a pattern.

- Stripes of normal polarity and reversed polarity alternate across the ocean bottom.

- Stripes form mirror images on either side of the mid-ocean ridges (**Figure** 4.7).
- Stripes end abruptly at the edges of continents, sometimes at a deep sea trench (**Figure** 4.8).

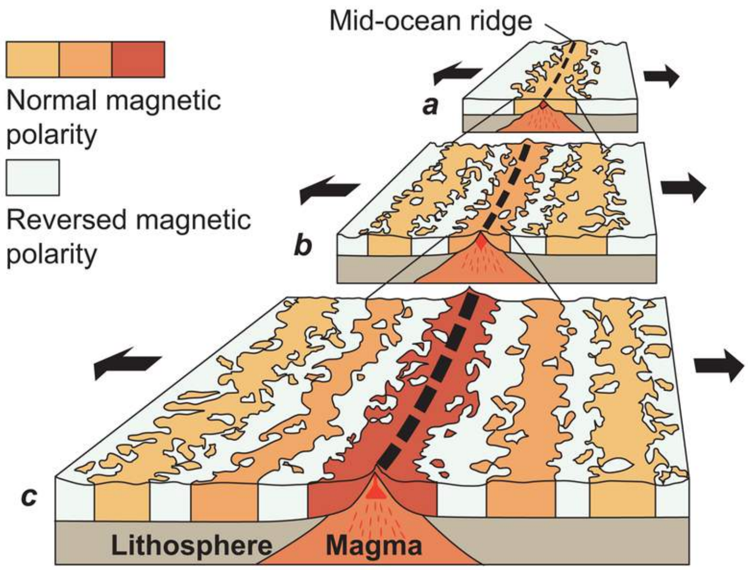


FIGURE 4.7

Magnetic polarity is normal at the ridge crest but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

The magnetic stripes are what created the **Figure** 4.7. Research cruises today tow magnetometers to add detail to existing magnetic polarity data.

Seafloor Age

By combining magnetic polarity data from rocks on land and on the seafloor with radiometric age dating and fossil ages, scientists came up with a time scale for the magnetic reversals. The first four magnetic periods are:

- Brunhes normal - present to 730,000 years ago.
- Matuyama reverse - 730,000 years ago to 2.48 million years ago.
- Gauss normal - 2.48 to 3.4 million years ago.
- Gilbert reverse –3.4 to 5.3 million years ago.

The scientists noticed that the rocks got older with distance from the mid-ocean ridges. The youngest rocks were located at the ridge crest and the oldest rocks were located the farthest away, abutting continents.

Scientists also noticed that the characteristics of the rocks and sediments changed with distance from the ridge axis as seen in the **Table** 4.1.

TABLE 4.1: **Characteristics of Crustal Rocks**

	Rock ages	Sediment thickness	Crust thickness	Heat flow
At ridge axis	youngest	none	thinnest	hottest
With distance from axis	becomes older	becomes thicker	becomes thicker	becomes cooler

Away from the ridge crest, sediment becomes older and thicker, and the seafloor becomes thicker. Heat flow, which indicates the warmth of a region, is highest at the ridge crest.

A map of sediment thickness is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sedimentthickness.html .

The oldest seafloor is near the edges of continents or deep sea trenches and is less than 180 million years old (**Figure** 4.8). Since the oldest ocean crust is so much younger than the oldest continental crust, scientists realized that something was happening to the older seafloor.

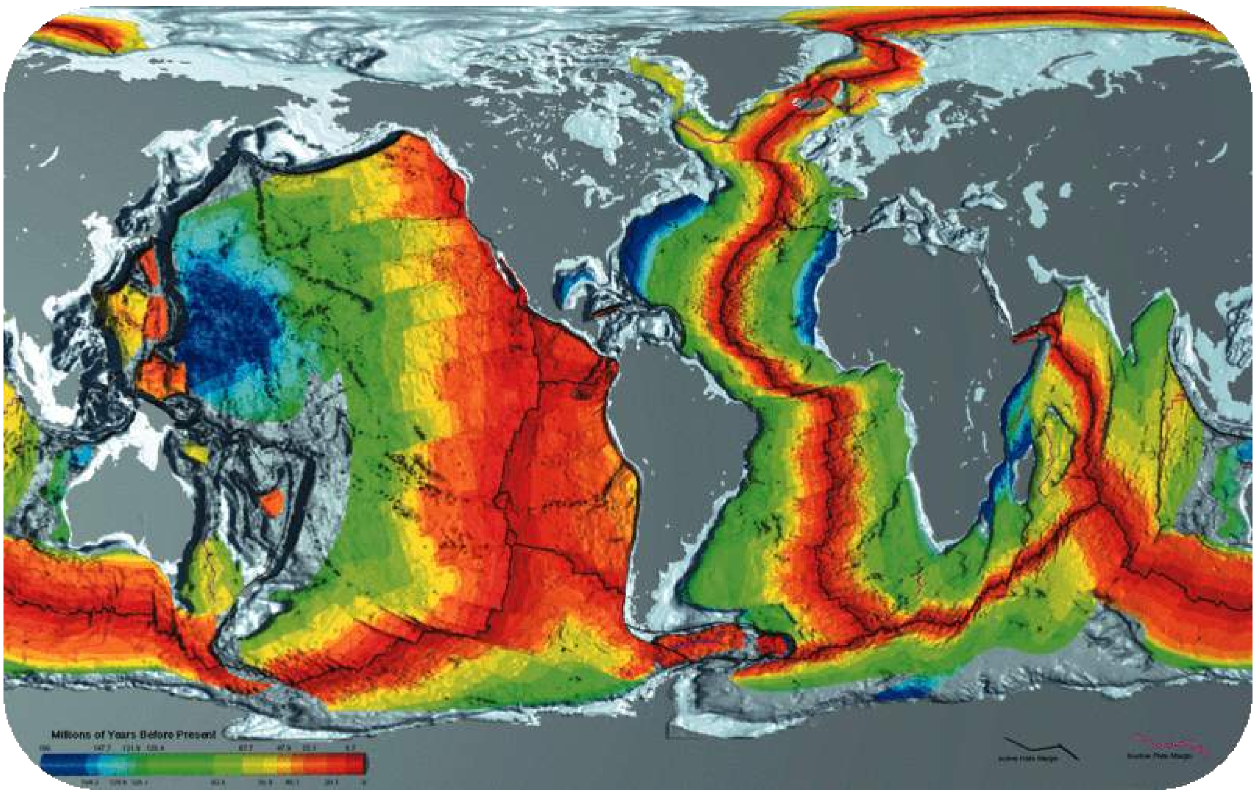


FIGURE 4.8
Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

How can you explain the observations that scientists have made in the oceans? Why is rock younger at the ridge and oldest at the farthest points from the ridge? The scientists suggested that seafloor was being created at the ridge. Since the planet is not getting larger, they suggested that it is destroyed in a relatively short amount of geologic time.

This 65 minute video explains "The Role of Paleomagnetism in the Evolution of Plate Tectonic Theory": http://online.wr.usgs.gov/calendar/2004/jul04.html .

Summary

- Data from magnetometers dragged behind ships looking for enemy submarines in WWII discovered amazing magnetic patterns on the seafloor.
- Rocks of normal and reversed polarity are found in stripes symmetrically about the mid-ocean ridge axis.

- The age of seafloor rocks increases from the ridge crest to rocks the farthest from the ridges. Still, the rocks of the ocean basins are much younger than most of the rocks of the continents.

Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/100-greatest-discoveries-shorts-magnetic-field-reversal.html

MEDIA
Click image to the left for more content.

1. What is the purpose of our magnetic field?
2. Where was Bernard Burnhes doing his research?
3. What did Burnhes discover?
4. Explain what Burnhes concluded from his discovery.
5. How many times has the magnetic field reversed?
6. What seems to be occurring now?

Review

1. Describe the pattern the magnetic stripes make in the ocean floor.
2. How does magnetic polarity reveal the age of a piece of seafloor?
3. What other indications do scientists have regarding the age of the seafloor in various locations?

4.6 Principles of Relative Dating

- Steno's laws are used to determine the order in which geological events took place.

Relative ages.

In most families a person's age fits into his or her generation: Siblings are around the same age as are first cousins. But in some families, multiple marriages, delayed childbearing, extended childbearing or other variations mixes up generations so that Aunt Julia may be five years younger than her nephew. In a family like this it's hard to tell how people are related simply by age. With rock units we use certain principles to tell their ages relative to each other.

Relative Age Dating

Early geologists had no way to determine the absolute age of a geological material. If they didn't see it form, they couldn't know if a rock was one hundred years or 100 million years old. What they could do was determine the ages of materials relative to each other. Using sensible principles they could say whether one rock was older than another and when a process occurred relative to those rocks.

Steno's Laws

Remember Nicholas Steno, who determined that fossils represented parts of once-living organisms? Steno also noticed that fossil seashells could be found in rocks and mountains far from any ocean. He wanted to explain how that could occur. Steno proposed that if a rock contained the fossils of marine animals, the rock formed from sediments that were deposited on the seafloor. These rocks were then uplifted to become mountains.

This scenario led him to develop the principles that are discussed below. They are known as Steno's laws. Steno's laws are illustrated in **Figure** 4.9.

- **Original horizontality**: Sediments are deposited in fairly flat, horizontal layers. If a sedimentary rock is found tilted, the layer was tilted after it was formed.
- **Lateral continuity**: Sediments are deposited in continuous sheets that span the body of water that they are deposited in. When a valley cuts through sedimentary layers, it is assumed that the rocks on either side of the valley were originally continuous.
- **Superposition**: Sedimentary rocks are deposited one on top of another. The youngest layers are found at the top of the sequence, and the oldest layers are found at the bottom.

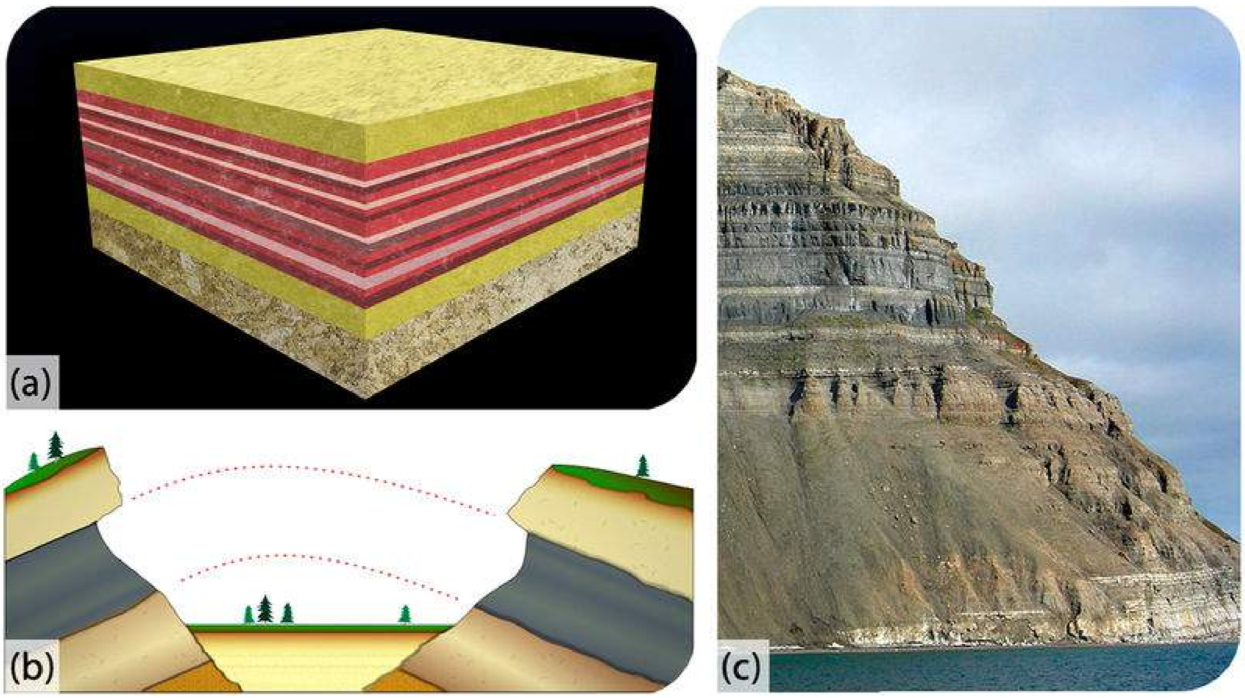


FIGURE 4.9
(a) Original horizontality. (b) Lateral continuity. (c) Superposition.

More Principles of Relative Dating

Other scientists observed rock layers and formulated other principles.

Geologist William Smith (1769-1839) identified the **principle of faunal succession**, which recognizes that:

- Some fossil types are never found with certain other fossil types (e.g. human ancestors are never found with dinosaurs) meaning that fossils in a rock layer represent what lived during the period the rock was deposited.
- Older features are replaced by more modern features in fossil organisms as species change through time; e.g. feathered dinosaurs precede birds in the fossil record.
- Fossil species with features that change distinctly and quickly can be used to determine the age of rock layers quite precisely.

Scottish geologist, James Hutton (1726-1797) recognized the **principle of cross-cutting relationships**. This helps geologists to determine the older and younger of two rock units (**Figure** 4.10).

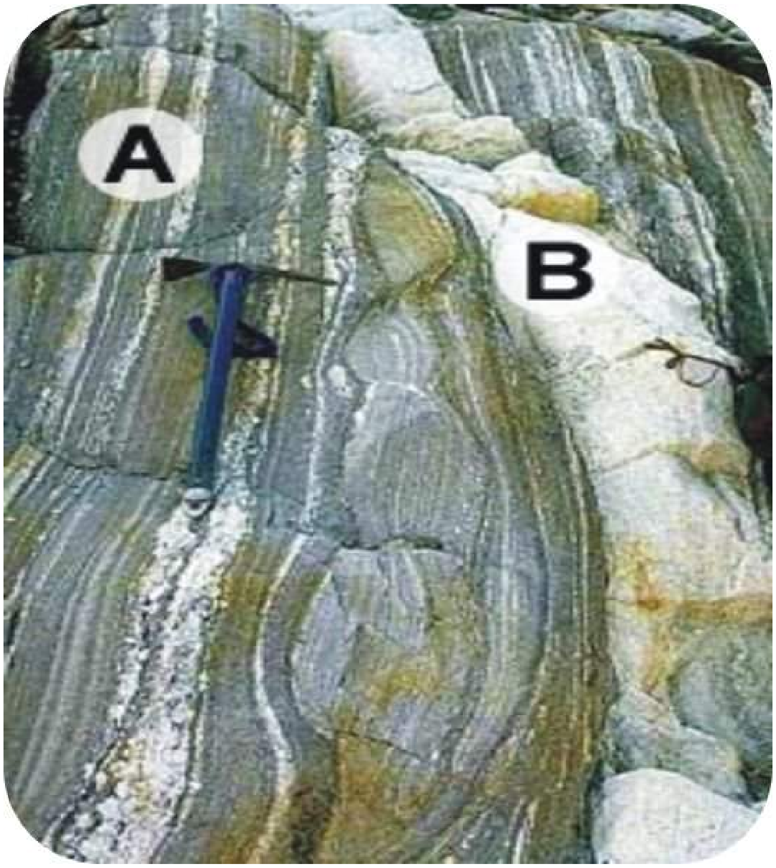


FIGURE 4.10
If an igneous dike (B) cuts a series of metamorphic rocks (A), which is older and which is younger? In this image, A must have existed first for B to cut across it.

The Grand Canyon

The Grand Canyon provides an excellent illustration of the principles above. The many horizontal layers of sedimentary rock illustrate the principle of original horizontality (**Figure** 4.11).

- The youngest rock layers are at the top and the oldest are at the bottom, which is described by the law of superposition.
- Distinctive rock layers, such as the Kaibab Limestone, are matched across the broad expanse of the canyon. These rock layers were once connected, as stated by the rule of lateral continuity.
- The Colorado River cuts through all the layers of rock to form the canyon. Based on the principle of cross-cutting relationships, the river must be younger than all of the rock layers that it cuts through.

Summary

- Sediments are deposited horizontally with the oldest at the bottom. Any difference in this pattern means that the rock units have been altered.
- The principle of faunal succession recognizes that species evolve and these changes can be seen in the rock record.
- The Grand Canyon exhibits many of the principles of relative dating and is a fantastic location for learning about the geology of the southwestern U.S.

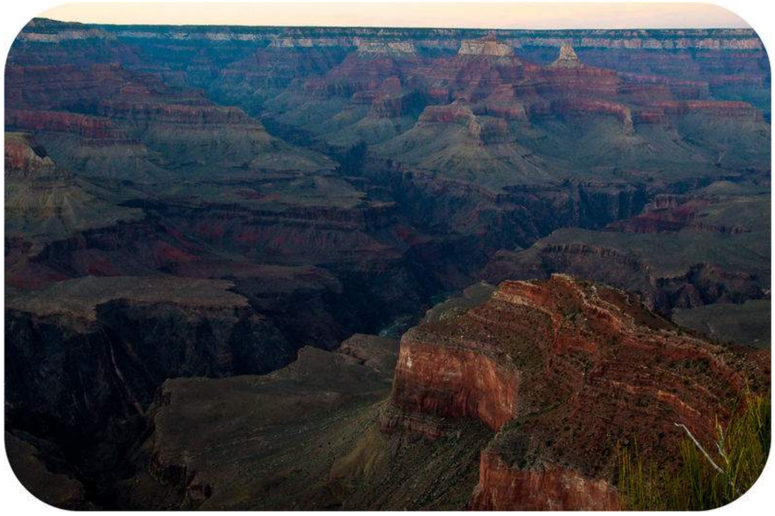


FIGURE 4.11
At the Grand Canyon, the Coconino Sandstone appears across canyons. The Coconino is the distinctive white layer; it is a vast expanse of ancient sand dunes.

Practice

Use this resource to answer the questions that follow.

Absolute vs. Relative Dating

http://www.youtube.com/watch?v=JNOmpXo2xlU

MEDIA
Click image to the left for more content.

1. What is superposition?
2. How can the age of the layers be determined?
3. How does volcanic ash help with relative dating?
4. What are the radioactive elements?
5. What is the clock for determining relative age?

Review

1. How do Steno's laws help geologists to decipher the geological history of a region?
2. What is the principle of faunal succession?
3. Why does just about every geology textbook use the Grand Canyon as the example in the sections on geological history?

4.7 Principle of Uniformitarianism

- Explain how scientists use knowledge of Earth in the present to understand Earth's history.

What does this mean: "the present is the key to the past"?

How can what you see in this photo help you to figure out what happened in Earth's history? You can see the molten lava and what it looks like when it cools. If you see that type of rock in an outcrop you can assume that it formed from molten lava. This reveals the best tool for understanding Earth history that Earth scientists have. They use what they know about materials and processes in the present to figure out what happened in the past.

Ask a Question –Earth History

The outcrop in the **Figure** 4.12 is at Checkerboard Mesa in Zion National Park, Utah. It has a very interesting pattern on it. As a geology student you may ask: how did this rock form?

If you poke at the rock and analyze its chemistry you will see that it's made of sand. In fact, the rock formation is called the Navajo sandstone. But knowing that the rock is sandstone doesn't tell you how it formed. It would be hard to design an experiment to show how this rock formed. But we can make observations now and apply them to this rock that formed long ago.

Uniformitarianism

James Hutton came up with this idea in the late 1700s. The present is the key to the past. He called this the **principle of uniformitarianism**. It is that if we can understand a geological process now and we find evidence of that same process in the past, then we can assume that the process operated the same way in the past.

Let's go back to that outcrop. What would cause sandstone to have layers that cross each other, a feature called cross-bedding?

FIGURE 4.12
Checkerboard Mesa in Zion National Park, Utah.

Answer a Question –Earth History

In the photo of the Mesquite sand dune in Death Valley National Park, California (**Figure** 4.13), we see that wind can cause cross-bedding in sand. Cross-bedding is due to changes in wind direction. There are also ripples caused by the wind waving over the surface of the dune.

FIGURE 4.13
The Mesquite sand dune in Death Valley National Park, California.

This doesn't look exactly like the outcrop of Navajo sandstone, but if you could cut a cross-section into the face of the dune it would look very similar.

Since we can observe wind forming sand dunes with these patterns now, we have a good explanation for how the Navajo sandstone formed. The Navajo sandstone is a rock formed from ancient sand dunes in which wind direction changed from time to time.

This is just one example of how geologists use observations they make today to unravel what happened in Earth's past. Rocks formed from volcanoes, oceans, rivers, and many other features are deciphered by looking at the geological work those features do today.

Summary

- You may need to apply what you know about the present to determine what happened in the past.
- The idea that the present is the key to the past was recognized by James Hutton in the late 1700s.
- If you see something forming by a process today and then find the end results of that process in the rock record, you can assume that the the process operated the same way in the past.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. How does a geologist use observations about how and where ripple marks are found to understand ripple marks in a rock?

2. What do the colors of the rocks tell us?

3. Explain, briefly, the principal of uniformitarianism.

4. Why are the principles discussed in this video important for Earth science?

Review

1. What does an Earth scientist often need to answer a question about something that happened in Earth's distant past?

2. James Hutton is sometimes called the father of geology. Why does he merit that title?

3. If you found a layer of ancient lava rock within a sandstone outcrop, what could you say about that lava rock using the principle of uniformitarianism?

4.8 Radiometric Dating

- Radiometric dating uses radioactive isotopes to get the absolute ages of rocks and other materials.

How do you date a rock (and who would want to)?

How you date a rock depends on what type of rock it is and how old it might be. Different radioactive isotopes have different half lives and so they are useful for dating different types and ages of rocks. Who would want to? Why, geologists, of course!

Radiometric Dating of Rocks

Radiometric dating is the process of using the concentrations of radioactive substances and daughter products to estimate the age of a material. Different isotopes are used to date materials of different ages. Using more than one isotope helps scientists to check the accuracy of the ages that they calculate.

Radiocarbon Dating

Radiocarbon dating is used to find the age of once-living materials between 100 and 50,000 years old. This range is especially useful for determining ages of human fossils and habitation sites (**Figure** 4.14).

The atmosphere contains three isotopes of carbon: carbon-12, carbon-13 and carbon-14. Only carbon-14 is radioactive; it has a half-life of 5,730 years. The amount of carbon-14 in the atmosphere is tiny and has been relatively stable through time.

Plants remove all three isotopes of carbon from the atmosphere during photosynthesis. Animals consume this carbon when they eat plants or other animals that have eaten plants. After the organism's death, the carbon-14 decays to stable nitrogen-14 by releasing a beta particle. The nitrogen atoms are lost to the atmosphere, but the amount of carbon-14 that has decayed can be estimated by measuring the proportion of radioactive carbon-14 to stable carbon-12. As time passes, the amount of carbon-14 decreases relative to the amount of carbon-12.

FIGURE 4.14
Carbon isotopes from the black material in these cave paintings places their creating at about 26,000 to 27,000 years BP (before present).

A video of carbon-14 decay is seen here: http://www.youtube.com/watch?v=81dWTeregEA ; a longer explanation is here: http://www.youtube.com/watch?v=udkQwW6aLik .

Potassium-Argon Dating

Potassium-40 decays to argon-40 with a half-life of 1.26 billion years. Argon is a gas so it can escape from molten magma, meaning that any argon that is found in an igneous crystal probably formed as a result of the decay of potassium-40. Measuring the ratio of potassium-40 to argon-40 yields a good estimate of the age of that crystal.

Potassium is common in many minerals, such as feldspar, mica, and amphibole. With its half-life, the technique is used to date rocks from 100,000 years to over a billion years old. The technique has been useful for dating fairly young geological materials and deposits containing the bones of human ancestors.

Uranium-Lead Dating

Two uranium isotopes are used for radiometric dating.

- Uranium-238 decays to lead-206 with a half-life of 4.47 billion years.
- Uranium-235 decays to form lead-207 with a half-life of 704 million years.

Uranium-lead dating is usually performed on zircon crystals (**Figure** 4.15). When zircon forms in an igneous rock, the crystals readily accept atoms of uranium but reject atoms of lead. If any lead is found in a zircon crystal, it can be assumed that it was produced from the decay of uranium.

Uranium-lead dating is useful for dating igneous rocks from 1 million years to around 4.6 billion years old. Zircon crystals from Australia are 4.4 billion years old, among the oldest rocks on the planet.

FIGURE 4.15
Zircon crystal.

Limitations of Radiometric Dating

Radiometric dating is a very useful tool for dating geological materials but it does have limits:

1. The material being dated must have measurable amounts of the parent and/or the daughter isotopes. Ideally, different radiometric techniques are used to date the same sample; if the calculated ages agree, they are thought to be accurate.
2. Radiometric dating is not very useful for determining the age of sedimentary rocks. To estimate the age of a sedimentary rock, geologists find nearby igneous rocks that can be dated and use relative dating to constrain the age of the sedimentary rock.

Using Radiometric Ages to Date Other Materials

As you've learned, radiometric dating can only be done on certain materials. But these important numbers can still be used to get the ages of other materials! How would you do this? One way is to constrain a material that cannot be dated by one or more that can. For example, if sedimentary rock A is below volcanic rock B and the age of volcanic rock B is 2.0 million years, then you know that sedimentary rock A is older than 2.0 million years. If sedimentary rock A is above volcanic rock C and it's age is 2.5 million years then you know that sedimentary rock A is between 2.0 and 2.5 million years. In this way, geologists can figure out the approximate ages of many different rock formations.

Summary

- Radiocarbon is useful for relatively young, carbon-based materials; other longer-lived isotopes are good for older rocks and minerals.
- Different isotope pairs are useful for certain materials of certain ages.
- Radiometric dating cannot be used if parent or daughter are not measurable or if one or the other has been lost from the system.

Practice

Use this resource to answer the questions that follow.

Radionetric Dating

http://www.youtube.com/watch?v=1920gi3swe4

MEDIA

Click image to the left for more content.

1. What do scientists want to answer with radiometric dating?
2. What is the easiest way to date rocks?
3. How do we get actual dates on rocks?
4. How is the rock crushed?
5. What are scientists looking for in this rock?
6. Who came up with the principle of radiometric dating?
7. What is the mass spectrometer? Who invented it?
8. What is the spectrometer separating in this rock?
9. Why is the dating of rocks important?
10. What is the age of the Earth?

Review

1. How would you determine which isotope pair to use for a particular material?
2. How does radiocarbon dating work and on what materials does it work best on?
3. What types of rocks are best fro radiometric dating and why?

4.9 Tree Rings, Ice Cores, and Varves

- Learn three ways that scientists can get an absolute age, tree rings, ice cores and varves.

How can scientists tell the oldest possible age of this painting?

The Netherlandish paintings, which were painted in the low-lying countries of and near the Netherlands, were painted on solid wood panels, usually oak. The wood was split radially so that tree rings are visible and dates for the paintings date, which are from the 15th and 16th centuries, can be determined. Why does this give the oldest possible age?

Tree Ring Dating

In locations where summers are warm and winters are cool, trees have a distinctive growth pattern. Tree trunks display alternating bands of light-colored, low density summer growth and dark, high density winter growth. Each light-dark band represents one year. By counting **tree rings** it is possible to find the number of years the tree lived (**Figure** 4.16).

The width of these growth rings varies with the conditions present that year. A summer drought may make the tree grow more slowly than normal and so its light band will be relatively small. These tree-ring variations appear in all trees in a region. The same distinctive pattern can be found in all the trees in an area for the same time period.

Scientists have created continuous records of tree rings going back over the past 2,000 years. Wood fragments from old buildings and ancient ruins can be age dated by matching up the pattern of tree rings in the wood fragment in question and the scale created by scientists. The outermost ring indicates when the tree stopped growing; that is, when it died. The tree-ring record is extremely useful for finding the age of ancient structures.

FIGURE 4.16
Cross-section showing growth rings.

An example of how tree-ring dating is used to date houses in the United Kingdom is found in this article: http://www.periodproperty.co.uk/ppuk_discovering_article_013.shtml .

Ice Cores

Besides tree rings, other processes create distinct yearly layers that can be used for dating. On a glacier, snow falls in winter but in summer dust accumulates. This leads to a snow-dust annual pattern that goes down into the ice (**Figure** 4.17). Scientists drill deep into ice sheets, producing **ice cores** hundreds of meters long. The information scientists gather allows them to determine how the environment has changed as the glacier has stayed in its position. Analyses of the ice tell how concentrations of atmospheric gases changed, which can yield clues about climate. The longest cores allow scientists to create a record of polar climate stretching back hundreds of thousands of years.

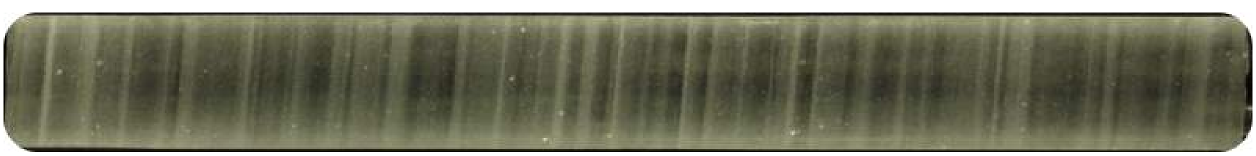


FIGURE 4.17
Ice core section showing annual layers.

Varves

Lake sediments, especially in lakes that are located at the end of glaciers, also have an annual pattern. In the summer, the glacier melts rapidly, producing a thick deposit of sediment. These alternate with thin, clay-rich layers deposited in the winter. The resulting layers, called **varves**, give scientists clues about past climate conditions (**Figure** 4.18). A warm summer might result in a very thick sediment layer while a cooler summer might yield a thinner layer.

FIGURE 4.18
Ancient varve sediments in a rock outcrop.

Summary

- Where conditions vary seasonally, trees develop distinctive rings, ice contains more or less dust, and lake sediments show more or less clay.
- Tree rings, ice cores and varves indicate the environmental conditions at the time they were made.
- The distinctive patterns of tree rings, ice cores and varves going back thousands of years can be used to determine the time they were made.

Practice

Use these resources to answer the questions that follow.

Science Nation - Lord of the Tree Rings

http://www.youtube.com/watch?v=FAOYkx8E-Gc

MEDIA
Click image to the left for more content.

1. What do tree rings tell scientists?
2. What can be learned from tree rings?
3. How are tree rings being used to help current climate change?
4. What type of trees do scientists look for? Why?

Science Nation - Ice Cores Secrets Could Reveal Answers to Global Warming

http://www.youtube.com/watch?v=NENZ6TSc1fo

MEDIA
Click image to the left for more content.

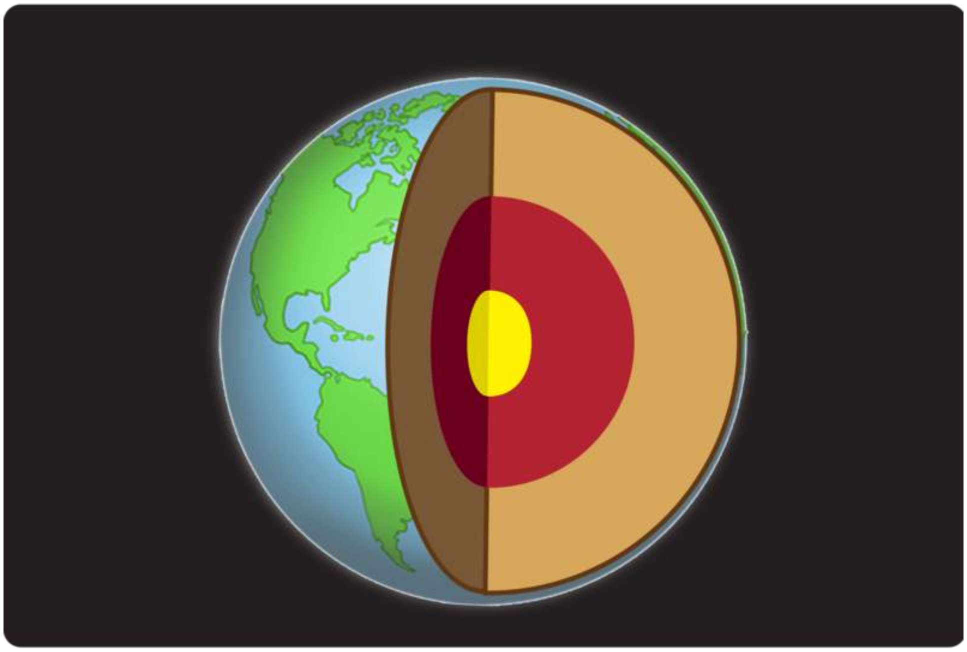
5. What is trapped in the ice cores?
6. How long have ice cores been studied?
7. What can be learned from ice cores?
8. Where are ice cores collected?

Review

1. What is dendrochronology?
2. How do tree rings, ice cores and varves indicate the time at which they were made?
3. How do tree rings, ice cores and varves indicate environmental conditions at the time they formed?

4.10 Earth's Layers

- Identify Earth's layers and describe their characteristics.



What's below our feet? What's way below?

If we could cut Earth open, we'd see the inner core at the center, then the outer core, the mantle in the middle and the crust on the outside. If you are talking about plates, though, there's the brittle lithosphere riding on the plastic asthenosphere. Whew!

Layers by Composition

The layers scientists recognize are pictured below (**Figure** 4.19).

Core, mantle, and crust are divisions based on composition:

1. The **crust** is less than 1% of Earth by mass. The two types are oceanic crust and continental crust.Continental crust is felsic and oceanic crust is mafic.
2. The **mantle** is hot, ultramafic rock. It represents about 68% of Earth's mass.
3. The **core** is mostly iron metal. The core makes up about 31% of the Earth.

Layers by Mechanical Properties

Lithosphere and asthenosphere are divisions based on mechanical properties:

1. The **lithosphere** is composed of both the crust and the portion of the upper mantle and behaves as a brittle, rigid solid.
2. The **asthenosphere** is partially molten upper mantle material and behaves plastically and can flow.

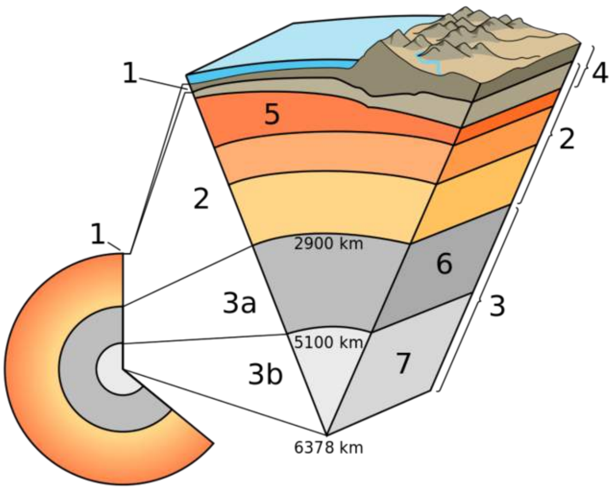


FIGURE 4.19
A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

This animation shows the layers by composition and by mechanical properties: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html .

Summary

- By composition, Earth is divided into core, mantle, and crust.
- By mechanical properties, the crust and upper mantle are divided into lithosphere and asthenosphere.
- Continental crust is felsic, oceanic crust is mafic, the mantle is ultramafic, and the core is metallic.

Interactive Practice

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/structure.html

1. What substances make up the inner core?

2. What is the structure of the inner core?

3. What is the structure of the outer core?

4. Explain the composition of the mantle.

5. What is the asthenosphere?

Review

1. What are the the layers of Earth based on composition and where are they located?

2. What is the composition of the different layers?

3. How do the lithosphere and asthenosphere differ from each other?

4.11 Earth's Core

- Describe the characteristics of Earth's inner core and outer core.

Do you want to take a journey to the center of the earth?

Jules Verne's imagined core was fiery. But we know that the outer core is molten metal, as seen above. As hot as a journey to Verne's center of the earth might have been, a visit to the real location would be worse.

Core

At the planet's center lies a dense metallic core. Scientists know that the core is metal because:

1. The density of Earth's surface layers is much less than the overall density of the planet, as calculated from the planet's rotation. If the surface layers are less dense than average, then the interior must be denser than average. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%.
2. Metallic meteorites are thought to be representative of the core. The 85% iron/15% nickel calculation above is also seen in metallic meteorites (**Figure** 4.20).

If Earth's core were not metal, the planet would not have a magnetic field. Metals such as iron are magnetic, but rock, which makes up the mantle and crust, is not.

Scientists know that the outer core is liquid and the inner core is solid because:

1. S-waves do not go through the outer core.

FIGURE 4.20
An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

2. The strong magnetic field is caused by convection in the liquid outer core. Convection currents in the outer core are due to heat from the even hotter inner core.

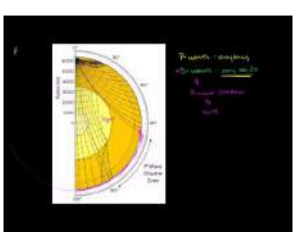
The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core.

Summary

- Earth's core is dense metal.
- The inner core is solid and the outer core is liquid, as indicated by seismic waves.
- Metallic meteorites, density calculations, and the magnetic field are all clues that about the composition of Earth's inner and outer core.

Interactive Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What materials can P-waves travel through?
2. What materials can S-waves travel through?
3. How do we know the outer core is liquid?

4. What happens to P-waves when they go through a liquid?

5. What do P-waves tell about the inner core?

Review

1. Why is there convection in the outer core and what is the result of this?

2. If scientists discovered a major mistake in their calculations and Earth's crust turned out to be much denser than they'd thought, what would this say about the material that makes up the core?

3. What is the outer core so hot?

4.12 Lithosphere and Asthenosphere

- Define lithosphere and asthenosphere, and describe their characteristics.

Can you think of a solid that can flow?

You use one twice a day! Toothpaste is a solid that can flow. Is the asthenosphere made of toothpaste? Only if the toothpaste is ultramafic in composition, and then it would only be able to flow if it were really, really hot. Still the toothpaste analogy gives you a good image of how the asthenosphere might behave if you squeezed it!

Lithosphere

The **lithosphere** is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid. The lithosphere is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. How are crust and lithosphere different from each other?

The definition of the lithosphere is based on how Earth materials behave, so it includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stresses act on the lithosphere, it breaks. This is what we experience as an earthquake.

Although we sometimes refer to Earth's plates as being plates of crust, the plates are actually made of lithosphere. Much more about Earth's plates follows in the chapter "Plate Tectonics."

Asthenosphere

The **asthenosphere** is solid upper mantle material that is so hot that it behaves plastically and can flow. The lithosphere rides on the asthenosphere.

Summary

- The lithosphere is the brittle crust and uppermost mantle.
- The asthenosphere is a solid but it can flow, like toothpaste.
- The lithosphere rests on the asthenosphere.

Interactive Practice

Use this resource to answer the questions that follow.

http://www.windows2universe.org/earth/interior/earths_crust.html

1. What is the lithosphere?

2. How far does the lithosphere extend?

3. What makes up the lithosphere?

4. Why does the lithosphere move?

5. What is the asthenosphere?

6. What causes the asthenosphere to move?

Review

1. Where is the lithosphere? What layers does it include?

2. What is the asthenosphere?

3. How do the lithosphere and asthenosphere differ?

4. If the lithosphere is resting on the asthenosphere and you put a lot of weight on the lithosphere, say ice in a glacier, how would the lithosphere respond?

4.13 Continental Margins

- Understand the differences between active and passive continental margins.

Can plate tectonics explain the differences in these beaches?

Plate tectonics explains why some beaches have lots of cliffs and some do not. A beach with lots of cliffs is near a plate boundary. A gentle beach is not. There are exceptions to this rule, but it works in some cases.

Continental Margins

Think of a continent, like North America. Surrounding the continent are **continental margins**. Continental crust grades into oceanic crust at continental margins. Continental margins are under water. Almost all of North America sits on the North American Plate (**Figure** 4.21). Both sides of the continent have continental margins, but each is very different. One continental margin of North America is an active margin. The other is a passive margin. Can you guess which is which?

Active Margins

If a continental margin is near a plate boundary, it is an **active margin**. The continental margin of western North America is near a set of plate boundaries. There are convergent boundaries, like where there is subduction off of the Pacific Northwest. There is a transform boundary, the San Andreas Fault. The small amount of the North American continent that is not on the North American Plate is across the San Andreas Fault. It is on the Pacific Plate. Western North America has a lot of volcanoes and earthquakes. Mountains line the region. California, with its volcanoes and earthquakes, is an important part of this active margin (**Figure** 4.22).

Passive Margins

There are no volcanoes and very few earthquakes on the eastern edge of North America. The continental margin is a smooth transition from continental to oceanic lithosphere. The continental margin there becomes oceanic lithosphere, but both are on the North American Plate. There is no plate boundary. The far eastern edge of the North American Plate is the mid-Atlantic Ridge. The portion of a plate that does not meet another plate has no geological activity. It is called a **passive margin** (**Figure** 4.23).

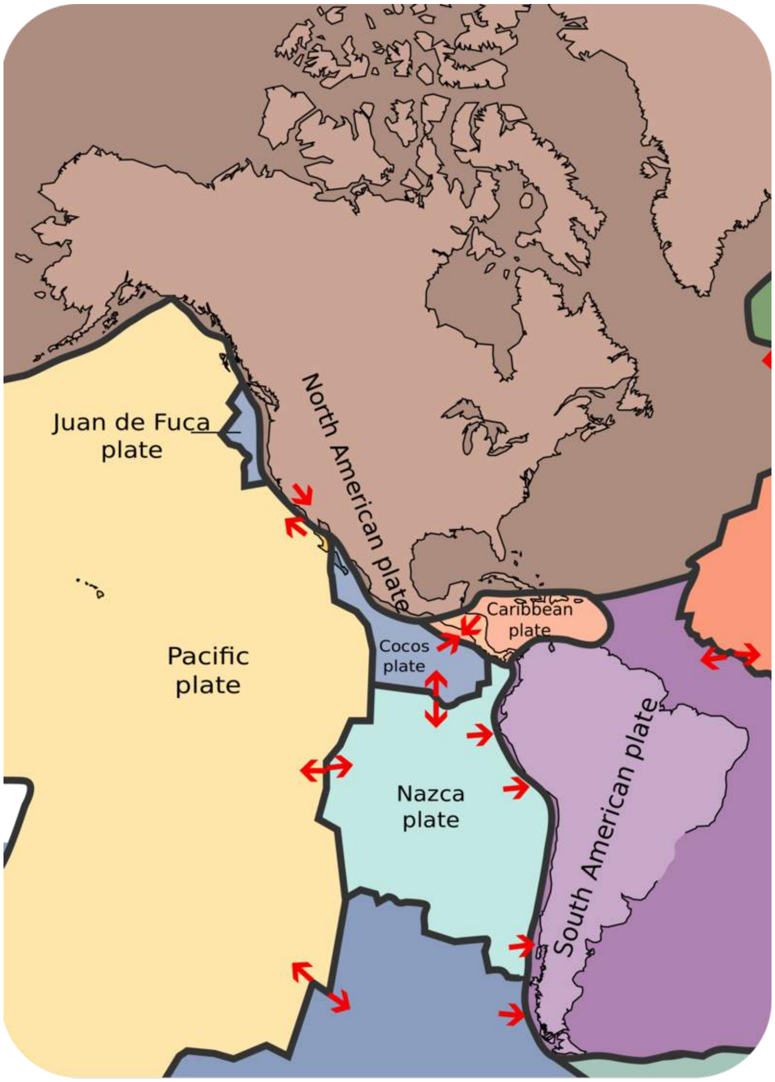


FIGURE 4.21
The North American plate and the plates that surround it.

FIGURE 4.22
Big Sur, in central California, has beautiful cliff-lined beaches.

FIGURE 4.23
The eastern U.S. is a passive margin. Daytona Beach in Florida is flat and sandy, typical of a passive margin.

Vocabulary

- **active margin**: Part of a plate that has a lot of geological activity; this is because this part of the plate meets another plate.
- **continental margin**: Outer edge of a continent where it transitions to oceanic lithosphere; the continental margin is under water.
- **passive margin**: Part of a plate that has no geological activity; this part of the plate is not meeting with another plate.

Summary

- Continental margins can be active or passive depending on whether they are near a plate boundary.
- Volcanoes and earthquakes are common at active margins. Active margins are near plate boundaries.
- Passive margins are passive. They have little or no geological activity.

Practice

Use the resource below to answer the questions that follow.

- **Features of the Continental Margins** at

http://www.onr.navy.mil/focus/ocean/regions/oceanfloor2.htm

1. What is the continental shelf?
2. What does the continental shelf contain?
3. What is the continental slope?
4. What is the continental margin?
5. What is the continental rise?

Review

1. Describe the continental margin of Western North America.

2. Describe the continental margin of Eastern North America.
3. Why are there mountain ranges at passive margins?

4.14 Divergent Plate Boundaries

- Describe the activity and features of divergent plate boundaries on land.

What can we see in Western North America?

When we got off the Atlantis in Iceland a new batch of scientists got on for a different scientific investigation. We're now going to fly to western North America to see a different set of plate tectonic features. Western North America has all three of the different types of plate boundaries and the features that are seen at them.

Tectonic Features of Western North America

We're on a new trip now. We will start in Mexico, in the region surrounding the Gulf of California, where a divergent plate boundary is rifting Baja California and mainland Mexico apart. Then we will move up into California, where plates on both sides of a transform boundary are sliding past each other. Finally we'll end up off of the Pacific Northwest, where a divergent plate boundary is very near a subduction zone just offshore.

In the **Figure** 4.24 a red bar where seafloor spreading is taking place. A long black line is a transform fault and a black line with hatch marks is a trench where subduction is taking place. Notice how one type of plate boundary transitions into another.

Plate Divergence on Land

A divergent plate boundary on land rips apart continents (**Figure** 4.25).

In **continental rifting**, magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, ultimately creating an ocean between continents. On either side of the ocean are now two different lithospheric plates. This is how continents split apart.

These features are well displayed in the East African Rift, where rifting has begun, and in the Red Sea, where water is filling up the basin created by seafloor spreading. The Atlantic Ocean is the final stage, where rifting is now separating two plates of oceanic crust.

FIGURE 4.24
This map shows the three major plate boundaries in or near California.

Baja California

Baja California is a state in Mexico just south of California. In the **Figure** 4.26, Baja California is the long, skinny land mass on the left. You can see that the Pacific Ocean is growing in between Baja California and mainland Mexico. This body of water is called the Gulf of California or, more romantically, the Sea of Cortez. Baja is on the Pacific Plate and the rest of Mexico is on the North American Plate. Extension is causing the two plates to move apart and will eventually break Baja and the westernmost part of California off of North America. The Gulf of California will expand into a larger sea.

Rifting has caused volcanic activity on the Baja California peninsula as seen in the **Figure** 4.27.

Can you relate what is happening at this plate boundary to what happened when Pangaea broke apart?

Summary

- Where continental rifting takes place, continents are split apart and an ocean may grow or be created between the two new plates.
- Baja California is rifting apart from mainland Mexico.
- Continental rifting can create major ocean basins, like the Atlantic.

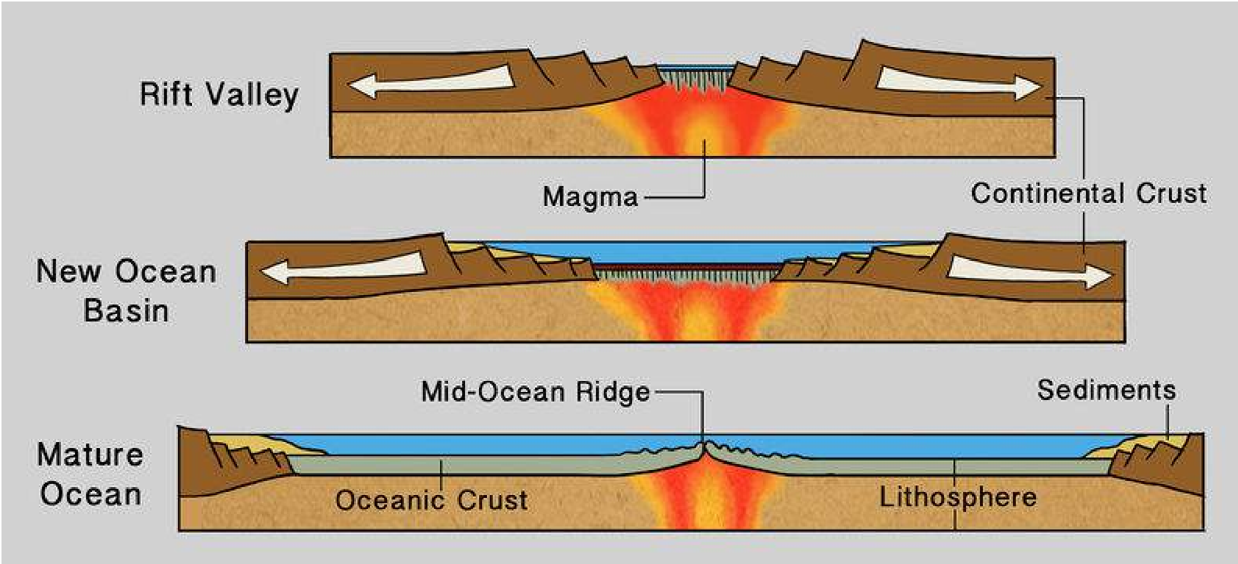
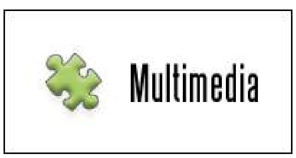


FIGURE 4.25
When plate divergence occurs on land, the continental crust rifts, or splits. This effectively creates a new ocean basin as the pieces of the continent move apart.

Making Connections



MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

http://www.cotf.edu/ete/modules/msese/earthsysflr/plates3.html

1. What are divergent boundaries?
2. What layer is pulled apart?
3. What occurs along the faults on land?
4. What results when the magma reaches the surface?
5. List examples of rift valleys on land.

Review

1. How is a divergent plate boundary on land different from one in the ocean?

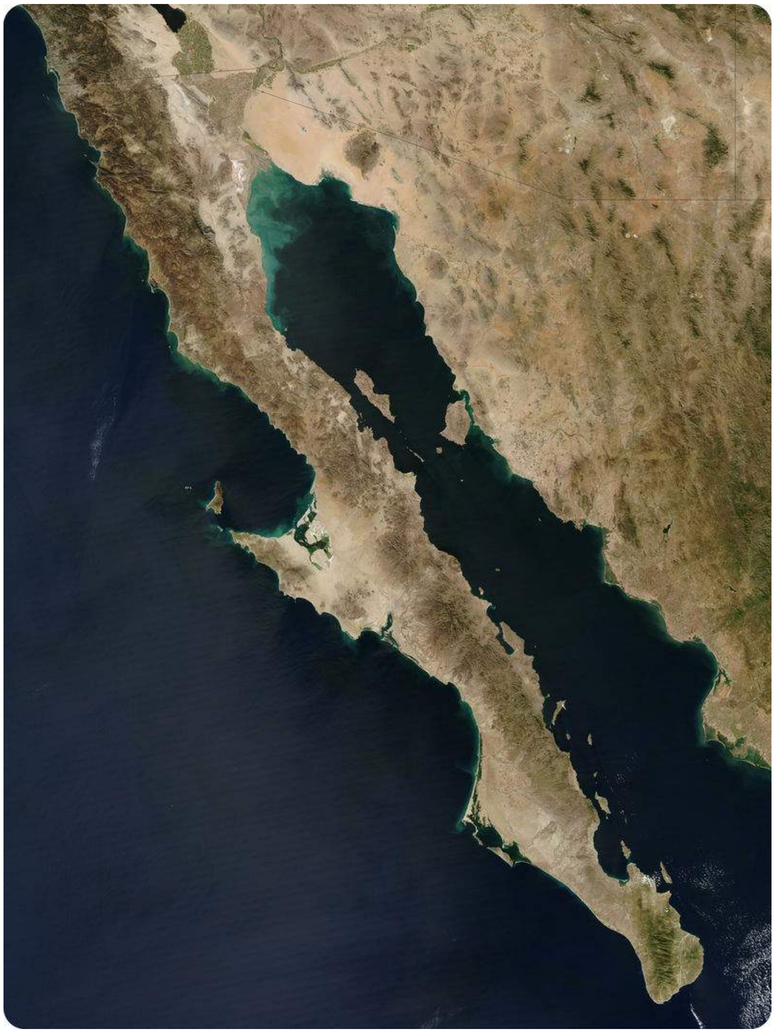


FIGURE 4.26
Baja California is rifting apart from mainland Mexico, as seen in this satellite image.

2. What is happening to the Baja California peninsula?
3. How did continental rifting play into the breakup of Pangaea?

FIGURE 4.27

Volcanism in Baja California is evidence of rifting.

4.15 Ocean-Continent Convergent Plate Boundaries

- Describe the activity and features of convergent plate boundaries where an oceanic plate meets a continental plate.

What do you see at an ocean-continent convergent boundary?

We continue our field trip up the West Coast. Just offshore from Washington, Oregon, and Northern California is a subduction zone, where the Juan de Fuca Plate is sinking into the mantle. The Juan de Fuca Plate is being created at a spreading center, the Juan de Fuca Ridge. Let's see the results of subduction of the Juan de Fuca Plate.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. The three possibilities are oceanic crust to oceanic crust, oceanic crust to continental crust, or continental crust to continental crust. If at least one of the slabs of lithosphere is oceanic, that oceanic plate will plunge into the trench and back into the mantle. The meeting of two enormous slabs of lithosphere and subduction of one results in magma generation and earthquakes. If both plates meet with continental crust, there will be mountain building. Each of the three possibilities is discussed in a different concept.

In this concept we look at subduction of an oceanic plate beneath a continental plate in the Pacific Northwest.

Ocean-Continent Convergence

When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process, called **subduction**, occurs at the oceanic trenches. The entire region is known as a **subduction zone**. Subduction zones have a lot of intense earthquakes and volcanic eruptions. The subducting plate causes melting in the mantle above the plate. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate (**Figure** 4.28). The volcanoes are known as a **continental arc**.

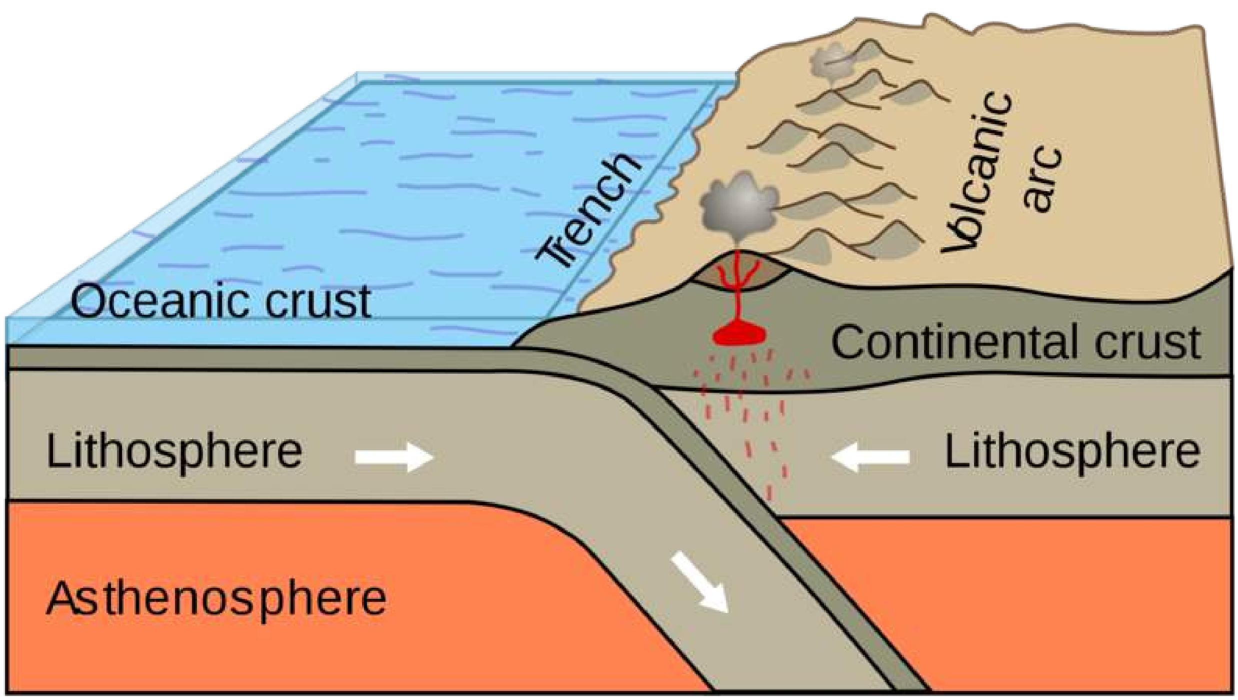


FIGURE 4.28
Subduction of an oceanic plate beneath a continental plate causes earthquakes and forms a line of volcanoes known as a continental arc.

The movement of crust and magma causes earthquakes. A map of earthquake epicenters at subduction zones is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_earthquakessubduction.html .

This animation shows the relationship between subduction of the lithosphere and creation of a volcanic arc: http://e arthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html .

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

Cascades Volcanoes

The volcanoes of northeastern California —Lassen Peak, Mount Shasta, and Medicine Lake volcano —along with the rest of the Cascade Mountains of the Pacific Northwest, are the result of subduction of the Juan de Fuca plate beneath the North American plate (**Figure** 4.29). The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.

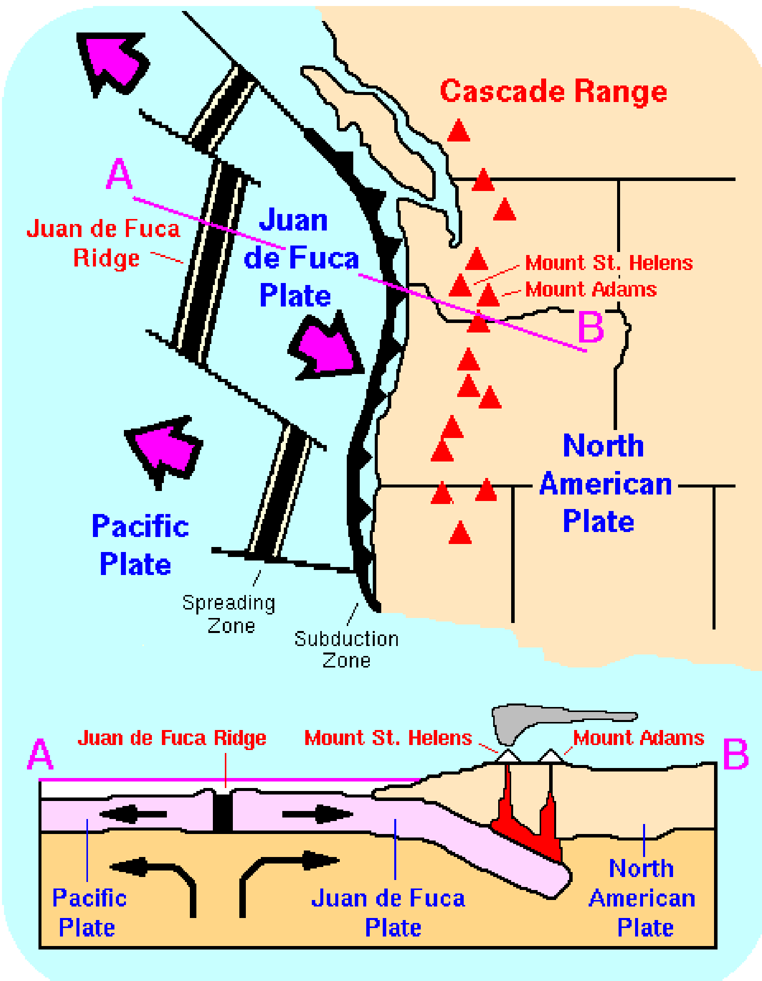


FIGURE 4.29
The Cascade Mountains of the Pacific Northwest are a continental arc.

Intrusions at a Convergent Boundary

If the magma at a continental arc is felsic, it may be too viscous (thick) to rise through the crust. The magma will cool slowly to form granite or granodiorite. These large bodies of intrusive igneous rocks are called **batholiths**, which may someday be uplifted to form a mountain range. California has an ancient set of batholiths that make up the Sierra Nevada mountains (**Figure** 4.30).

FIGURE 4.30
The Sierra Nevada batholith cooled beneath a volcanic arc roughly 200 million years ago. The rock is well exposed here at Mount Whitney. Similar batholiths are likely forming beneath the Andes and Cascades today.

An animation of an ocean continent plate boundary is seen here: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Convergent_480.mov .

Summary

- When two plates come towards each other they create a convergent plate boundary.
- The plates can meet where both have oceanic crust or both have continental crust, or they can meet where one has oceanic and one has continental.
- Dense oceanic crust will subduct beneath continental crust or a less dense slab of oceanic crust.
- The oceanic plate subducts into a trench, resulting in earthquakes. Melting of mantle material creates volcanoes at the subduction zone.
- If the magma is too viscous to rise to the surface it will become stuck in the crust to create intrusive igneous rocks.

Making Connections

MEDIA

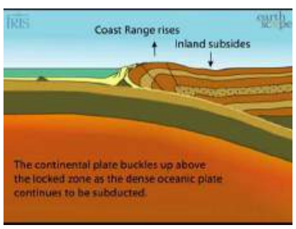
Click image to the left for more content.

Practice

Use these resources to answer the questions that follow.

http://www.nature.nps.gov/geology/usgsnps/pltec/converge.html

1. Describe a subduction zone.
2. What forms this subduction zone?
3. How far does the subducting oceanic plate descend?
4. What is formed on the continental plate?
5. Where can an example of this plate boundary be found?



MEDIA

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6. What is a locked zone?
7. What is produced when the locked zone is released?

Review

1. What is the direction of plate motion at a convergent plate boundary?
2. Describe the relationship between the convection cell and subduction at a trench.
3. Subduction is sometimes called crustal recycling. Why do you think this is the case?
4. What happens if magma is too viscous to rise through the crust to erupt at the surface?

4.16 Ocean-Ocean Convergent Plate Boundaries

- Learn the activity and features of convergent plate boundaries where one oceanic plate subducts beneath another oceanic plate.

What do you see in this satellite photo?

We continue our trip up western North America to find a convergent plate boundary where oceanic crust subducts beneath oceanic crust. North of the contiguous U.S. lies Canada, and north of Canada lies Alaska. A line of volcanoes, known as the Aleutian Islands, is the result of ocean-ocean convergence. In this satellite image is an erupting volcano, topped by snow or ice, and surrounded by seawater - a member of the Aleutian chain. Let's take a look at this boundary and the volcanic arc.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. We explored what happens when oceanic crust meets continental crust. Another type of convergent plate boundary is found where two oceanic plates meet. In this case the older, denser slab of oceanic crust will plunge beneath the less dense one.

Ocean-Ocean

The features of a subduction zone where an oceanic plate subducts beneath another oceanic plate are the same as a continent-ocean subduction zone. An ocean trench marks the location where the plate is pushed down into the mantle. In this case, the line of volcanoes that grows on the upper oceanic plate is an **island arc**. Do you think earthquakes are common in these regions (**Figure** 4.31)?

In the north Pacific, the Pacific Plate is subducting beneath the North American Plate just as it was off of the coast of the Pacific Northwest. The difference is that here the North American plate is covered with oceanic crust. Remember

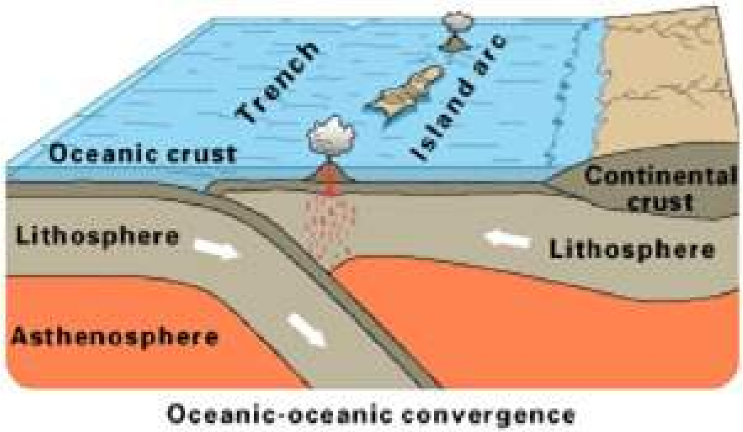


FIGURE 4.31
Subduction of an ocean plate beneath other oceanic crust results in a volcanic island arc, an ocean trench, and many earthquakes

that most plates are made of different types of crust. This subduction creates the Aleutian Islands, many of which are currently active (see **Figure** 4.32). Airplanes sometimes must avoid flying over these volcanoes for fear of being caught in an eruption.

Summary

- If the two plates that meet at a convergent plate boundary both are of oceanic crust, the older, denser plate will subduct beneath the less dense plate.
- The features of an ocean-ocean subduction zone are the same as those of an ocean-continent subduction zone, except that the volcanic arc will be a set of islands known as an island arc.
- The older plate subducts into a trench, resulting in earthquakes. Melting of mantle material creates volcanoes at the subduction zone.

Practice

Use this resource to answer the questions that follow.

http://science7.com/ES-PlateTect-PlateMove.htm

1. What forms where two oceanic plates converge?

2. Explain how an island volcano forms.

3. What is an island arc?

4. Give two examples of island arcs.

5. How is magma produced?

Review

1. Compare and contrast the features of an ocean-ocean convergent plate boundary with the features of an ocean-continent convergent plate boundary.

2. How do the Aleutian volcanoes differ from the Cascades volcanoes?

3. How do island arcs get their name?

FIGURE 4.32

The arc of the island arc that is the Aleutian Islands is easily seen in this map of North Pacific air routes over the region.

4.17 Transform Plate Boundaries

- Describe the activity and features of transform plate boundaries on land and in the ocean.

What could cause such an enormous scar on the land?

A transform plate boundary! As we continue up the West Coast, we move from a divergent plate boundary to a transform plate boundary. As in Iceland, where we could walk across a short bridge connecting two continental plates, we could walk from the Pacific Plate to the North American plate across this transform plate boundary. In this image, the San Andreas Fault across central California is the gash that indicates the plate boundary.

Transform Plate Boundaries

With transform plate boundaries, the two slabs of lithosphere are sliding past each other in opposite directions. The boundary between the two plates is a **transform fault**.

Transform Faults On Land

Transform faults on continents separate two massive plates of lithosphere. As they slide past each other, they may have massive earthquakes.

The San Andreas Fault in California is perhaps the world's most famous transform fault. Land on the west side is moving northward relative to land on the east side. This means that Los Angeles is moving northward relative to Palm Springs. The San Andreas Fault is famous because it is the site of many earthquakes, large and small. (**Figure** 4.33).

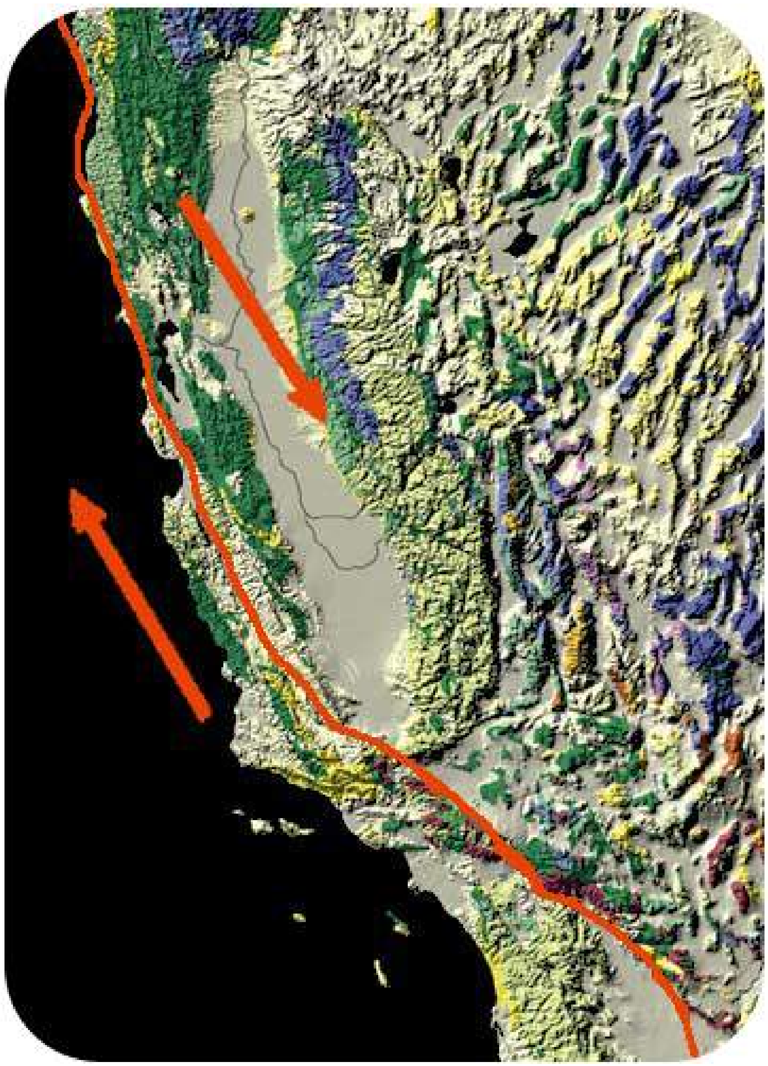


FIGURE 4.33

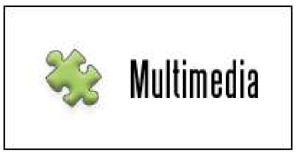
At the San Andreas Fault in California, the Pacific Plate is sliding northeast relative to the North American plate, which is moving southwest. At the northern end of the picture, the transform boundary turns into a subduction zone.

Transform plate boundaries are also found in the oceans. They divide mid-ocean ridges into segments. In the diagram of western North America, the mid-ocean ridge up at the top, labeled the Juan de Fuca Ridge, is broken apart by a transform fault in the oceans. A careful look will show that different plates are found on each side of the ridge: the Juan de Fuca plate on the east side and the Pacific Plate on the west side.

Summary

- A transform plate boundary divides two plates that are moving in opposite direction from each other.
- On land, transform faults are the site of massive earthquakes because they are where large slabs of lithosphere slide past each other.
- Transform faults in the oceans break mid-ocean ridges into segments.

Making Connections



MEDIA

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Practice

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/slip3.html

1. Describe the motion of transform boundaries.
2. What is a fault?
3. What do transform boundaries produce?
4. Explain a strike-slip fault.
5. What is the best studied fault?
6. What two plates make this boundary?
7. Which direction are each of these plates moving?

Review

1. What is the direction of plate motion at a transform plate boundary?
2. Why are transform faults on continents prone to massive earthquakes?
3. How do transform faults in the oceans compare with those on land?

4.18 Earthquake Characteristics

- Define earthquakes, and explain how they occur.

Does ground shaking cause the greatest damage in an earthquake?

This photo shows the Mission District of San Francisco burning after the 1906 earthquake. The greatest damage in earthquakes is often not from the ground shaking but from the effects of that shaking. In this earthquake, the shaking broke the gas mains and the water pipes so that when the gas caught fire there was no way to put it out. Do you wonder why the people standing in the street are looking toward the fire rather than running in the opposite direction?

Earthquake!

An **earthquake** is sudden ground movement caused by the sudden release of energy stored in rocks. Earthquakes happen when so much stress builds up in the rocks that the rocks rupture. The energy is transmitted by seismic waves. Earthquakes can be so small they go completely unnoticed, or so large that it can take years for a region to recover.

Elastic Rebound Theory

The description of how earthquakes occur is called **elastic rebound theory** (**Figure** 4.34).

Elastic rebound theory in an animation: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Elastic+Rebound&flash_file=elasticrebound&flash_width=300&flash_height=350 .

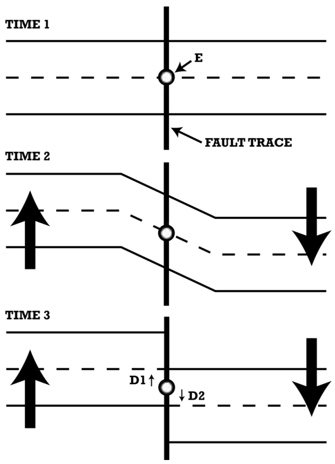


FIGURE 4.34
Elastic rebound theory. Stresses build on both sides of a fault, causing the rocks to deform plastically (Time 2). When the stresses become too great, the rocks break and end up in a different location (Time 3). This releases the built up energy and creates an earthquake.

Focus and Epicenter

In an earthquake, the initial point where the rocks rupture in the crust is called the **focus**. The **epicenter** is the point on the land surface that is directly above the focus (**Figure** 4.35).

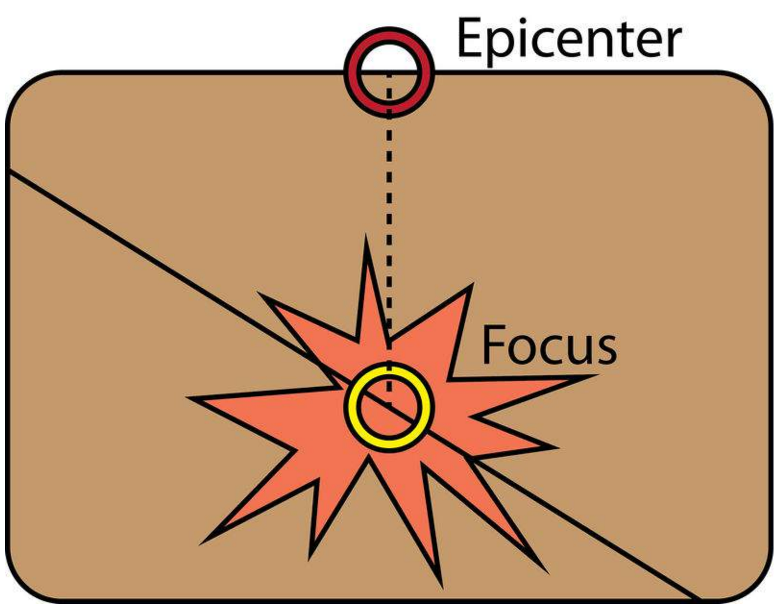


FIGURE 4.35
In the vertical cross section of crust, there are two features labeled - the focus and the epicenter, which is directly above the focus.

In about 75% of earthquakes, the focus is in the top 10 to 15 kilometers (6 to 9 miles) of the crust. Shallow earthquakes cause the most damage because the focus is near where people live. However, it is the epicenter of an earthquake that is reported by scientists and the media.

Summary

- A sudden release of energy stored in rocks causes an earthquake.
- The focus is where the rocks rupture. The epicenter is the point on the ground directly above the focus.
- Most earthquakes are shallow; these do the most damage.

Practice

Use this resource to answer the questions that follow.

http://www.pbs.org/wnet/savageearth/animations/earthquakes/main.html

1. What causes an earthquake?
2. What is the focus?
3. Which waves travel the fastest?
4. Which waves cannot travel through the core?
5. What happens to the waves as distance increases?

Review

1. How does elastic rebound theory describe how an earthquake takes place?
2. Where is an earthquake's focus? Where is its epicenter?
3. Why do shallow earthquakes cause the most damage?

4.19 Seismic Waves

- Identify and define the components of a wave.
- Identify and define the types of seismic waves.
- Explain how scientists use seismic waves to study Earth's interior.

How is a seismologist like a medical doctor?

Just as a medical doctor uses an MRI, CT scan, or x-ray to see inside a patient's body, seismologists use wave energy to learn about Earth's interior. The difference is that the doctor can run the energy through the patient at any time. Scientists need to wait for an earthquake to get information about Earth's interior.

Waves

Energy is transmitted in waves. Every wave has a high point called a **crest** and a low point called a **trough**. The height of a wave from the center line to its crest is its **amplitude**. The distance between waves from crest to crest (or trough to trough) is its **wavelength**. The parts of a wave are illustrated in **Figure** 4.36.

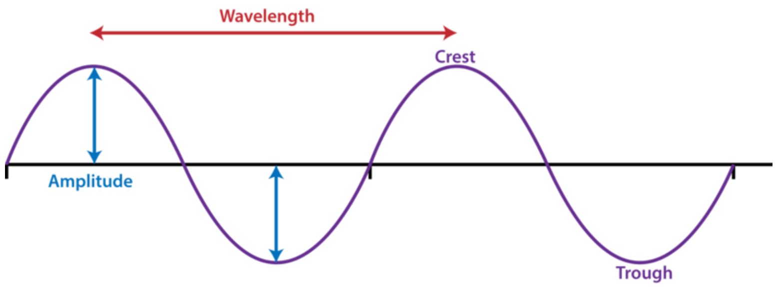


FIGURE 4.36
The crest, trough, and amplitude are illustrated in this diagram.

Earthquake Waves

The energy from earthquakes travels in waves. The study of seismic waves is known as **seismology**. Seismologists use seismic waves to learn about earthquakes and also to learn about the Earth's interior.

One ingenious way scientists learn about Earth's interior is by looking at earthquake waves. Seismic waves travel outward in all directions from where the ground breaks and are picked up by seismographs around the world. Two types of seismic waves are most useful for learning about Earth's interior.

Body Waves

P-waves and S-waves are known as **body waves** because they move through the solid body of the Earth. P-waves travel through solids, liquids, and gases. S-waves only move through solids (**Figure** 4.37). Surface waves only travel along Earth's surface. In an earthquake, body waves produce sharp jolts. They do not do as much damage as surface waves.

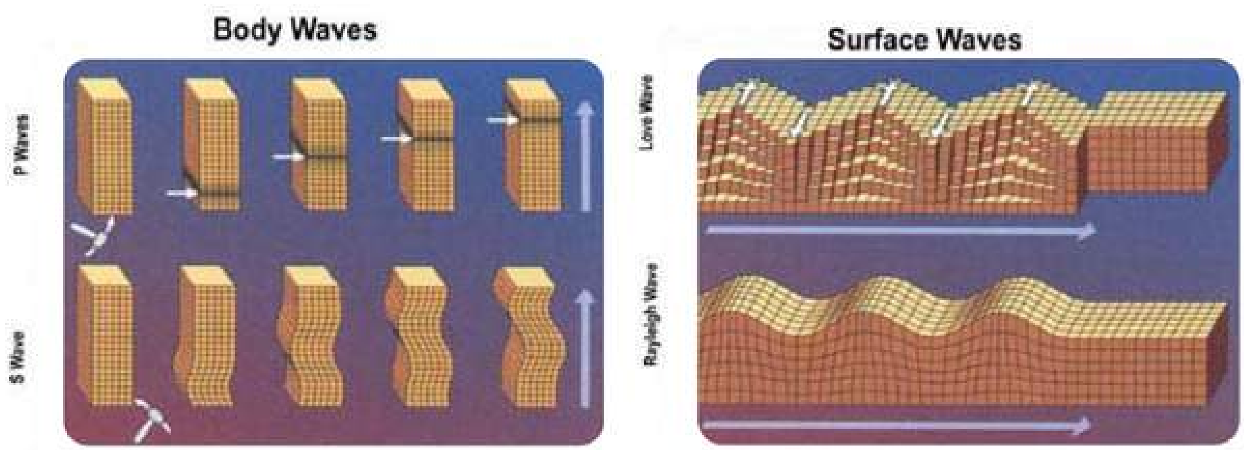


FIGURE 4.37

- **P-waves** (primary waves) are fastest, traveling at about 6 to 7 kilometers (about 4 miles) per second, so they arrive first at the seismometer. P-waves move in a compression/expansion type motion, squeezing and unsqueezing Earth materials as they travel. This produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. Seismic waves move faster through denser or more rigid material. As P-waves encounter the liquid outer core, which is less rigid than the mantle, they slow down. This makes the P-waves arrive later and further away than would be expected. The result is a P-wave shadow zone. No P-waves are picked up at seismographs 104^o to 140^o from the earthquakes focus.

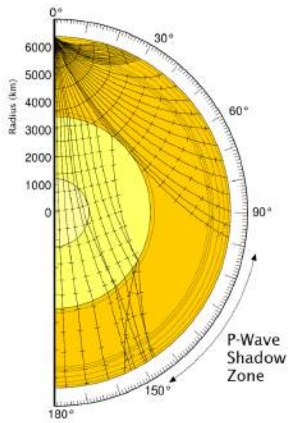


FIGURE 4.38
How P-waves travel through Earth's interior.

- **S-waves** (secondary waves) are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second, and arrive second at seismographs. S-waves move in an up and down motion perpendicular to the direction of wave travel. This produces a change in shape for the Earth materials they move through. Only solids resist a change in shape, so S-waves are only able to propagate through solids. S-waves cannot travel through liquid.

Earth's Interior

By tracking seismic waves, scientists have learned what makes up the planet's interior (**Figure** 4.39).

- P-waves slow down at the mantle core boundary, so we know the outer core is less rigid than the mantle.
- S-waves disappear at the mantle core boundary, so we know the outer core is liquid.

Surface Waves

Surface waves travel along the ground, outward from an earthquake's epicenter. Surface waves are the slowest of all seismic waves, traveling at 2.5 km (1.5 miles) per second. There are two types of surface waves. The rolling motions of surface waves do most of the damage in an earthquake.

Interesting earthquake videos are seen at National Geographic Videos, Environment Video, Natural Disasters, Earthquakes: http://video.nationalgeographic.com/video/player/environment/ . Titles include:

- "Earthquake 101."
- "Inside Earthquakes" looks at this sudden natural disaster.

This animation shows a seismic wave shadow zone: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Shadow+Zone&flash_file=shadowzone&flash_width=220&flash_height=320 .

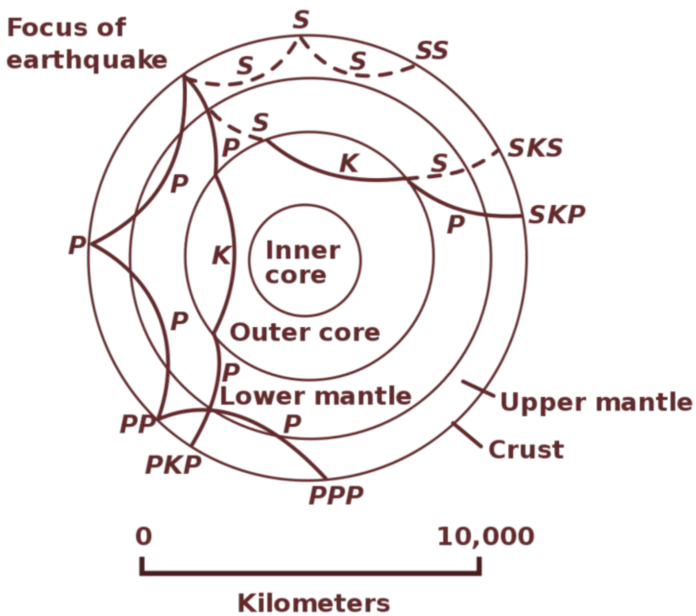


FIGURE 4.39
Letters describe the path of an individual P-wave or S-wave. Waves traveling through the core take on the letter K.

Summary

- P-waves arrive first to a seismograph because they are faster. They travel through solids, liquids, and gases.
- S-waves arrive second to a seismograph, and they only travel through solids.
- The behavior of P- and S-waves indicates that the outer core is liquid.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What types of waves do earthquakes produce?
2. What are the fastest body waves?
3. What is the shadow zone?
4. What do S-waves do?
5. List and explain the two types of surface waves.

Review

1. What are the properties of P-waves?

2. What are the properties of S-waves?
3. How do scientists use seismic waves to learn about Earth's interior?

4.20 Scales that Represent Earthquake Magnitude

- Describe how scientists express the size and intensity of an earthquake.

How do scientists measure earthquakes?

This 6.3 magnitude earthquake in Christchurch, New Zealand in 2011 caused 181 deaths and thousands of injuries. Earthquakes and the damage they cause can be measured in a few different ways based on the damage they cause or the energy of the quake.

Measuring Earthquakes

People have always tried to quantify the size of and damage done by earthquakes. Since early in the 20^{th} century, there have been three methods. What are the strengths and weaknesses of each?

Mercalli Intensity Scale

Earthquakes are described in terms of what nearby residents felt and the damage that was done to nearby structures. What factors would go into determining the damage that was done and what the residents felt in a region?

Richter Magnitude Scale

Developed in 1935 by Charles Richter, this scale uses a seismometer to measure the magnitude of the largest jolt of energy released by an earthquake.

Moment Magnitude Scale

This scale measures the total energy released by an earthquake. Moment magnitude is calculated from the area of the fault that is ruptured and the distance the ground moved along the fault.

Log Scales

The Richter scale and the moment magnitude scale are **logarithmic scales**.

- The amplitude of the largest wave increases ten times from one integer to the next.
- An increase in one integer means that thirty times more energy was released.
- These two scales often give very similar measurements.

How does the amplitude of the largest seismic wave of a magnitude 5 earthquake compare with the largest wave of a magnitude 4 earthquake? How does it compare with a magnitude 3 quake? The amplitude of the largest seismic wave of a magnitude 5 quake is 10 times that of a magnitude 4 quake and 100 times that of a magnitude 3 quake.

How does an increase in two integers on the moment magnitude scale compare in terms of the amount of energy released? Two integers equals a 900-fold increase in released energy.

Moment Magnitude Scale is Best

Which scale do you think is best? With the Richter scale, a single sharp jolt measures higher than a very long intense earthquake that releases more energy. The moment magnitude scale more accurately reflects the energy released and the damage caused. Most seismologists now use the moment magnitude scale.

The way scientists measure earthquake intensity and the two most common scales, Richter and moment magnitude, are described along with a discussion of the 1906 San Francisco earthquake in *Measuring Earthquakes* video **(3d)**: http://www.youtube.com/watch?v=wtlu_aDteCA (2:54).

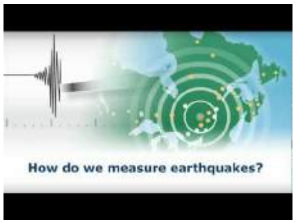
MEDIA
Click image to the left for more content.

Summary

- Mercalli Intensity Scale depends on many factors besides the amount of energy released in the earthquake including the type of basement rock and the quality of the structures built in the area.
- The Richter scale is a logarithmic scale that measures the largest jolt of energy released by an earthquake.
- The moment magnitude scale is a logarithmic scale that measures the total amount of energy released by an earthquake.

Practice

Use this resource to answer the questions that follow.



MEDIA

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1. How is earthquake strength measured?
2. What is magnitude?
3. What do scientists use to measure earthquakes?
4. How is magnitude calculated?
5. What is intensity?
6. What does intensity depend upon?
7. How does geology affect intensity?

Review

1. Under what circumstances might the Mercalli Intensity Scale be useful today? Why was it replaced by the Richter and then the moment magnitude scales?

2. Why do scientists prefer the moment magnitude scale to the Richter scale?

3. How much difference is there between the 5.8 magnitude quake that struck Virginia and the 9.0 quake that struck Japan, both in 2011, in their energy released and largest wave amplitude?

4.21 Locating Earthquake Epicenters

- Explain how to find an earthquake epicenter.

Can you find an earthquake epicenter?

The epicenter of the 2011 Japan earthquake was just offshore of Sendai where the Pacific Plate plunges into a subduction zone. The quake had a relatively shallow depth of 20 miles (32 km). Remember that shallow quakes typically cause the most damage. How do scientists find an earthquake epicenter?

Finding the Epicenter

Here are the steps to finding an earthquake epicenter using three seismograms:

1. Determine the epicenter distance from three different seismographs. The longer the time between the arrival of the P-wave and S-wave, the farther away is the epicenter. So the difference in the P- and S-wave arrival times determines the distance between the epicenter and a seismometer.

This animation shows how to determine distance using P, S, and surface waves: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/12/IRIStravelTime_Bounce_480.mov .

2. Draw a circle with a radius equal to the distance from the epicenter for that seismograph. The epicenter is somewhere along that circle. Do this for three locations. Using data from two seismographs, the two circles will intercept at two points. A third circle will intercept the other two circles at a single point. This point is the earthquake epicenter (**Figure** 4.40).

Seismic stations record ten earthquakes in this animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/12/TravelTime_Sphere_10Stn_480.mov .

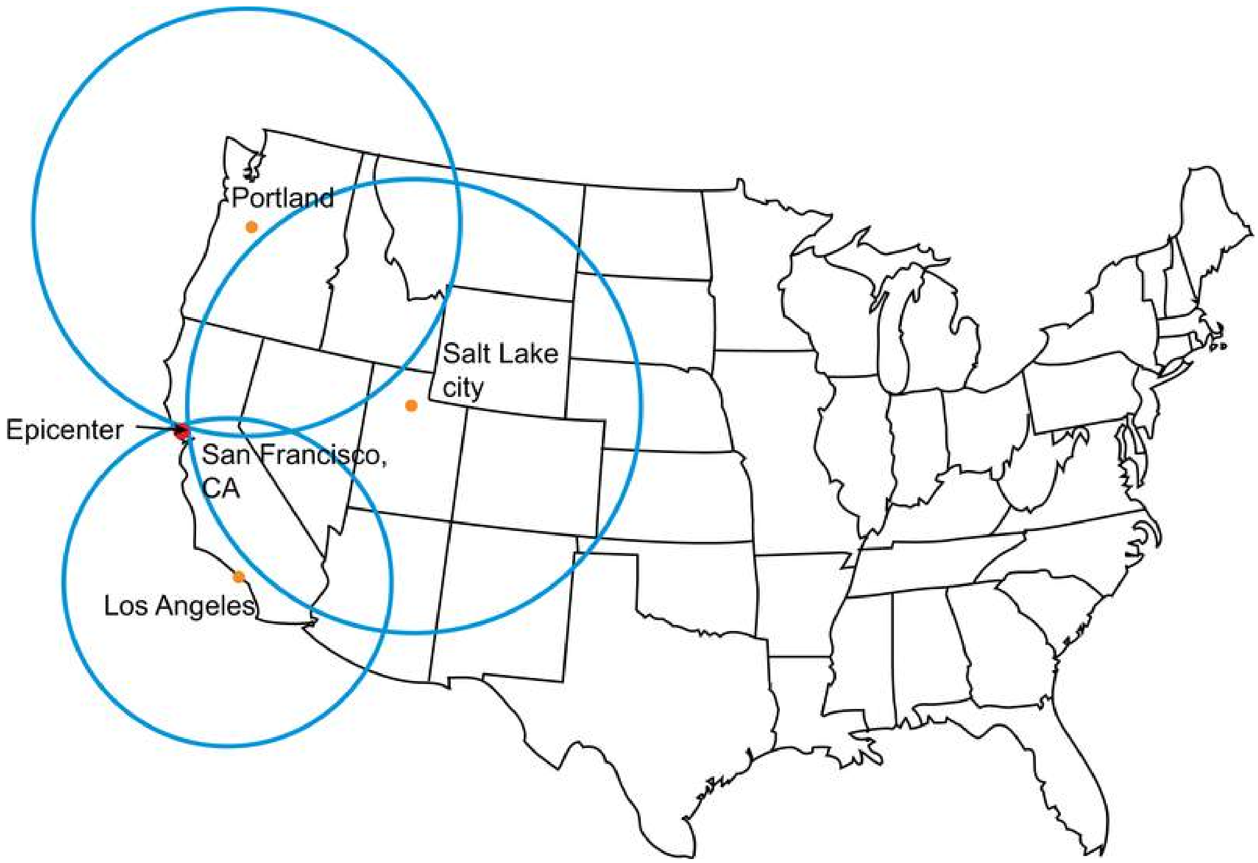


FIGURE 4.40
Three circles drawn from three seismic stations each equal to the radius from the station to the epicenter of the quake will intercept at the actual epicenter.

Of course, it's been a long time since scientists drew circles to locate an earthquake epicenter. This is all done digitally now. but it's a great way to learn the basics of how locating an epicenter works.

Summary

- To find an earthquake epicenter you need at least three seismographs.
- Find the distance from each seismograph to the earthquake epicenter.
- The interception of the three circles is the epicenter.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What is a seismogram?
2. What waves does a seismogram show?
3. What is the S-P interval?
4. How many data stations are required to determine the epicenter?
5. What is triangulation?

Review

1. How do you determine the distance from the seismograph to the earthquake epicenter?
2. How do you find the epicenter from three seismographs? What if you have more seismographs involved?
3. In what circumstance would three seismographs not give you enough information to find an earthquake epicenter?

4.22 Predicting Earthquakes

- Explain how scientists attempt to predict earthquakes.

What if you could predict an earthquake?

What would make a good prediction? Knowing where, when, and the magnitude of the quake would make it possible for people to evacuate.

A Good Prediction

Scientists are a long way from being able to predict earthquakes. A good prediction must be detailed and accurate. Where will the earthquake occur? When will it occur? What will be the magnitude of the quake? With a good prediction authorities could get people to evacuate. An unnecessary evacuation is expensive and causes people not to believe authorities the next time an evacuation is ordered.

Where?

Where an earthquake will occur is the easiest feature to predict. How would you predict this? Scientists know that earthquakes take place at plate boundaries and tend to happen where they've occurred before (**Figure** 4.41). Fault segments behave consistently. A segment with frequent small earthquakes or one with infrequent huge earthquakes will likely do the same thing in the future.

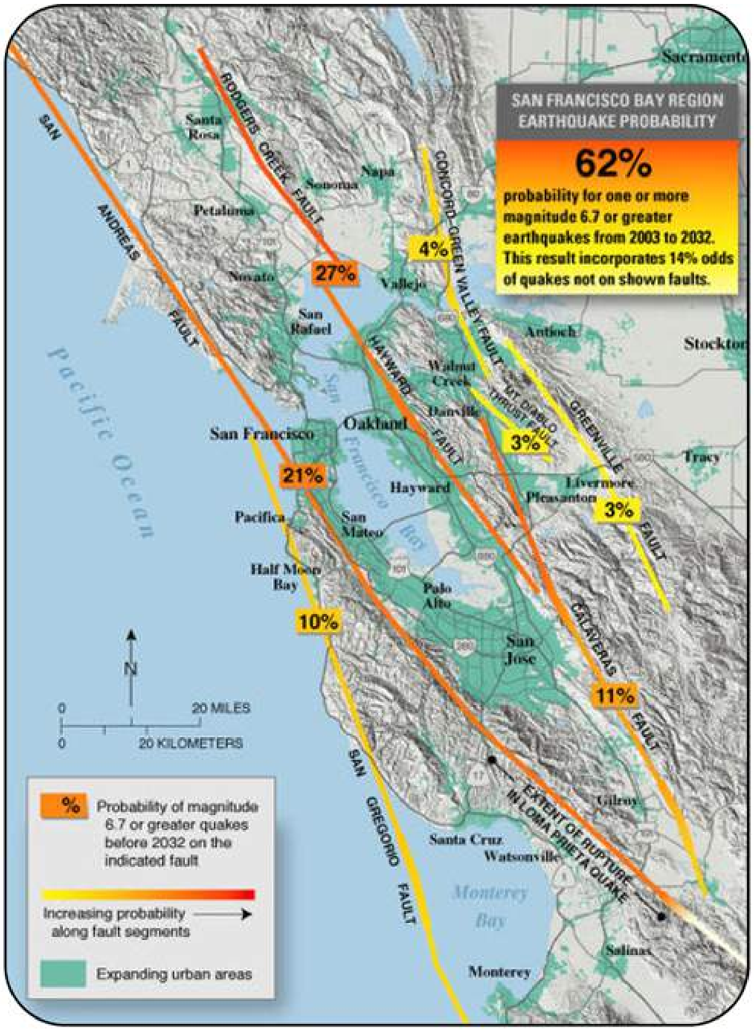


FIGURE 4.41
The probabilities of earthquakes striking along various faults in the San Francisco area between 2003 (when the work was done) and 2032.

When?

When an earthquake will occur is much more difficult to predict. Since stress on a fault builds up at the same rate over time, earthquakes should occur at regular intervals (**Figure** 4.42). But so far scientists cannot predict when quakes will occur even to within a few years.

Earthquake Signs

Signs sometimes come before a large earthquake. Small quakes, called **foreshocks**, sometimes occur a few seconds to a few weeks before a major quake. However, many earthquakes do not have foreshocks, and small earthquakes are not necessarily followed by a large earthquake. Ground tilting, caused by the buildup of stress in the rocks, may precede a large earthquake, but not always. Water levels in wells fluctuate as water moves into or out of fractures before an earthquake. This is also an uncertain predictor of large earthquakes. The relative arrival times of P-waves and S-waves also decreases just before an earthquake occurs.

Folklore tells of animals behaving erratically just before an earthquake. Mostly, these anecdotes are told after the earthquake. If indeed animals sense danger from earthquakes or tsunami, scientists do not know what it is they could be sensing, but they would like to find out.

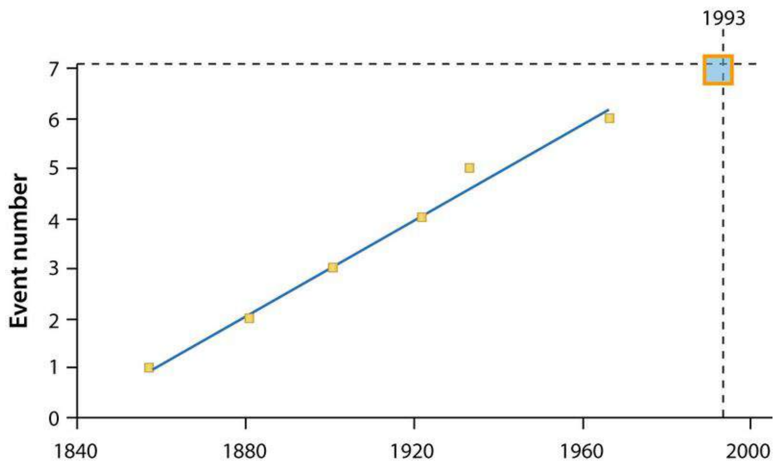


FIGURE 4.42
Around Parkfield, California, an earthquake of magnitude 6.0 or higher occurs about every 22 years. So seismologists predicted that one would strike in 1993, but that quake came in 2004 - 11 years late.

Earthquake prediction is very difficult and not very successful, but scientists are looking for a variety of clues in a variety of locations and to try to advance the field.

See more at http://science.kqed.org/quest/video/earthquakes-breaking-new-ground/ .

MEDIA
Click image to the left for more content.

It's been twenty years since the Loma Prieta Earthquake ravaged downtown Santa Cruz and damaged San Francisco's Marina District and the Bay Bridge. QUEST looks at the dramatic improvements in earthquake prediction technology since 1989. But what can be done with ten seconds of warning?

Find out more by listening to this audio report at http://science.kqed.org/quest/audio/predicting-the-next-big-one/ .

MEDIA
Click image to the left for more content.

Summary

- A good prediction must indicate when and where an earthquake will take place with detail and accuracy.
- Fault segments tend to behave the same way over time.
- Signs that an earthquakes may occur include foreshocks, ground tilting, water levels in wells and the relative arrival times of P and S waves.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What magnitude was the 2010 Haiti earthquake?
2. How did scientists recognize that the fault was active?
3. What evidence led to the prediction?
4. What can not be predicted?
5. What type of fault is at the Hayward Fault?

Review

1. Why are earthquakes so hard to predict?
2. Why is it easier to predict where a quake will occur than when?
3. Describe some of the signs that scientists use to predict earthquakes.
4. It's now nine years after the map of earthquake probabilities in the San Francisco Bay area was made. What do you think the fact that no large earthquakes have struck those faults yet does to the probability that one will strike by 2032?

4.23 Tsunami

- Describe the wave features of tsunami.

What is a tsunami?

"Tsunami" is a Japanese word meaning "harbor wave." Some people call them tidal waves. But these deadly waves are not related to tides and they are not restricted to harbors. Few words can express the horror these waves can bring.

Tsunami as Waves

Tsunami are deadly ocean waves from the sharp jolt of an undersea earthquake. Less frequently, these waves can be generated by other shocks to the sea, like a meteorite impact. Fortunately, few undersea earthquakes, and even fewer meteorite impacts, generate tsunami.

Wave Height

Tsunami waves have small wave heights relative to their long wavelengths, so they are usually unnoticed at sea. When traveling up a slope onto a shoreline, the wave is pushed upward. As with wind waves, the speed of the bottom of the wave is slowed by friction. This causes the wavelength to decrease and the wave to become unstable. These factors can create an enormous and deadly wave.

Landslides, meteorite impacts, or any other jolt to ocean water may form a tsunami. Tsunami can travel at speeds of 800 kilometers per hour (500 miles per hour).

A video explanation of tsunami is here: http://www.youtube.com/watch?v=StdqGoezNrY .

Wavelength

Since tsunami are long-wavelength waves, a long time can pass between crests or troughs. Any part of the wave can make landfall first.

In 1755 in Lisbon, Portugal, a tsunami trough hit land first. A large offshore earthquake did a great deal of damage on land. People rushed out to the open space of the shore. Once there, they discovered that the water was flowing seaward fast and some of them went out to observe. What do you think happened next? The people on the open beach drowned when the crest of the wave came up the beach.

Large tsunami in the Indian Ocean and more recently Japan have killed hundreds of thousands of people in recent years. The west coast is vulnerable to tsunami since it sits on the Pacific Ring of Fire. Scientists are trying to learn everything they can about predicting tsunamis before a massive one strikes a little closer to home.

Although most places around the Indian Ocean did not have warning systems in 2005, there is a tsunami warning system in that region now. Tsunami warning systems have been placed in most locations where tsunami are possible.

See more at http://science.kqed.org/quest/video/scary-tsunamis/ .

MEDIA

Click image to the left for more content.

Summary

- Tsunami have relatively low wave heights, so they are not noticeable until they move up a shore.
- Tsunami have long wavelengths. The time between two crests or two troughs can be many minutes.
- Tsunami warning systems have been placed in most locations where tsunami are possible.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What does the word tsunami mean?

2. Why has Japan had so many tsunamis?
3. What causes a tsunami?
4. How fast do the waves travel?
5. What happens to the tsunami as it reaches the continental shelf?
6. How do tsunamis differ from regular waves?
7. What was the deadliest tsunami ever recorded?
8. What does the Pacific Tsunami Warning Center do?

Review

1. Why is a wave that is so powerful and tall on land unnoticeable at sea?
2. What should you do if you are at the beach and the water suddenly is sucked offshore?
3. Describe tsunami as waves in the way they travel up a shoreline and may strike as crests or troughs.

4.24 Staying Safe in an Earthquake

- Identify the preparations for and actions during and after an earthquake that increase safety.

How can you prepare for an earthquake?

If you live in earthquake country the actions you take before, during, and after a quake could make the difference in your comfort for several days or even your survival.

Protecting Yourself in an Earthquake

There are many things you can do to protect yourself before, during, and after an earthquake.

Before the Earthquake

- Have an engineer evaluate the house for structural integrity. Make sure the separate pieces —floor, walls, roof, and foundation —are all well-attached to each other.
- Bracket or brace brick chimneys to the roof.
- Be sure that heavy objects are not stored in high places.
- Secure water heaters all around and at the top and bottom.
- Bolt heavy furniture onto walls with bolts, screws, or strap hinges.
- Replace halogen and incandescent light bulbs with fluorescent bulbs to lessen fire risk.

- Check to see that gas lines are made of flexible material so that they do not rupture. Any equipment that uses gas should be well secured.
- Everyone in the household should know how to shut off the gas line.
- Prepare an earthquake kit with three days supply of water and food, a radio, and batteries.
- Place flashlights all over the house and in the glove box of your car.
- Keep several fire extinguishers around the house to fight small fires.
- Be sure to have a first aid kit. Everyone should know basic first aid and CPR.
- Plan in advance how you will evacuate and where you will go. Do not plan on driving, as roadways will likely be damaged.

During the Earthquake

- If you are in a building, get beneath a sturdy table, cover your head, and hold on.
- Stay away from windows, mirrors, and large furniture.
- If the building is structurally unsound, get outside as fast as possible.
- If you are outside, run to an open area away from buildings and power lines that may fall.
- If you are in a car, stay in the car and stay away from structures that might collapse, such as overpasses, bridges, or buildings.

After the Earthquake

- Be aware that aftershocks are likely.
- Avoid dangerous areas like hillsides that may experience a landslide.
- Turn off water and power to your home.
- Use your phone only if there is an emergency. Many people will be trying to get through to emergency services.
- Be prepared to wait for help or instructions. Assist others as necessary.

Summary

- Before an earthquake, be sure that your home is secure and that you have supplies to last a few days.
- During an earthquake, get to a safe place.
- After an earthquake, avoid dangerous situations, wait for instructions, and assist as necessary.

Practice

Use these resources to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is California's 4th season?
2. What should you do to prepare your home?
3. What should an emergency plan include?

4. What should you have in you disaster preparedness kit?

Earthquake Safety at http://www.youtube.com/watch?v=piZ_tfbUp2E

MEDIA

Click image to the left for more content.

5. What should you do when an earthquakes hits and you are in your home?

6. What should you do if you are outside when an earthquake hits?

7. How should you organize your home?

Review

1.What should you do to prepare for an earthquake?

2. What should you do during an earthquake?

3. What should you do after an earthquake?

4.25 Mountain Building

- Explain how converging or diverging plates can create mountain ranges.

How do plate motions create mountains?

Plate tectonic processes create some of the world's most beautiful places. The North Cascades Mountains in Washington State are a continental volcanic arc. The mountains currently host some glaciers and there are many features left by the more abundant ice age glaciers. Changes in altitude make the range a habitable place for many living organisms.

Converging Plates

Converging plates create the world's largest mountain ranges. Each combination of plate types —continent-continent, continent-ocean, and ocean-ocean —creates mountains.

Converging Continental Plates

Two converging continental plates smash upwards to create gigantic mountain ranges (**Figure** 4.43). Stresses from this **uplift** cause folds, reverse faults, and thrust faults, which allow the crust to rise upwards. As was stated previously there is currently no mountain range of this type in the western U.S., but we can find one where India is pushing into Eurasia.

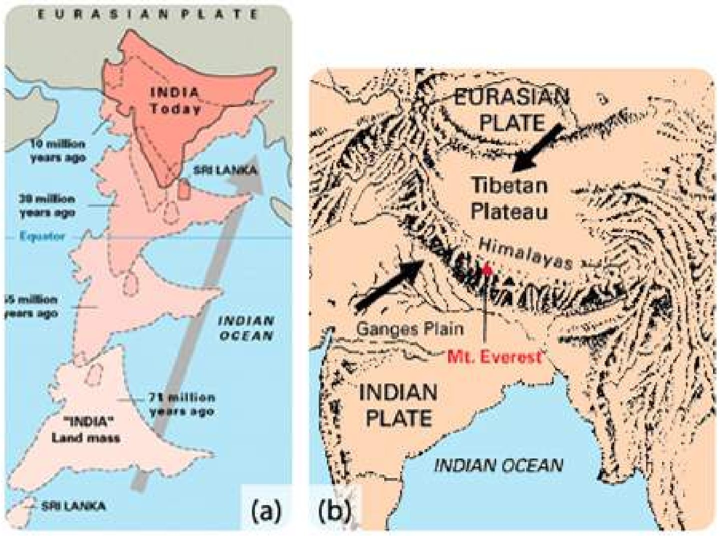


FIGURE 4.43
(a) The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. (b) The crumpling of the Indian and Eurasian plates of continental crust creates the Himalayas.

Subducting Oceanic Plates

Subduction of oceanic lithosphere at convergent plate boundaries also builds mountain ranges. This happens on continental crust, as in the Andes Mountains (**Figure** 4.44), or on oceanic crust, as with the Aleutian Islands, which we visited earlier. The Cascades Mountains of the western U.S. are also created this way.

FIGURE 4.44
The Andes Mountains are a chain of continental arc volcanoes that build up as the Nazca Plate subducts beneath the South American Plate.

Diverging Plates

Amazingly, even divergence can create mountain ranges. When tensional stresses pull crust apart, it breaks into blocks that slide up and drop down along normal faults. The result is alternating mountains and valleys, known as a basin-and-range (**Figure** 4.45). In basin-and-range, some blocks are uplifted to form ranges, known as horsts, and some are down-dropped to form basins, known as grabens.

This is a very quick animation of movement of blocks in a basin-and-range setting: http://earthquake.usgs.gov/learn

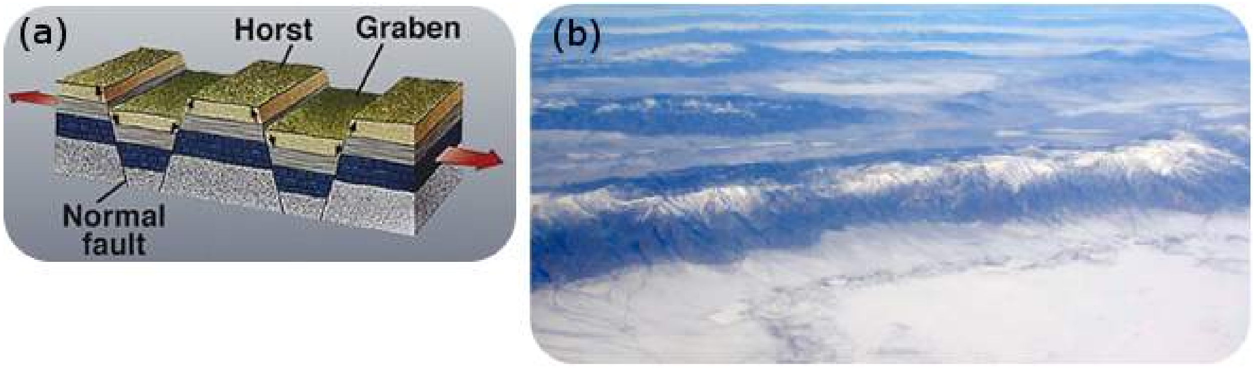


FIGURE 4.45

(a) Horsts and grabens. (b) Mountains in Nevada are of classic basin-and-range form.

/animations/animation.php?flash_title=Horst+%26amp%3B+Graben&flash_file=horstandgraben&flash_width=380&flash_height=210 .

Summary

- Converging or diverging plates cause mountains to grow.
- Subduction of oceanic crust beneath a continental or oceanic plate creates a volcanic arc.
- Tensional forces bring about block faulting, which creates a basin-and-range topography.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What created the landscape we see today on Earth?
2. What can cause mountains to form?
3. How tall are the Alps?
4. How were the Alps formed?
5. Explain the forces that caused the Alps to form.

Review

1. Describe how plate interactions create mountain ranges like the Himalayas.

2. Diagram how pulling apart continental crust could create mountains and basins. What are the mountains and basins called?

3. How are the Andes Mountains similar to the Aleutian Islands? How are they different?

4.26 Geological Stresses

- Define the types of geological stress and describe their affect on various types of rock under a range of conditions.

When people have too much stress they may break. What happens if a rock gets too much stress?

With all the movement occurring on Earth's surface —slabs of crust smashing into each other, sideways movements along faults, magma rising through solid rock —it's no wonder that rocks experience stress. Rocks respond differently to different types of stress and under different conditions.

Causes and Types of Stress

Stress is the force applied to an object. In geology, stress is the force per unit area that is placed on a rock. Four types of stresses act on materials.

- A deeply buried rock is pushed down by the weight of all the material above it. Since the rock cannot move, it cannot deform. This is called **confining stress.**
- **Compression** squeezes rocks together, causing rocks to fold or fracture (break) (**Figure** 4.46). Compression is the most common stress at convergent plate boundaries.

FIGURE 4.46
Stress caused these rocks to fracture.

- Rocks that are pulled apart are under **tension**. Rocks under tension lengthen or break apart. Tension is the major type of stress at divergent plate boundaries.
- When forces are parallel but moving in opposite directions, the stress is called **shear** (**Figure** 4.47). Shear stress is the most common stress at transform plate boundaries.

FIGURE 4.47
Shearing in rocks. The white quartz vein has been elongated by shear.

When stress causes a material to change shape, it has undergone **strain** or **deformation**. Deformed rocks are common in geologically active areas.

A rock's response to stress depends on the rock type, the surrounding temperature, the pressure conditions the rock is under, the length of time the rock is under stress, and the type of stress.

Responses to Stress

Rocks have three possible responses to increasing stress (illustrated in **Figure** 4.48):

- **elastic deformation**: the rock returns to its original shape when the stress is removed.
- **plastic deformation**: the rock does not return to its original shape when the stress is removed.
- **fracture**: the rock breaks.

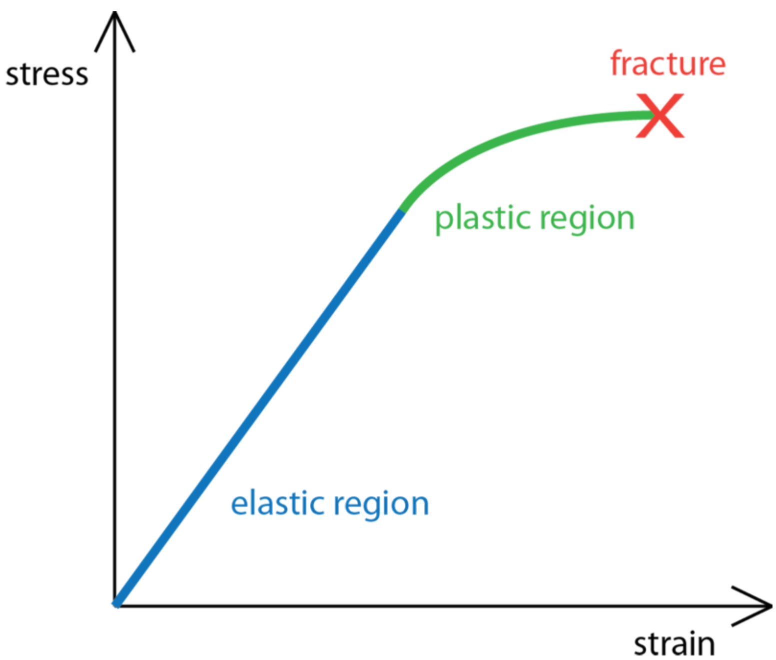


FIGURE 4.48
With increasing stress, the rock undergoes: (1) elastic deformation, (2) plastic deformation, and (3) fracture.

Under what conditions do you think a rock is more likely to fracture? Is it more likely to break deep within Earth's crust or at the surface? What if the stress applied is sharp rather than gradual?

- At the Earth's surface, rocks usually break quite quickly, but deeper in the crust, where temperatures and pressures are higher, rocks are more likely to deform plastically.
- Sudden stress, such as a hit with a hammer, is more likely to make a rock break. Stress applied over time often leads to plastic deformation.

Summary

- Stress is the force applied to an object. Stresses can be confining, compression, tension, or shear.
- Rocks under stress may show strain or deformation. Deformation can be elastic or plastic, or the rock may fracture.
- Rocks respond to stress differently under different conditions.

Practice

Use this resource to answer the questions that follow.

https://www.as.uky.edu/sites/default/files/elearning/module10swf.swf

Select Overview.

1. What is stress?
2. What are the three directions in which stress can be applied?
3. What does tension cause?
4. What does compression cause?
5. What is shearing?

Review

1. What type of stress would you find at a transform fault? At a subduction zone? What type of stress at a continental rift zone?
2. Compare and contrast fracture, plastic deformation, and elastic deformation.
3. What do you think happens with stressed rocks in an earthquake zone?

4.27 Folds

- Identify and define types of folds and related structures.

Can you see the anticline at Anticline Overlook?

Moving around the desert Southwest, we see a lot of folds. This view is from the Anticline Overlook at Canyonlands National Park. Look up what an anticline is below and then see if you can spot this one. Remember you may only be able to see part of it in the photo. All of the folds (not the basin) pictured below are found in the arid Southwest.

Folds

Rocks deforming plastically under compressive stresses crumple into **folds**. They do not return to their original shape. If the rocks experience more stress, they may undergo more folding or even fracture.

You can see three types of folds.

Monocline

A **monocline** is a simple bend in the rock layers so that they are no longer horizontal (see **Figure** 4.49 for an example).

FIGURE 4.49
At Utah's Cockscomb, the rocks plunge downward in a monocline.

What you see in the image appears to be a monocline. Are you certain it is a monocline? What else might it be? What would you have to do to figure it out?

Anticline

Anticline: An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (**Figure** 4.50). The oldest rocks are at the center of an anticline and the youngest are draped over them.

When rocks arch upward to form a circular structure, that structure is called a **dome**. If the top of the dome is sliced off, where are the oldest rocks located?

Syncline

A **syncline** is a fold that bends downward. The youngest rocks are at the center and the oldest are at the outside (**Figure** 4.51).

When rocks bend downward in a circular structure, that structure is called a **basin** (**Figure** 4.52). If the rocks are exposed at the surface, where are the oldest rocks located?

FIGURE 4.50
Anticlines are formations that have folded rocks upward.

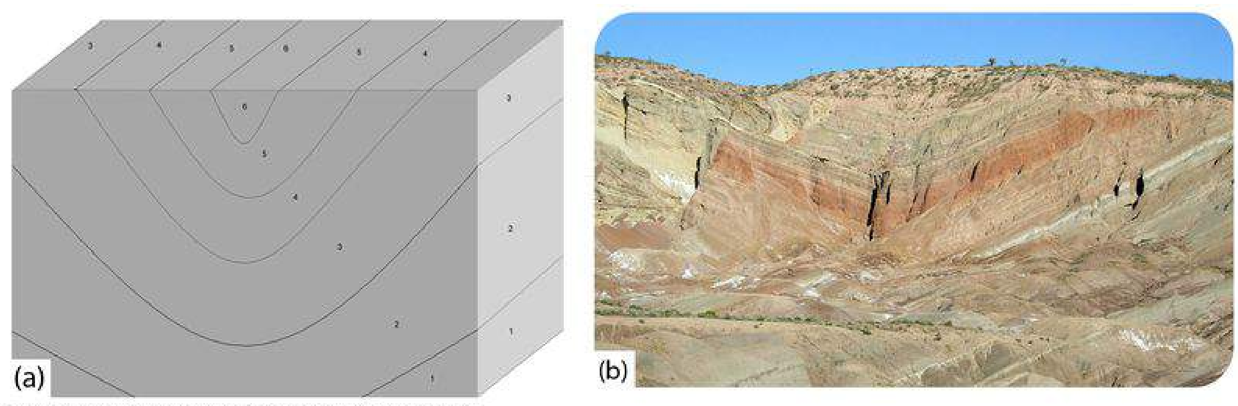


FIGURE 4.51
(a) Schematic of a syncline. (b) This syncline is in Rainbow Basin, California.

Summary

- Rocks deform by compressive stress into folds.
- A monocline is a simple bend.
- In anticline, rocks arch upward. A three-dimensional anticline is a dome.

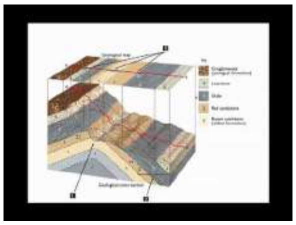
FIGURE 4.52
Basins can be enormous. This is a geologic map of the Michigan Basin, which is centered in the state of Michigan but extends into four other states and a Canadian province.

FIGURE 4.53
Some folding can be fairly complicated. What do you see in the photo above?

- In a syncline, rocks arch downward. A three-dimensional syncline is a basin.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What causes folds?
2. What are the folds called?
3. What is a dip?
4. What is a strike?
5. What does a block diagram show you?
6. What is the strike and dip symbol?
7. What do the arrows on the diagram tell you?
8. Describe the effects of erosion.

Review

1. Draw a picture to show how compressive stresses lead to the formation of anticlines and synclines.
2. Do you think that anticlines and synclines are ordinarily found separately or adjacent to each other?
3. If you found a bulls-eye of rock on the flat ground with no structure to guide you, how could you tell if the structure had been a syncline or an anticline?

4. What folds can you find in this photo of Monument Valley in Arizona? Notice the rock layers at the top of the ridge. What is the geologic history of this region?

4.28 Faults

- Describe the results of rocks fracturing under stress, forming joints or faults.
- Identify types of faults.

Why is this called a fault?

The word "fault" refers to a defect. There may be no greater defect than the scar of the San Andreas Fault across California. Rocks on either side of the fault are estimated to have originated in locations about 350 miles apart! We're still in the arid western United States, but now our searching for geological features is more dangerous!

Fractures

A rock under enough stress will fracture. There may or may not be movement along the fracture.

Joints

If there is no movement on either side of a fracture, the fracture is called a **joint**. The rocks below show horizontal and vertical jointing. These joints formed when the confining stress was removed from the rocks as shown in (

Figure 4.54).

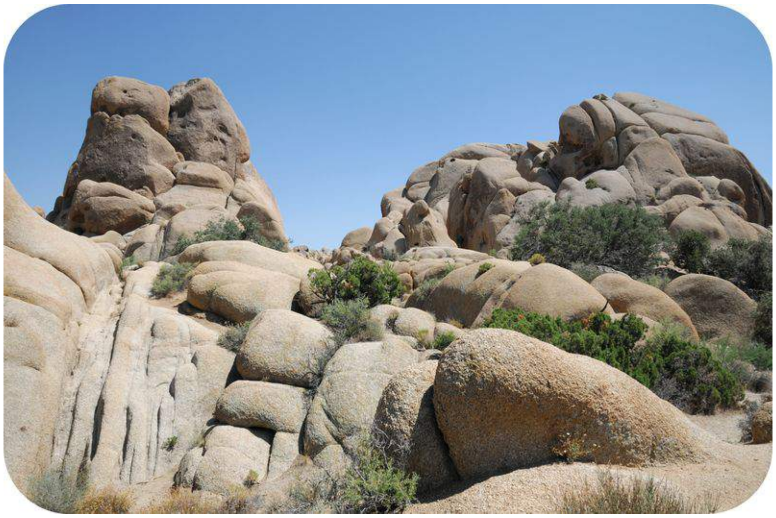


FIGURE 4.54
Joints in rocks at Joshua Tree National Park, in California.

Faults

If the blocks of rock on one or both sides of a fracture move, the fracture is called a **fault** (**Figure** 4.55). Stresses along faults cause rocks to break and move suddenly. The energy released is an earthquake.

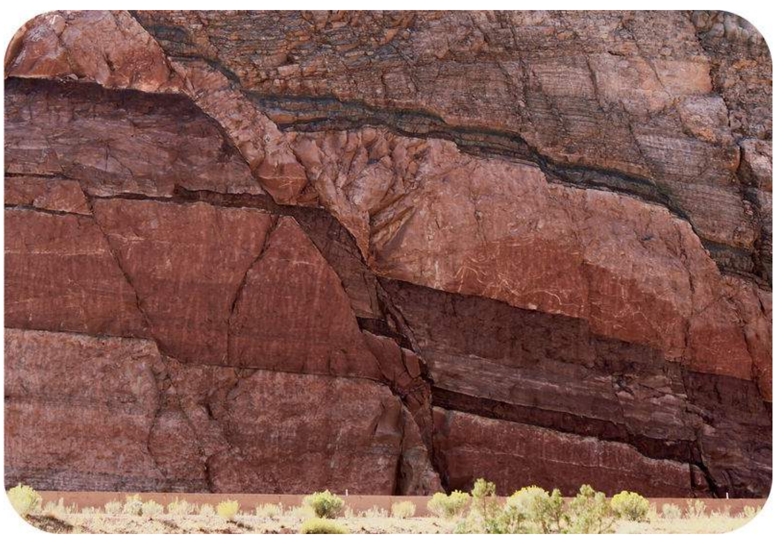


FIGURE 4.55
Faults are easy to recognize as they cut across bedded rocks.

How do you know there's a fault in this rock? Try to line up the same type of rock on either side of the lines that cut across them. One side moved relative to the other side, so you know the lines are a fault.

Slip is the distance rocks move along a fault. Slip can be up or down the fault plane. Slip is relative, because there is usually no way to know whether both sides moved or only one. Faults lie at an angle to the horizontal surface of the Earth. That angle is called the fault's **dip.** The dip defines which of two basic types a fault is. If the fault's dip is inclined relative to the horizontal, the fault is a **dip-slip fault** (**Figure** 4.56).

Dip-Slip Faults

There are two types of dip-slip faults. In a **normal fault**, the hanging wall drops down relative to the footwall. In a **reverse fault**, the footwall drops down relative to the hanging wall.

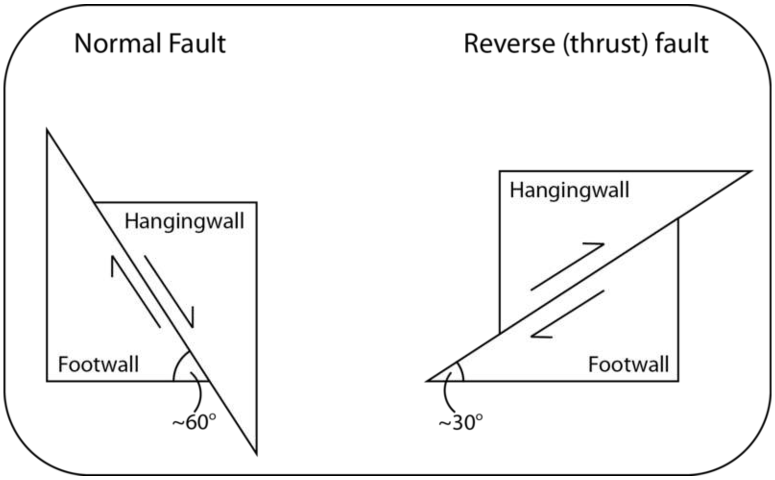


FIGURE 4.56
This diagram illustrates the two types of dip-slip faults: normal faults and reverse faults. Imagine miners extracting a resource along a fault. The hanging wall is where miners would have hung their lanterns. The footwall is where they would have walked.

An animation of a normal fault is seen here: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Normal+Fault&flash_file=normalfault&flash_width=220&flash_height=320 .

A **thrust fault** is a type of reverse fault in which the fault plane angle is nearly horizontal. Rocks can slip many miles along thrust faults (**Figure** 4.57).

An animation of a thrust fault is seen here: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Thrust+Fault&flash_file=thrustfault&flash_width=220&flash_height=320 .

FIGURE 4.57
At Chief Mountain in Montana, the upper rocks at the Lewis Overthrust are more than 1 billion years older than the lower rocks. How could this happen?

Normal faults can be huge. They are responsible for uplifting mountain ranges in regions experiencing tensional stress.

Strike-Slip Faults

A **strike-slip fault** is a dip-slip fault in which the dip of the fault plane is vertical. Strike-slip faults result from shear stresses. Imagine placing one foot on either side of a strike-slip fault. One block moves toward you. If that block moves toward your right foot, the fault is a right-lateral strike-slip fault; if that block moves toward your left foot, the fault is a left-lateral strike-slip fault (**Figure** 4.58).

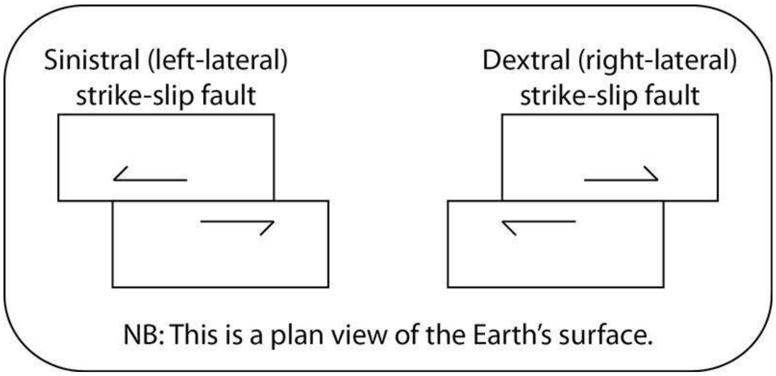


FIGURE 4.58
Strike-slip faults.

California's San Andreas Fault is the world's most famous strike-slip fault. It is a right-lateral strike slip fault (See opening image).

A strike-slip fault animation: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Strike-Slip+Fault&flash_file=strikeslip&flash_width=240&flash_height=310 .

People sometimes say that California will fall into the ocean someday, which is not true. This animation shows movement on the San Andreas into the future: http://visearth.ucsd.edu/VisE_Int/aralsea/bigone.html .

Summary

- A fracture with no movement on either side is a joint.
- Dip-slip faults show vertical movement. In a normal fault, the hanging wall drops down relative to the footwall. The reverse is true of a reverse fault.
- Strike-slip faults have horizontal motions due to shear stress.

Practice

Use this resource to answer the questions that follow.

http://www.iris.edu/gifs/animations/faults.htm

1. What causes normal fault motion?

2. What type of motion results from a normal fault?

3. Explain a reverse fault. What type of motion results from this fault?

4. Describe a strike-slip fault.

5. What causes an oblique-slip fault?

Review

1. Imagine you're looking at an outcrop. What features would you see to indicate a fault?

2. If the San Andreas Fault has had 350 miles of displacement, where did the rocks in San Francisco (on the west side of the fault) originate? How do scientists know?

3. How do you imagine the Grand Teton mountain range rose? In one earthquake? Along one fault? Or is there a more complex geological history?

4.29 Types of Volcanoes

- Describe the magma compositions and characteristics of different types of volcanoes.

What does an active volcano look like?

Climbing up Mount St. Helens and looking into the crater at the steaming dome is an incredible experience. The slope is steep and the landscape is like something from another planet. Nothing's alive up there, except maybe a bird. When you're standing on the top you can see off to others of the Cascades volcanoes: Mt. Adams, Rainier, Hood, Jefferson, and sometimes more.

Volcanoes

A volcano is a vent through which molten rock and gas escape from a magma chamber. Volcanoes differ in many features, such as height, shape, and slope steepness. Some volcanoes are tall cones and others are just cracks in the ground (**Figure** 4.59). As you might expect, the shape of a volcano is related to the composition of its magma.

Composite Volcanoes

Composite volcanoes are constructed of felsic to intermediate rock. The viscosity of the lava means that eruptions at these volcanoes are often explosive.

Eruptions at Composite Volcanoes

Viscous lava cannot travel far down the sides of the volcano before it solidifies, which creates the steep slopes of a composite volcano. In some eruptions the pressure builds up so much that the material explodes as ash and small rocks. The volcano is constructed layer by layer, as ash and lava solidify, one upon the other (**Figure** 4.61). The result is the classic cone shape of composite volcanoes.

FIGURE 4.59
Mount St. Helens was a beautiful, classic, cone-shaped volcano. In May 1980 the volcano blew its top off in an explosive eruption, losing 1,300 feet off its summit.

FIGURE 4.60
Mt. Fuji in Japan is one of the world's most easily recognized composite volcanoes.

Shield Volcanoes

Shield volcanoes get their name from their shape. Although shield volcanoes are not steep, they may be very large. Shield volcanoes are common at spreading centers or intraplate hot spots (**Figure** 4.62). Hawaii has some spectacular shield volcanoes including Mauna Kea, which is the largest mountain on Earth from base to top. The mountain stands 33,500 ft high, about 4,000 feet greater than the tallest mountain above sea level, Mt. Everest.

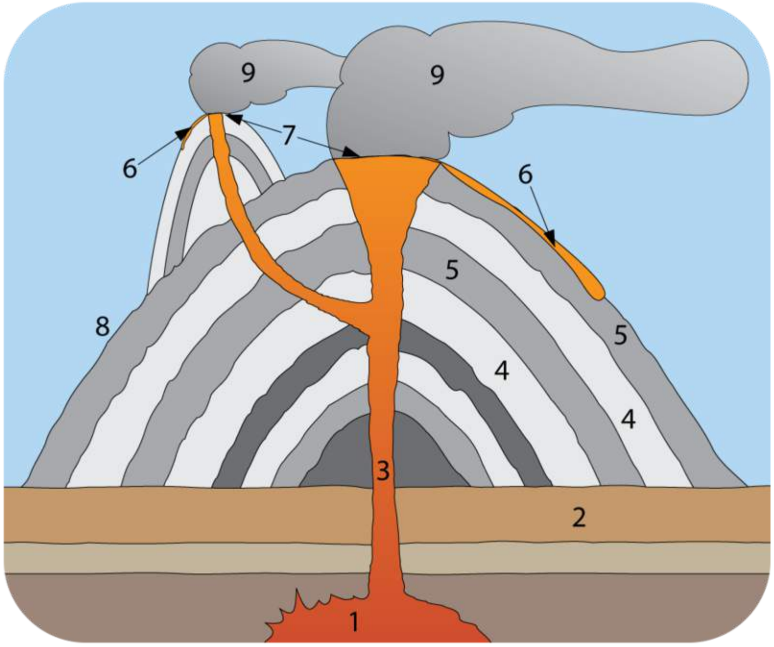


FIGURE 4.61
A cross section of a composite volcano reveals alternating layers of rock and ash: (1) magma chamber, (2) bedrock, (3) pipe, (4) ash layers, (5) lava layers, (6) lava flow, (7) vent, (8) lava, (9) ash cloud. Frequently there is a large crater at the top from the last eruption.

FIGURE 4.62
Mauna Kea on the Big Island of Hawaii is a classic shield volcano.

Eruptions at Shield Volcanoes

The lava that creates shield volcanoes is fluid and flows easily. The spreading lava creates the shield shape. Shield volcanoes are built by many layers over time and the layers are usually of very similar composition. The low viscosity also means that shield eruptions are non-explosive.

This "Volcanoes 101" video from National Geographic discusses where volcanoes are found and what their properties come from: http://www.youtube.com/watch?v=uZp1dNybgfc (3:05).

MEDIA
Click image to the left for more content.

Cinder Cones

Cinder cones are the most common type of volcano. A cinder cone has a cone shape, but is much smaller than a composite volcano. Cinder cones rarely reach 300 meters in height, but they have steep sides. Cinder cones grow rapidly, usually from a single eruption cycle. These volcanoes usually flank shield or composite volcanoes. Many cinder cones are found in Hawaii.

FIGURE 4.63
A lava fountain erupts from Pu'u O'o, a cinder cone on Kilauea.

Eruptions at Cinder Cones

Cinder cones are composed of small fragments of rock, such as pumice, piled on top of one another. The rock shoots up in the air and doesn't fall far from the vent. The exact composition of a cinder cone depends on the composition of the lava ejected from the volcano. Cinder cones usually have a crater at the summit. Most cinder cones are active only for a single eruption.

Summary

- Magma composition determines both eruption type and volcano type.
- Composite cones are built of felsic to intermediate lava and shield volcanoes of mafic lava.
- Cinder cones are made of small fragments of a variety of compositions usually from a single eruption.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use these resources to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Composite Volcanoes**

1. What is another name for composite volcanoes?
2. Explain the composite volcano's typical structure.
3. List two examples of composite volcanoes. What is the location of each?

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Cinder Cones**

4. How is a cinder cone formed?
5. What is cinder cone's typical maximum height?
6. Where is Lava Butte located?
7. When did Izalco last erupt?

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Shield Volcanoes**

8. Describe a shield volcano's structure.
9. What is the height of Mauna Loa?
10. Where is Mount Washington located? How old is it?

Review

1. Why do mafic lavas produce shield-shaped volcanoes and felsic lavas produce cone-shaped volcanoes?
2. From what does a composite volcano get its name?
3. Describe how a cinder cone forms.

4.30 Volcanoes at Hotspots

- Explain the relationship between hotspots and volcanic activity away from plate boundaries.

Hawaii is a hotspot, or is it a hot spot?

Both, actually. Hawaii is definitely a hot vacation spot, particularly for honeymooners. The Hawaiian Islands are formed from a hotspot beneath the Pacific Ocean. Volcanoes grow above the hotspot. Lava flows down the hillsides and some of it reaches the ocean, causing the islands to grow. Too hot now, but a great place in the future for beach lovers!

Intraplate Volcanoes

Although most volcanoes are found at convergent or divergent plate boundaries, intraplate volcanoes may be found in the middle of a tectonic plate. These volcanoes rise at a hotspot above a **mantle plume**. Melting at a hotspot is due to pressure release as the plume rises through the mantle.

Earth is home to about 50 known hotspots. Most of these are in the oceans because they are better able to penetrate oceanic lithosphere to create volcanoes. But there are some large ones in the continents. Yellowstone is a good example of a mantle plume erupting within a continent.

Pacific Hotspots

The South Pacific has many hotspot volcanic chains. The hotspot is beneath the youngest volcano in the chain and older volcanoes are found to the northwest. A volcano forms above the hotspot, but as the Pacific Plate moves, that volcano moves off the hotspot. Without its source of volcanism, it no longer erupts. The crust gets cooler and the volcano erodes. The result is a chain of volcanoes and seamounts trending northwest from the hotspot.

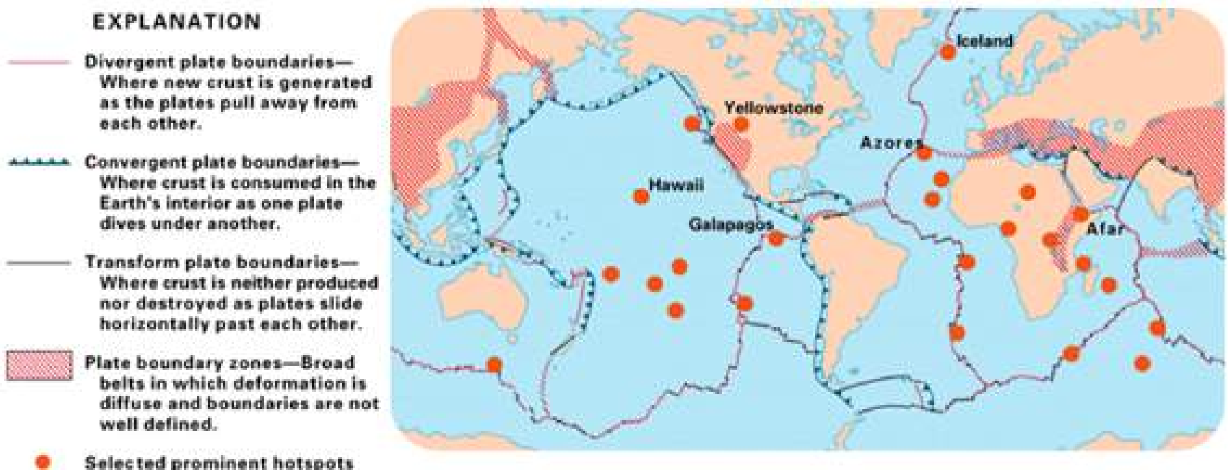


FIGURE 4.64

Prominent hotspots of the world.

The Society Islands are the exposed peaks of a great chain of volcanoes that lie on the Pacific Plate. The youngest island sits directly above the Society hotspot (**Figure** 4.65).

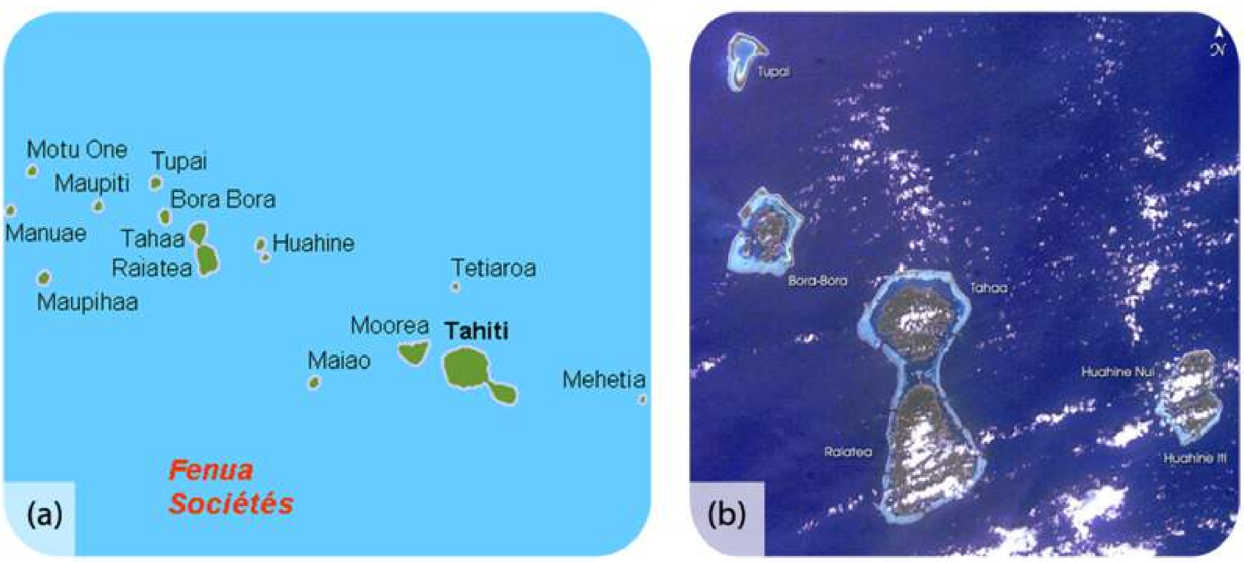


FIGURE 4.65

(a) The Society Islands formed above a hotspot that is now beneath Mehetia and two submarine volcanoes. (b) The satellite image shows how the islands become smaller and coral reefs became more developed as the volcanoes move off the hotspot and grow older.

The most famous example of a hotspot in the oceans is the Hawaiian Islands. Forming above the hotspot are massive shield volcanoes that together create the islands. The lavas are mafic and have low viscosity. These lavas produce beautiful ropy flows of pāhoehoe and clinkery flows of a'a, which will be described in more detail in Effusive Eruptions.

A hot spot beneath Hawaii, the origin of the voluminous lava produced by the shield volcano Kilauea can be viewed here: http://www.youtube.com/watch?v=byJp5o49IF4 (2:06).

MEDIA

Click image to the left for more content.

Continental Hotspots

The hotspots that are known beneath continents are extremely large. The reason is that it takes a massive mantle plume to generate enough heat to penetrate through the relatively thick continental crust. The eruptions that come from these hotspots are infrequent but massive, often felsic and explosive. All that's left at Yellowstone at the moment is a giant caldera and a very hot spot beneath.

Hotspot Versus Island Arc Volcanoes

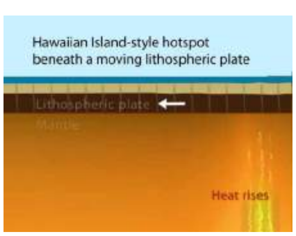
How would you be able to tell hotspot volcanoes from island arc volcanoes? At island arcs, the volcanoes are all about the same age. By contrast, at hotspots the volcanoes are youngest at one end of the chain and oldest at the other.

Summary

- Volcanoes grow above hotspots, which are zones of melting above a mantle plume.
- Hotspot volcanoes are better able to penetrate oceanic crust, so there are more chains of hotspot volcanoes in the oceans.
- Shield volcanoes commonly form above hotspots in the oceans.

Practice

Use this resource to answer the questions that follow.



MEDIA

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1. What is a hotspot?

2. What does a thermal plume allow for?

3. What causes convection?

4. What does the volcano build?

5. What carries the volcanoes away from a hotspot?

Review

1. What causes melting at a hotspot?

2. Why are there a relatively large number of hotspots in the Pacific Ocean basin?

3. Why do you think there are so many hotspots at mid-ocean ridges; e.g. four along the Mid-Atlantic Ridge and two at the East Pacific Rise?

4.31 Rocks and Processes of the Rock Cycle

- Explain the processes of the rock cycle.

Is this what geologists mean by the rock cycle?

Okay, very punny. The rock cycle shows how any type of rock can become any other type of rock. Some rocks may stay the same type for a long time, for example, if they're at the base of the crust, but other rocks may relatively rapidly change from one type to another.

The Rock Cycle

The **rock cycle**, illustrated in **Figure** 4.66, depicts how the three major rock types –igneous, sedimentary, and metamorphic - convert from one to another. Arrows connecting the rock types represent the processes that accomplish these changes.

Rocks change as a result of natural processes that are taking place all the time. Most changes happen very slowly. Rocks deep within the Earth are right now becoming other types of rocks. Rocks at the surface are lying in place before they are next exposed to a process that will change them. Even at the surface, we may not notice the changes. The rock cycle has no beginning or end.

The Three Rock Types

Rocks are classified into three major groups according to how they form. These three types are described in more detail in other concepts in this chapter, but here is a summary.

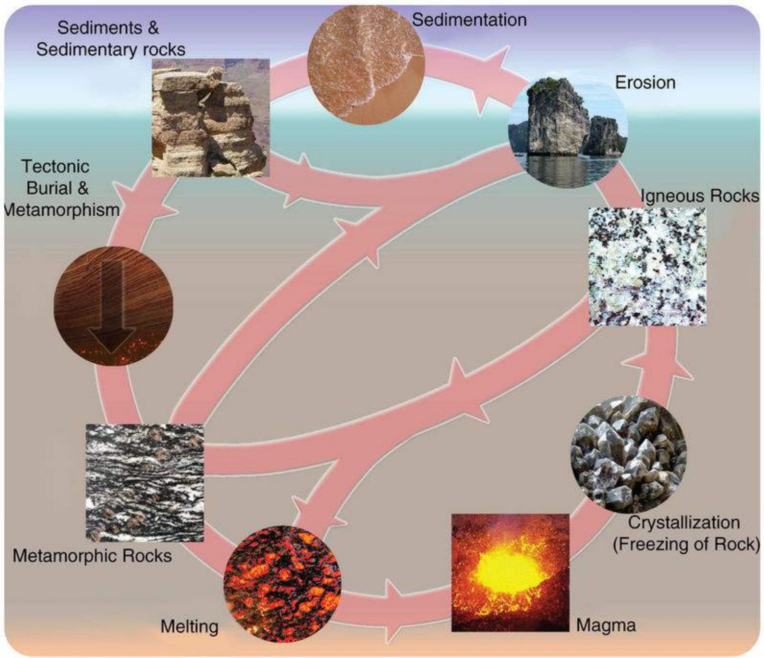


FIGURE 4.66
The Rock Cycle.

- **Igneous rocks** form from the cooling and hardening of molten magma in many different environments. The chemical composition of the magma and the rate at which it cools determine what rock forms. Igneous rocks can cool slowly beneath the surface or rapidly at the surface. These rocks are identified by their composition and texture. More than 700 different types of igneous rocks are known.
- **Sedimentary rocks** form by the compaction and cementing together of **sediments**, broken pieces of rock-like gravel, sand, silt, or clay. Those sediments can be formed from the weathering and erosion of preexisting rocks. Sedimentary rocks also include chemical **precipitates**, the solid materials left behind after a liquid evaporates.
- **Metamorphic rocks** form when the minerals in an existing rock are changed by heat or pressure below the surface.

A simple explanation of the three rock types and how to identify them can be seen in this video: http://www.youtube.com/watch?v=tQUe9C40NEE .

This video discusses how to identify igneous rocks: http://www.youtube.com/watch?v=Q0XtLjE3siE .

This video discusses how to identify a metamorphic rocks: http://www.youtube.com/watch?v=qs9x_bTCiew .

The Processes of the Rock Cycle

Several processes can turn one type of rock into another type of rock. The key processes of the rock cycle are crystallization, erosion and sedimentation, and metamorphism.

Crystallization

Magma cools either underground or on the surface and hardens into an igneous rock. As the magma cools, different crystals form at different temperatures, undergoing **crystallization**. For example, the mineral olivine crystallizes out of magma at much higher temperatures than quartz. The rate of cooling determines how much time the crystals will have to form. Slow cooling produces larger crystals.

Erosion and Sedimentation

Weathering wears rocks at the Earth's surface down into smaller pieces. The small fragments are called sediments. Running water, ice, and gravity all transport these sediments from one place to another by **erosion**. During **sedimentation**, the sediments are laid down or deposited. In order to form a sedimentary rock, the accumulated sediment must become compacted and cemented together.

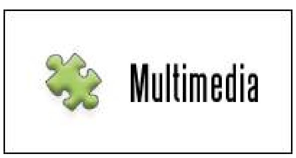
Metamorphism

When a rock is exposed to extreme heat and pressure within the Earth but does not melt, the rock becomes metamorphosed. **Metamorphism** may change the mineral composition and the texture of the rock. For that reason, a metamorphic rock may have a new mineral composition and/or texture.

Summary

- The three main rock types are igneous, metamorphic and sedimentary.
- The three processes that change one rock to another are crystallization, metamorphism, and erosion and sedimentation.
- Any rock can transform into any other rock by passing through one or more of these processes. This creates the rock cycle.

Making Connections



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Click image to the left for more content.

Practice

Use these resources to answer the questions that follow.

This *Science Made Fun* video discusses the conditions under which the three main rock types form **(3c)**: http://www.youtube.com/watch?v=G7AWGhQynTY (3:41).

MEDIA
Click image to the left for more content.

1. How do igneous rocks form?

2. What are the two types of igneous rocks and how do they differ?

3. What are metamorphic rocks?

4. How do metamorphic rocks form?

5. How do sedimentary rocks form?

6. List three examples of igneous rocks.

7. List three examples of sedimentary rocks.

8. What forms coal?

9. List three examples of metamorphic rocks.

10. Can an igneous rock become an igneous rock? Can a sedimentary rock become a sedimentary rock? Can a metamorphic rock become a metamorphic rock?

11. Draw an diagram of the rock cycle and include the processes that transform rocks from one type to another.

Review the rock cycle - click a rock to begin.

http://www.phschool.com/atschool/phsciexp/active_art/rock_cycle/index.html

Test your rock identification skills with this activity:

Name that Rock - http://library.thinkquest.org/J002289/rocks.html

Review

1. What processes must a metamorphic rock go through to become an igneous rock?
2. What processes must a sedimentary rock go through to become a metamorphic rock?
3. What types of rocks can become sedimentary rocks and how does that happen?

4.32 Minerals

- Describe the characteristics that define minerals.

Are you a mineral?

There used to be a TV commercial that said "you are what you eat." If that's true - and to some extent it is - then you are a mineral. Nearly all of our food is salted, and what is salt but the mineral halite? You also wear minerals, play with and on minerals, and admire the beauty of minerals. However, a mineral by definition cannot be organic, so despite what you heard on TV, you aren't what you eat!

What is a Mineral?

Minerals are everywhere! Scientists have identified more than 4,000 minerals in Earth's crust, although the bulk of the planet is composed of just a few.

A **mineral** possesses the following qualities:

- It must be solid.
- It must be crystalline, meaning it has a repeating arrangement of atoms.
- It must be naturally occurring.
- It must be inorganic.
- It must have a specific chemical composition.

Minerals can be identified by their physical properties, such as hardness, color, luster (shininess), and odor. The most common laboratory technique used to identify a mineral is X-ray diffraction (XRD), a technique that involves shining an X-ray light on a sample, and observing how the light exiting the sample is bent. XRD is not useful in the field, however.

The definition of a mineral is more restricted than you might think at first. For example, glass is made of sand, which is rich in the mineral quartz. But glass is not a mineral, because it is not crystalline. Instead, glass has a random assemblage of molecules. What about steel? Steel is made by mixing different metal minerals like iron, cobalt, chromium, vanadium, and molybdenum, but steel is not a mineral because it is made by humans and therefore is not naturally occurring. However, almost any rock you pick up is composed of minerals. Below we explore the qualities of minerals in more detail.

Crystalline Solid

Minerals are "crystalline" solids. A **crystal** is a solid in which the atoms are arranged in a regular, repeating pattern. Notice that in **Figure** 4.67 the green and purple spheres, representing sodium and chlorine, form a repeating pattern. In this case, they alternate in all directions.

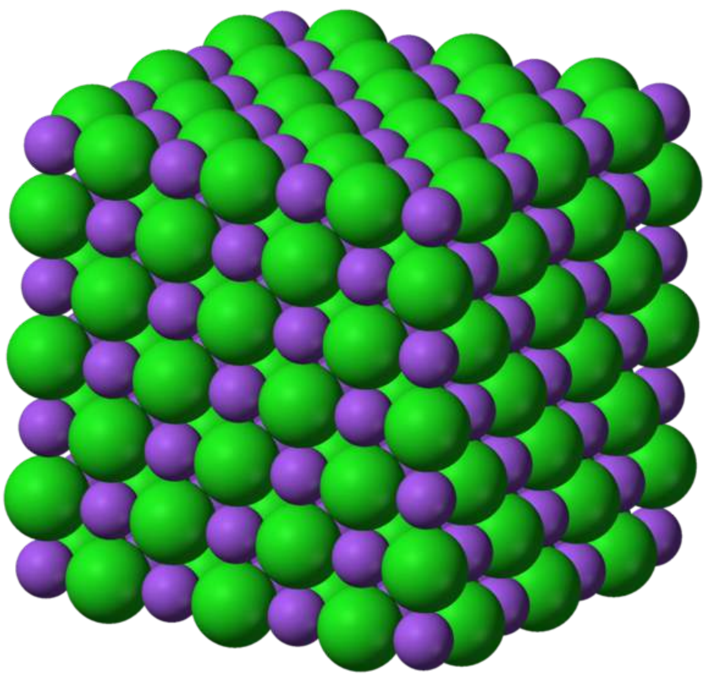


FIGURE 4.67
Sodium ions (purple balls) bond with chloride ions (green balls) to make table salt (halite). All of the grains of salt that are in a salt shaker have this crystalline structure.

Inorganic

Organic substances are the carbon-based compounds made by living creatures and include proteins, carbohydrates, and oils. Inorganic substances have a structure that is not characteristic of living bodies. Coal is made of plant and animal remains. Is it a mineral? Coal is a classified as a sedimentary rock, but is not a mineral.

Naturally Occurring

Minerals are made by natural processes, those that occur in or on Earth. A diamond created deep in Earth's crust is a mineral, but a diamond made in a laboratory by humans is not. Be careful about buying a laboratory-made “diamond” for jewelry. It may look pretty, but it's not a diamond and is not technically a mineral.

Chemical Composition

Nearly all (98.5%) of Earth's crust is made up of only eight elements –oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium –and these are the elements that make up most minerals.

All minerals have a specific chemical composition. The mineral silver is made up of only silver atoms and diamond is made only of carbon atoms, but most minerals are made up of **chemical compounds**. Each mineral has its own chemical formula. Table salt (also known as halite), pictured in **Figure** 4.67, is NaCl (sodium chloride). Quartz is always made of two oxygen atoms (red) bonded to a silicon atom (grey), represented by the chemical formula SiO_2 (**Figure** 4.68).

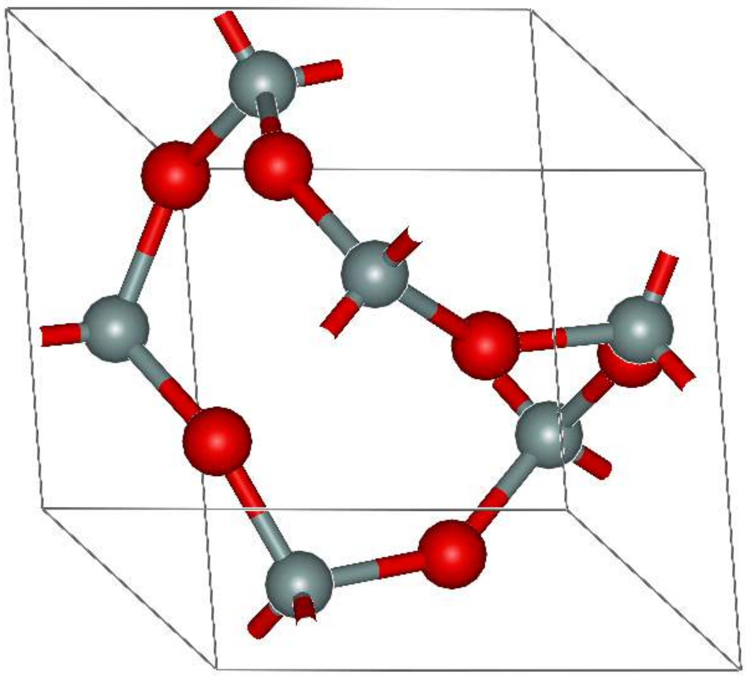


FIGURE 4.68
Quartz is made of two oxygen atoms (red) bonded to a silicon atom (grey).

In nature, things are rarely as simple as in the lab, and so it should not come as a surprise that some minerals have a range of chemical compositions. One important example in Earth science is olivine, which always has silicon and oxygen as well as some iron and magnesium, $(Mg, Fe)_2SiO_4$.

Physical Properties

Some minerals can be identified with little more than the naked eye. We do this by examining the physical properties of the mineral in question, which include:

- Color: the color of the mineral.
- Streak: the color of the mineral's powder (this is often different from the color of the whole mineral).
- Luster: shininess.
- Density: mass per volume, typically reported in "specific gravity," which is the density relative to water.
- Cleavage: the mineral's tendency to break along planes of weakness.
- Fracture: the pattern in which a mineral breaks.
- Hardness: which minerals it can scratch and which minerals can scratch it.

How physical properties are used to identify minerals is described in the concept "Mineral Identification."

Summary

- A mineral is an inorganic, crystalline solid.
- A mineral is formed through natural processes and has a definite chemical composition.
- Minerals can be identified by their characteristic physical properties, such as crystalline structure, hardness, density, breakage, and color.

Practice

Use this resource to answer the questions that follow.

http://library.thinkquest.org/J002289/minerals.html

1. What are minerals?
2. How many minerals have been found?
3. List three examples of gems.
4. How are minerals identified?
5. What is the hardest mineral?
6. What is slate used for?

Review

1. Is coal a mineral? Why or why not?
2. Is a diamond made in a laboratory a mineral? Why or why not?
3. How does the internal structure of a mineral reflect in its physical appearance?

4.33 Mineral Identification

- Explain how minerals are identified by their physical characteristics.

Can you identify this mineral?

Check out the mineral above. How would you figure out what kind of mineral it is? By color? Shape? Whether it's shiny or dull? Are there lines (striations) running across the minerals? This mineral has shiny, gold, cubic crystals with striations, and smells like sulfur. What is it? In this concept, we will discuss how to identify a mineral as one would "in the field," that is, without using fancy lab equipment.

How Are Minerals Identified?

There are a multitude of laboratory and field techniques for identifying minerals. While a mineralogist might use a high-powered microscope to identify some minerals, or even techniques like x-ray diffraction, most are recognizable using physical properties.

The most common field techniques put the observer in the shoes of a detective, whose goal it is to determine, by process of elimination, what the mineral in question is. The process of elimination usually includes observing things like color, hardness, smell, solubility in acid, streak, striations and/or cleavage.

Check out the mineral in the opening image. What is the mineral's color? What is its shape? Are the individual crystals shiny or dull? Are there lines (striations) running across the minerals? In this concept, the properties used to identify minerals are described in more detail.

Color, Streak, and Luster

Color

Color may be the first feature you notice about a mineral, but color is not often important for mineral identification. For example, quartz can be colorless, purple (amethyst), or a variety of other colors depending on chemical impurities **Figure** 4.69.

FIGURE 4.69
Purple quartz, known as amethyst, and clear quartz are the same mineral despite the different colors.

Streak

Streak is the color of a mineral's powder, which often is not the same color as the mineral itself. Many minerals, such as the quartz in the **Figure** 4.69, do not have streak.

Hematite is an example of a mineral that displays a certain color in hand sample (typically black to steel gray, sometimes reddish), and a different streak color (red/brown).

Luster

Luster describes the reflection of light off a mineral's surface. Mineralogists have special terms to describe luster. One simple way to classify luster is based on whether the mineral is metallic or non-metallic. Minerals that are opaque and shiny, such as pyrite, have a metallic luster. Minerals such as quartz have a non-metallic luster. Different types of non-metallic luster are described in **Table** 4.2.

TABLE 4.2: **Six types of non-metallic luster.**

Luster	Appearance
Adamantine	Sparkly
Earthy	Dull, clay-like
Pearly	Pearl-like
Resinous	Like resins, such as tree sap
Silky	Soft-looking with long fibers
Vitreous	Glassy

FIGURE 4.70
The streak of hematite across an unglazed porcelain plate is red-brown.

Specific Gravity

Density describes how much matter is in a certain amount of space: density = mass/volume.

Mass is a measure of the amount of matter in an object. The amount of space an object takes up is described by its volume. The density of an object depends on its mass and its volume. For example, the water in a drinking glass has the same density as the water in the same volume of a swimming pool.

Gold has a density of about 19 g/cm^3; pyrite has a density of about 5 g/cm^3 - that's another way to tell pyrite from gold. Quartz is even less dense than pyrite and has a density of 2.7 g/cm^3.

The specific gravity of a substance compares its density to that of water. Substances that are more dense have higher specific gravity.

Hardness

Hardness is a measure of whether a mineral will scratch or be scratched. Mohs Hardness Scale, shown in **Table** 4.3, is a reference for mineral hardness.

TABLE 4.3: **Mohs Hardness Scale: 1 (softest) to 10 (hardest).**

Hardness	Mineral
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Feldspar
7	Quartz
8	Topaz

TABLE 4.3: (continued)

Hardness	Mineral
9	Corundum
10	Diamond

With a Mohs scale, anyone can test an unknown mineral for its hardness. Imagine you have an unknown mineral. You find that it can scratch fluorite or even apatite, but feldspar scratches it. You know then that the mineral's hardness is between 5 and 6. Note that no other mineral can scratch diamond.

Cleavage and Fracture

Breaking a mineral breaks its chemical bonds. Since some bonds are weaker than other bonds, each type of mineral is likely to break where the bonds between the atoms are weaker. For that reason, minerals break apart in characteristic ways.

Cleavage is the tendency of a mineral to break along certain planes to make smooth surfaces. Halite (**Figure** 4.71) breaks between layers of sodium and chlorine to form cubes with smooth surfaces.

FIGURE 4.71
Halite has cubic cleavage.

Mica has cleavage in one direction and forms sheets (**Figure** 4.72).

Minerals can cleave into polygons. Magnetite forms octahedrons (**Figure** 4.73).

One reason gemstones are beautiful is that the cleavage planes make an attractive crystal shape with smooth faces.

Fracture is a break in a mineral that is not along a cleavage plane. Fracture is not always the same in the same mineral because fracture is not determined by the structure of the mineral.

Minerals may have characteristic fractures (**Figure** 4.74). Metals usually fracture into jagged edges. If a mineral splinters like wood, it may be fibrous. Some minerals, such as quartz, form smooth curved surfaces when they fracture.

FIGURE 4.72
Sheets of mica.

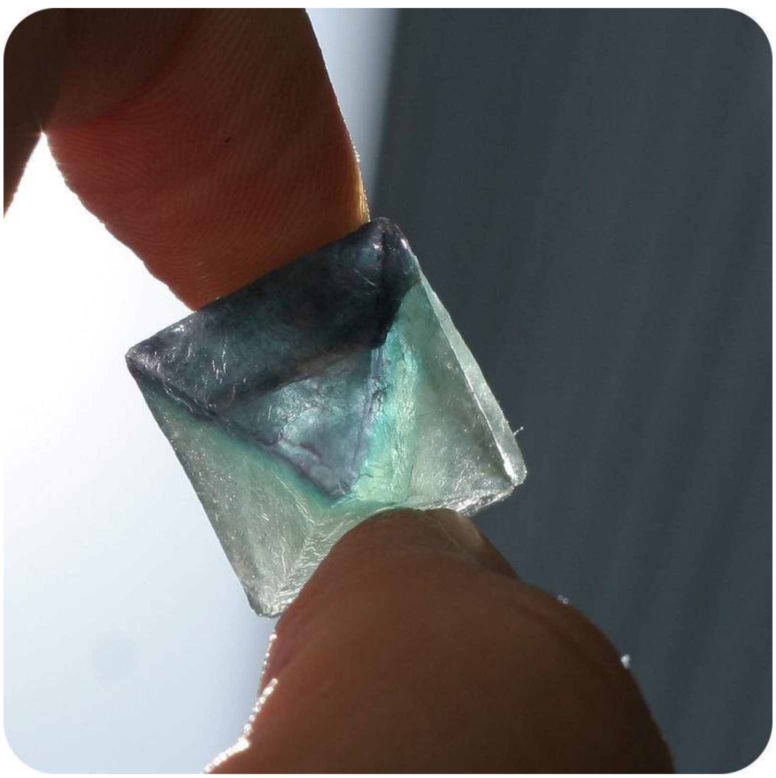


FIGURE 4.73
Fluorite has octahedral cleavage.

Other Identifying Characteristics

Some minerals have other unique properties, some of which are listed in **Table** 4.4. Can you name a unique property that would allow you to instantly identify a mineral that's been described quite a bit in this concept? (Hint: It is most likely found on your dinner table.)

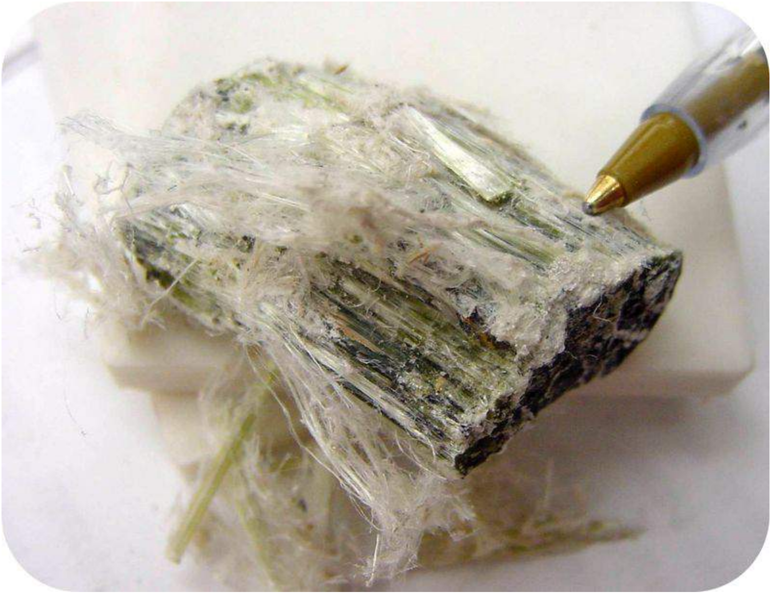


FIGURE 4.74
Chrysotile has splintery fracture.

TABLE 4.4: **Some minerals have unusual properties that can be used for identification.**

Property	Description	Example of Mineral
Fluorescence	Mineral glows under ultraviolet light	Fluorite
Magnetism	Mineral is attracted to a magnet	Magnetite
Radioactivity	Mineral gives off radiation that can be measured with Geiger counter	Uraninite
Reactivity	Bubbles form when mineral is exposed to a weak acid	Calcite
Smell	Some minerals have a distinctive smell	Sulfur (smells like rotten eggs)
Taste	Some minerals taste salty	Halite

A simple lesson on how to identify minerals is seen in this video: http://www.youtube.com/watch?v=JeFVwqBuYl4 .

Summary

- Some minerals have a unique property that makes them fairly easy to identify, such as high specific gravity or salty taste.
- Color is not a reliable indicator of mineral type for most minerals, but streak is for certain minerals.
- Cleavage can be a unique and beautiful indicator of mineral type.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

11. How can you tell that fluorite is not a calcite mineral?

12. How many sides does garnet have?

Review

1. How does color differ from streak and luster?

2. How does cleavage differ from fracture?

3. What's the first thing you should do when trying to identify a mineral? What do you do if you still can't identify it?

4.34 Igneous Rocks

- Describe the factors that determine the composition of igneous rocks.

What makes this landscape so remarkable?

This photo is of the Sierra Nevada Mountains in California. The rocks look so uniform because they are all igneous intrusive rocks that cooled from a felsic magma to create the granite that you see. Later, the rock was uplifted and modified by glaciers during the Pleistocene ice ages.

Magma Composition

Different factors play into the composition of a magma and the rock it produces.

Composition of the Original Rock

The rock beneath the Earth's surface is sometimes heated to high enough temperatures that it melts to create magma. Different magmas have different composition and contain whatever elements were in the rock or rocks that melted. Magmas also contain gases. The main elements are the same as the elements found in the crust. **Table** 4.5 lists the abundance of elements found in the Earth's crust and in magma. The remaining 1.5% is made up of many other elements that are present in tiny quantities.

TABLE 4.5: **Elements in Earth's Crust and Magma**

Element	Symbol	Percent

TABLE 4.5: (continued)

Element	**Symbol**	**Percent**
Oxygen	O	46.6%
Silicon	Si	27.7%
Aluminum	Al	8.1%
Iron	Fe	5.0%
Calcium	Ca	3.6%
Sodium	Na	2.8%
Potassium	K	2.6%
Magnesium	Mg	2.1%
Total		**98.5%**

How Rocks Melt

Whether rock melts to create magma depends on:

- Temperature: Temperature increases with depth, so melting is more likely to occur at greater depths.
- Pressure: Pressure increases with depth, but increased pressure raises the melting temperature, so melting is less likely to occur at higher pressures.
- Water: The addition of water changes the melting point of rock. As the amount of water increases, the melting point decreases.
- Rock composition: Minerals melt at different temperatures, so the temperature must be high enough to melt at least some minerals in the rock. The first mineral to melt from a rock will be quartz (if present) and the last will be olivine (if present).

The different geologic settings that produce varying conditions under which rocks melt will be discussed in the chapter Plate Tectonics.

What Melts and What Crystallizes

As a rock heats up, the minerals that melt at the lowest temperatures melt first. **Partial melting** occurs when the temperature on a rock is high enough to melt only some of the minerals in the rock. The minerals that will melt will be those that melt at lower temperatures. **Fractional crystallization** is the opposite of partial melting. This process describes the crystallization of different minerals as magma cools.

Bowen's Reaction Series indicates the temperatures at which minerals melt or crystallize (**Figure** 4.75). An understanding of the way atoms join together to form minerals leads to an understanding of how different igneous rocks form. Bowen's Reaction Series also explains why some minerals are always found together and some are never found together.

To see a diagram illustrating Bowen's Reaction Series, visit this website: http://csmres.jmu.edu/geollab/Fichter/RockMin/RockMin.html .

This excellent video that explains Bowen's Reaction Series in detail: http://www.youtube.com/watch?v=en6ihAM9fe8 .

If the liquid separates from the solids at any time in partial melting or fractional crystallization, the chemical composition of the liquid and solid will be different. When that liquid crystallizes, the resulting igneous rock will have a different composition from the parent rock.

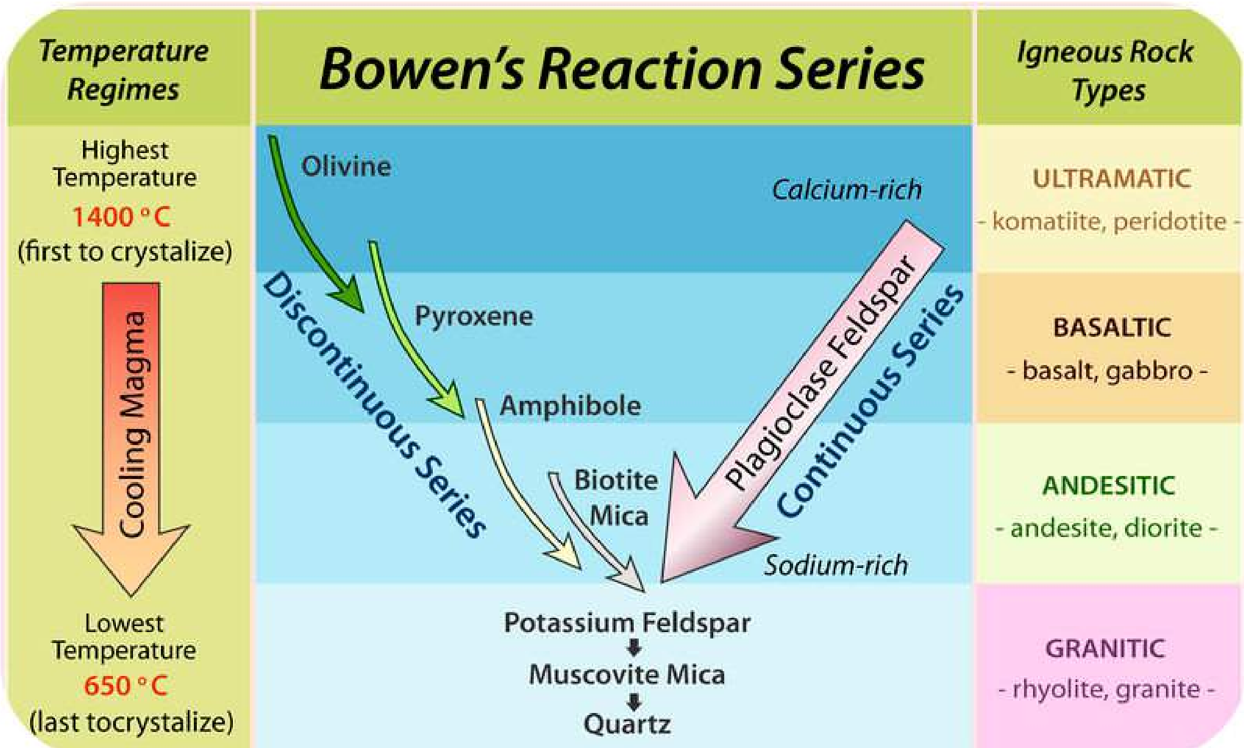


FIGURE 4.75
Bowen's Reaction Series.

Summary

- Melting of an existing rock to create magma depends on that rock's composition and on the temperature, pressure, and water content found in that environment.
- Bowen's Reaction Series indicates the temperatures at which minerals crystallize from a magma or melt from a rock.
- Since minerals melt at different temperatures, a rock in which some minerals have melted has undergone partial melting; the opposite process, in which some minerals crystallize out of a magma, is fractional crystallization.

Practice

Use this resource to answer the questions that follow.

Geology: Igneous Rocks

http://www.videojug.com/film/geology-igneous-rocks

MEDIA

Click image to the left for more content.

1. How is igneous rock formed?
2. How does crystallization occur?
3. Explain how extrusive igneous rock is formed.
4. Explain how intrusive igneous rock is formed.
5. What is pyroclastic rock?
6. How are pyroclastic rocks formed?

Review

1. Why are olivine and quartz never found together in an igneous rock?
2. How do changes in temperature, pressure, and fluids cause melting?
3. Briefly describe what Bowen's Reaction Series depicts.

4.35 Igneous Rock Classification

- Explain how igneous rocks are classified by composition and by cooling rate.

Is this an intrusive or an extrusive igneous rock?

From this view the amazing structure of rocks that make up Devil's Tower doesn't really indicate whether the structure formed slowly or quickly. A close up view would show small crystals in a mafic rock, indicating a rapid cooling from a basalt lava. Cooling was slow enough that the hexagonal "posts" could form.

Igneous Rock Classification

Igneous rocks are first classified by their composition, from felsic to ultramafic. The characteristics and example minerals in each type are included in **Table** 4.6.

TABLE 4.6: **Properties of Igneous Rock Compositions**

Composition	Color	Density	Minerals
Felsic	Light	Low	Quartz, orthoclase feldspar
Intermediate	Intermediate	Intermediate	Plagioclase feldspar, biotite, amphibole
Mafic	Dark	High	Olivine, pyroxene
Ultramafic	Very dark	Very high	Olivine

Second to composition in igneous rock classification is texture. Texture indicates how the magma that formed the rock cooled.

TABLE 4.7: Silica Composition and Texture of Major Igneous Rocks

Type	Amount of Silica	Extrusive	Intrusive
Ultramafic	<45%	Komatiite	Peridotite
Mafic	45-52%	Basalt	Gabbro
Intermediate	52-63%	Andesite	Diorite
Intermediate-Felsic	63-69%	Dacite	Granodiorite
Felsic	>69% SiO_2	Rhyolite	Granite

Some of the rocks in **Table** 4.7 were pictured earlier in this concept. Look back at them and, using what you know about the size of crystals in extrusive and intrusive rocks and the composition of felsic and mafic rocks, identify the rocks in the photos in **Figure** 4.76:

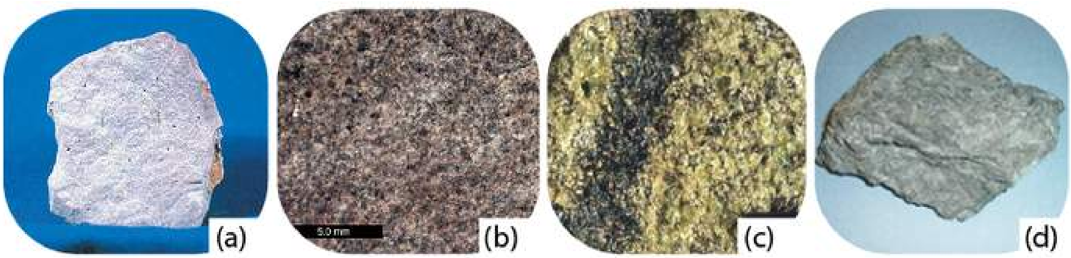


FIGURE 4.76
These are photos of A) rhyolite, B) gabbro, C) peridotite, and D) komatiite.

Summary

- Composition is the first criteria on which to classify igneous rocks, with categories from felsic to ultramafic; color is a first order indicator of composition.
- Texture is the second criteria for classifying igneous rocks because texture indicates how a rock cooled.
- Igneous rocks are categorized in pairs with the same composition but different textures: gabbro-basalt, diorite-andesite, and granite-rhyolite.

Practice

Use this resource to answer the questions that follow.

Types of Igneous Rocks

http://www.youtube.com/watch?v=dgn-xSZHItU

MEDIA
Click image to the left for more content.

1. Describe andesite.
2. What is basalt?
3. What is diorite?
4. Describe gabbro.
5. What is granite?
6. How is obsidian formed? What is it?
7. What is pegmatite?
8. What is peridotite composed of?
9. What is pumice?
10. What is rhyolite?
11. Describe scoria. How does it differ from pumice?
12. What is tuff?

Review

1. Describe the formation of the igneous rock pair gabbro-basalt. What makes the rocks the same and what makes them different?
2. How does the composition of a rock affect its color?
3. What are ultramafic rocks and where are they likely to be found?

4.36 Sedimentary Rocks

- Describe factors that determine the composition of sedimentary rocks.

What is this material and what created the ripples?

If you've walked on a sandy beach or on a sand dune, you may have seen ripples like this formed from wind or waves. Sand is small broken pieces of rock that can be moved around. They can also be lithified to become a rock known as sandstone.

Sediments

Sandstone is one of the common types of sedimentary rocks that form from sediments. There are many other types. Sediments may include:

- fragments of other rocks that often have been worn down into small pieces, such as sand, silt, or clay.
- **organic** materials, or the remains of once-living organisms.
- chemical precipitates, which are materials that get left behind after the water evaporates from a solution.

Rocks at the surface undergo mechanical and chemical weathering. These physical and chemical processes break rock into smaller pieces. Mechanical weathering simply breaks the rocks apart. Chemical weathering dissolves the less stable minerals. These original elements of the minerals end up in solution and new minerals may form. Sediments are removed and transported by water, wind, ice, or gravity in a process called erosion (**Figure** 4.77). Much more information about weathering and erosion can be found in the chapter Surface Processes and Landforms.

FIGURE 4.77
Water erodes the land surface in Alaska's Valley of Ten Thousand Smokes.

Streams carry huge amounts of sediment (**Figure** 4.78). The more energy the water has, the larger the particle it can carry. A rushing river on a steep slope might be able to carry boulders. As this stream slows down, it no longer has the energy to carry large sediments and will drop them. A slower moving stream will only carry smaller particles.

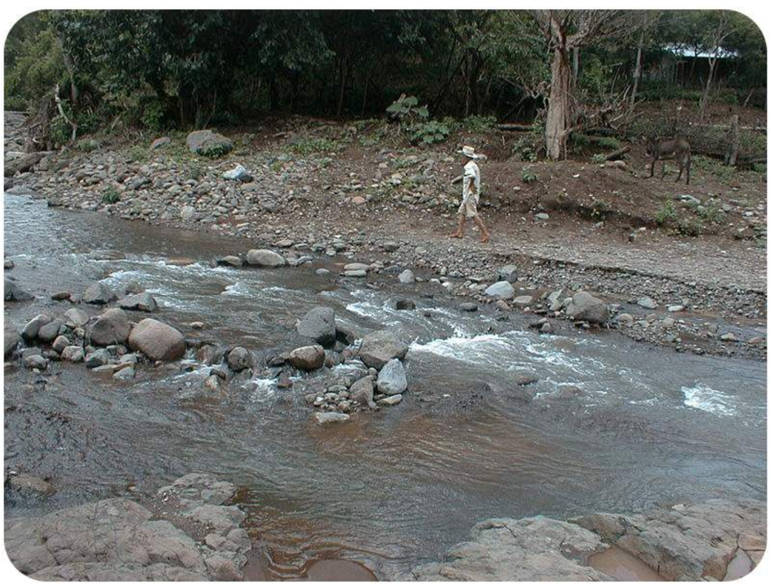


FIGURE 4.78
A river dumps sediments along its bed and on its banks.

Sediments are deposited on beaches and deserts, at the bottom of oceans, and in lakes, ponds, rivers, marshes, and swamps. Landslides drop large piles of sediment. Glaciers leave large piles of sediments, too. Wind can only transport sand and smaller particles. The type of sediment that is deposited will determine the type of sedimentary rock that can form. Different colors of sedimentary rock are determined by the environment where they are deposited. Red rocks form where oxygen is present. Darker sediments form when the environment is oxygen poor.

Summary

- Rocks undergo chemical or mechanical weathering to form smaller pieces.

- Sediments range in size from tiny bits of silt or clay to enormous boulders.
- Sediments are transported by wind, water, ice, or gravity into different environments.

Practice

Use these resources to answer the questions that follow.

http://www.windows2universe.org/earth/geology/sed_intro.html

1. What percentage of rocks are sedimentary?

2. Where are sedimentary rocks found?

3. What can scientists learn from sedimentary rocks?

4. List and explain each of the types of sedimentary rocks?

http://www.windows2universe.org/earth/geology/sed_clastic.html

5. How is clastic sedimentary rock formed?

6. What holds the sediment together?

7. What is Cathedral Rocked made of?

Review

1. What does sediment size indicate about the history of that sediment?

2. How are chemical precipitates different from rocks that form from sediment particles?

3. Why are organic materials considered sediments but not minerals?

4.37 Sedimentary Rock Classification

- Describe how sedimentary rocks are classified.

How do you know that this is a sedimentary rock?

If you look closely at the rock you will see that it is made of sand-sized particles that have been lithified to create sandstone. The rock is eroding into very unique shapes, but these shapes are more likely to form from a rock made of small cemented together grains than from an igneous or metamorphic rock.

Types of Sedimentary Rocks

TABLE 4.8: Sedimentary rock sizes and features

Rock	Sediment Size	Other Features
Conglomerate	Large	Rounded
Breccia	Large	Angular
Sandstone	Sand-sized	
Siltstone	Silt-sized, smaller than sand	
Shale	Clay-sized, smallest	

When sediments settle out of calmer water, they form horizontal layers. One layer is deposited first, and another layer is deposited on top of it. So each layer is younger than the layer beneath it. When the sediments harden, the layers are preserved. Sedimentary rocks formed by the crystallization of chemical precipitates are called **chemical sedimentary rocks**. As discussed in the concepts on minerals, dissolved ions in fluids precipitate out of the fluid and settle out, just like the halite in **Figure** 4.79.

FIGURE 4.79
The evaporite, halite, on a cobble from the Dead Sea, Israel.

Biochemical sedimentary rocks form in the ocean or a salt lake. Living creatures remove ions, such as calcium, magnesium, and potassium, from the water to make shells or soft tissue. When the organism dies, it sinks to the ocean floor to become a biochemical sediment, which may then become compacted and cemented into solid rock (**Figure** 4.80).

FIGURE 4.80
Fossils in a biochemical rock, limestone, in the Carmel Formation in Utah.

Table 4.9 shows some common types of sedimentary rocks.

TABLE 4.9: Common Sedimentary Rocks

Picture	Rock Name	Type of Sedimentary Rock
	Conglomerate	Clastic (fragments of non-organic sediments)
	Breccia	Clastic
	Sandstone	Clastic
	Siltstone	Clastic
	Shale	Clastic
	Rock Salt	Chemical precipitate

TABLE 4.9: (continued)

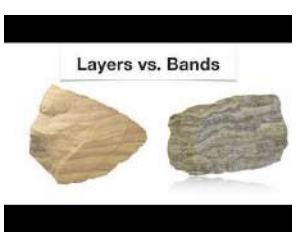
Picture	Rock Name	Type of Sedimentary Rock
	Rock Gypsum	Chemical precipitate
	Dolostone	Chemical precipitate
	Limestone	Bioclastic (sediments from organic materials, or plant or animal remains)
	Coal	Organic

Summary

- Sediments settle out of water in horizontal layers.
- Sedimentary rocks are classified based on how they form and on the size of the sediments, if they are clastic.
- Clastic sedimentary rocks are formed from rock fragments, or clasts; chemical sedimentary rocks precipitate from fluids; and biochemical sedimentary rocks form as precipitation from living organisms.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. List the three types of sedimentary rocks.

2. List the characteristics of clastic rocks.
3. How do clastic rocks form?
4. Contrast conglomerates and breccia rocks.
5. What can be found in clastic rocks?
6. Explain the difference between layers and bands.
7. What can we learn from sedimentary rocks?
8. How do chemical rocks form?
9. What are bioclastic rocks?
10. List the two types of biocalstic rocks.

Review

1. How does an organism become a sedimentary rock?
2. How do chemical sedimentary rocks differ from clastic sedimentary rocks?
3. What are the different sedimentary rock types based on grain size, from small to large?

4.38 Metamorphic Rocks

- Explain how metamorphic rocks form.

Can you decipher the history of this rock?

The rock in this photo is a banded gneiss. The bands are of different composition, more felsic and more mafic, that separated as a result of heat and pressure. The waviness of the bands also shows how the rock was hot enough to alter but not to melt all the way.

Metamorphism

Any type of rock –igneous, sedimentary, or metamorphic —can become a metamorphic rock. All that is needed is enough heat and/or pressure to alter the existing rock's physical or chemical makeup without melting the rock entirely. Rocks change during metamorphism because the minerals need to be stable under the new temperature and pressure conditions. The need for stability may cause the structure of minerals to rearrange and form new minerals. Ions may move between minerals to create minerals of different chemical composition. Hornfels, with its alternating bands of dark and light crystals, is a good example of how minerals rearrange themselves during metamorphism. Hornfels is shown in the table for the "Metamorphic Rock Classification" concept.

Texture

Extreme pressure may also lead to **foliation**, the flat layers that form in rocks as the rocks are squeezed by pressure (**Figure** 4.81). Foliation normally forms when pressure is exerted in only one direction. Metamorphic rocks may also be non-foliated. Quartzite and marble, shown in the concept "Metamorphic Rock Classification," are non-foliated.

FIGURE 4.81
A foliated metamorphic rock.

Types of Metamorphism

The two main types of metamorphism are both related to heat within Earth:

1. **Regional metamorphism**: Changes in enormous quantities of rock over a wide area caused by the extreme pressure from overlying rock or from compression caused by geologic processes. Deep burial exposes the rock to high temperatures.
2. **Contact metamorphism**: Changes in a rock that is in contact with magma. The changes occur because of the magma's extreme heat.

Summary

- Any type of rock - igneous, sedimentary or metamorphic - can become a metamorphic rock.
- Foliated rocks form when rocks being metamorphosed are exposed to pressure in one direction.
- Regional metamorphism occurs over a large area but contact metamorphism occurs when a rock is altered by a nearby magma.

Practice

Use this resource to answer the questions that follow.

http://library.thinkquest.org/J002289/meta.html

1. How do metamorphic rocks form?

2. Where does the heat come from to change these rocks?

3. What produces the pressure to change these rocks?

4. List the characteristics of metamorphic rocks.

5. List examples of metamorphic rocks.

Review

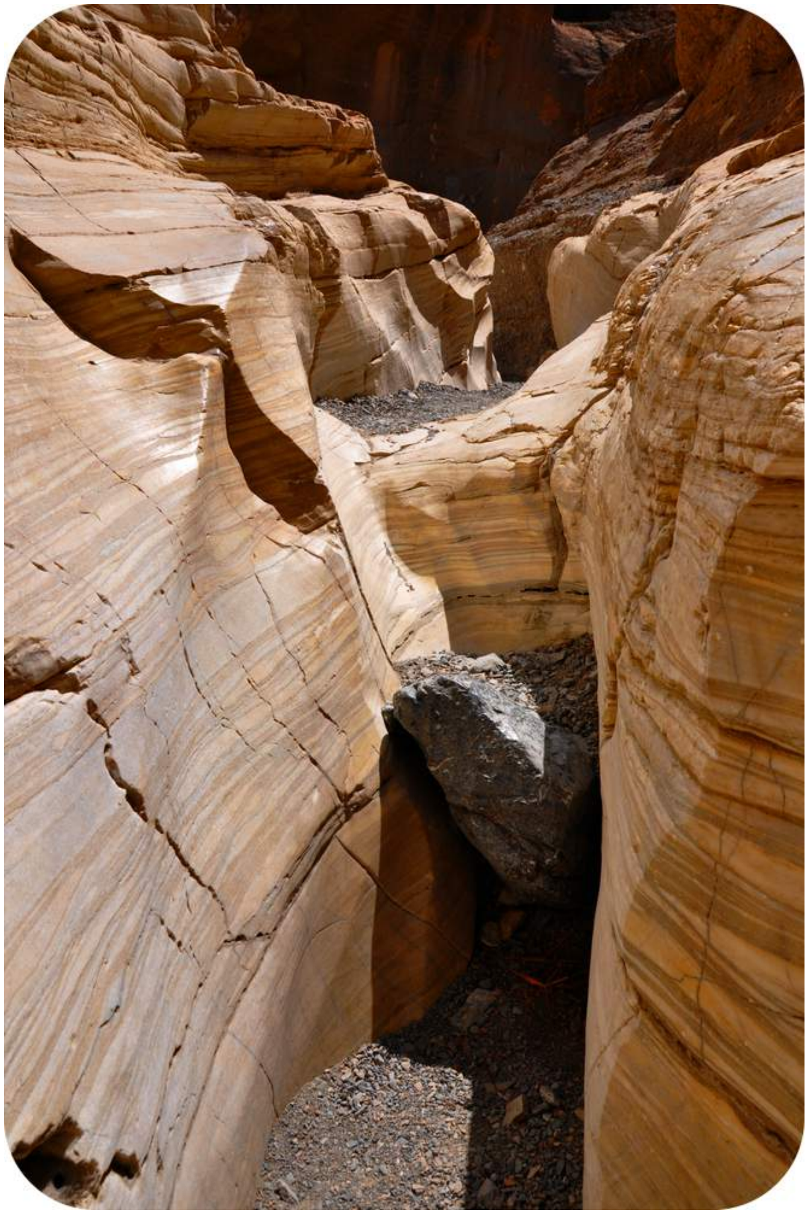
1. Why do changes in temperature or pressure cause rocks to change?

2. What are the similarities and differences in conditions that cause regional versus contact metamorphism?

3. What causes foliation in a metamorphic rock? Under what circumstances would you expect this to happen?

4.39 Metamorphic Rock Classification

- Describe how metamorphic rocks are classified.



Why is this called Marble Canyon?

Marble Canyon in the Grand Canyon is made of sedimentary rock. But Marble Canyon in Death Valley is made of marble, metamorphosed limestone. Notice how shiny the marble is where it was smoothed by sand in rushing water. The rock has the altered appearance of metamorphic rock.

Metamorphic Rocks

Table 4.10 shows some common metamorphic rocks and their original parent rock.

TABLE 4.10: Common Metamorphic Rocks

Picture	Rock Name	Type of Metamorphic Rock	Comments
	Slate	Foliated	Metamorphism of shale
	Phyllite	Foliated	Metamorphism of slate, but under greater heat and pressure than slate
	Schist	Foliated	Often derived from metamorphism of claystone or shale; metamorphosed under more heat and pressure than phyllite
	Gneiss	Foliated	Metamorphism of various different rocks, under extreme conditions of heat and pressure
	Hornfels	Non-foliated	Contact metamorphism of various different rock types
	Quartzite	Non-foliated	Metamorphism of quartz sandstone

TABLE 4.10: (continued)

Picture	Rock Name	Type of Metamorphic Rock	Comments
	Marble	Non-foliated	Metamorphism of limestone
	Metaconglomerate	Non-foliated	Metamorphism of conglomerate

Summary

- Foliated metamorphic rocks are platy; non-foliated metamorphic rocks are massive.
- The more extreme the amount of metamorphism, the more difficult it is to tell what the original rock was.
- Marble is metamorphosed limestone.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. How are metamorphic rocks classified?
2. How do metamorphic rocks form?
3. What is recrystallization?
4. Why are these rocks the most dense?
5. Where do metamorphic rocks form?
6. Where does regional metamorphism occur?
7. What is a foliated rock?
8. What does shale become when heated and put under pressure?
9. What is schist?

10. Describe gneiss.
11. What is the evidence for regional metamorphosis?
12. What is contact metamorphism?
13. Where does contact metamorphism occur?
14. Describe non-foliated rocks.
15. Why is hornfels unique?

Review

1. How do geologists tell what the parent rock of a metamorphic rock was, particularly a rock that was highly metamorphosed?

2. How do slate, phyllite, and schist differ from each other? How are they the same?

3. How does quartzite differ from a metamorphosed sandstone that is made of more than one mineral?

4.40 References

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61. Zachary Wilson. Cross section of a composite volcano, revealing alternating layers of rock and ash. CC BY-NC 3.0
62. Vadim Kurland. The Mauna Kea volcano in Hawaii is a shield volcano. CC BY 2.0
63. Courtesy of C. Heliker/US Geological Survey. A lava fountain erupts from Pu'u O'o, a cinder cone on Kilauea. Public Domain
64. Courtesy of US Geological Survey. Map of hotspots around the world. Public Domain
65. (a) Holger Behr (User:Hobe/Wikimedia Commons); (b) Courtesy of Johnson Space Center/NASA's Earth Observatory. Map of the Society Islands. Public Domain
66. User:Woudloper/Woodwalker; modified by CK-12 Foundation. The rock cycle. Public Domain
67. Ben Mills (User:Benjah-bmm27/Wikimedia Commons). Halite crystals form from sodium and chloride ions. Public Domain
68. User:Materialscientist/Wikipedia. Quartz is made of two oxygen atoms bonded to a silicon atom. Public Domain
69. Left: Stephanie Clifford; Right: Mauro Cateb. . CC BY 2.0

70. CK-12 Foundation. . CC BY-NC 3.0
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75. Hana Zavadska. Bowen's Reaction Series indicates how different igneous rocks form. CC BY-NC 3.0
76. A) Courtesy of the US Geological Survey and the Mineral Information Institute; B) Mark A. Wilson (User:Wilson44691/Wi Commons); C) User:Omphacite/Wikimedia Commons; D) User:GeoRanger/Wikipedia. Pictures of rhyolite, gabbro, peridotite, and komtiite. Public Domain
77. Courtesy of the National Oceanic and Atmospheric Administration. Water erosion in Alaska's Valley of Ten Thousand Smokes. Public Domain
78. User:ZackClark/Wikimedia Commons. A river dumps sediments along its bed and on its banks. Public Domain
79. Mark A. Wilson (User:Wilson44691/Wikimedia Commons). Halite forming on a rock in the Dead Sea. Public Domain
80. Mark A. Wilson (User:Wilson44691/Wikimedia Commons). Fossils in limestone in the Carmel Formation. Public Domain
81. Steven Coutts. A foliated metamorphic rock. CC BY 2.0

CHAPTER 5 Hydrology & Weathering

Chapter Outline

5.1 Processes of the Water Cycle

- Describe the water cycle and describe the processes that carry water between reservoirs.
- Define the processes by which water changes state and explain the role each plays in the water cycle.

Where have these water molecules been?

Because of the unique properties of water, water molecules can cycle through almost anywhere on Earth. The water molecule found in your glass of water today could have erupted from a volcano early in Earth's history. In the intervening billions of years, the molecule probably spent time in a glacier or far below the ground. The molecule surely was high up in the atmosphere and maybe deep in the belly of a dinosaur. Where will that water molecule go next?

The Water Cycle

The movement of water around Earth's surface is the **hydrological (water) cycle** (**Figure** 5.1). Water inhabits reservoirs within the cycle, such as ponds, oceans, or the atmosphere. The molecules move between these reservoirs by certain processes, including condensation and precipitation. There are only so many water molecules and these molecules cycle around. If climate cools and glaciers and ice caps grow, there is less water for the oceans and sea level will fall. The reverse can also happen.

The following section looks at the reservoirs and the processes that move water between them.

Solar Energy

The Sun, many millions of kilometers away, provides the energy that drives the water cycle. Our nearest star directly impacts the water cycle by supplying the energy needed for evaporation.

Oceans

Most of Earth's water is stored in the oceans, where it can remain for hundreds or thousands of years.

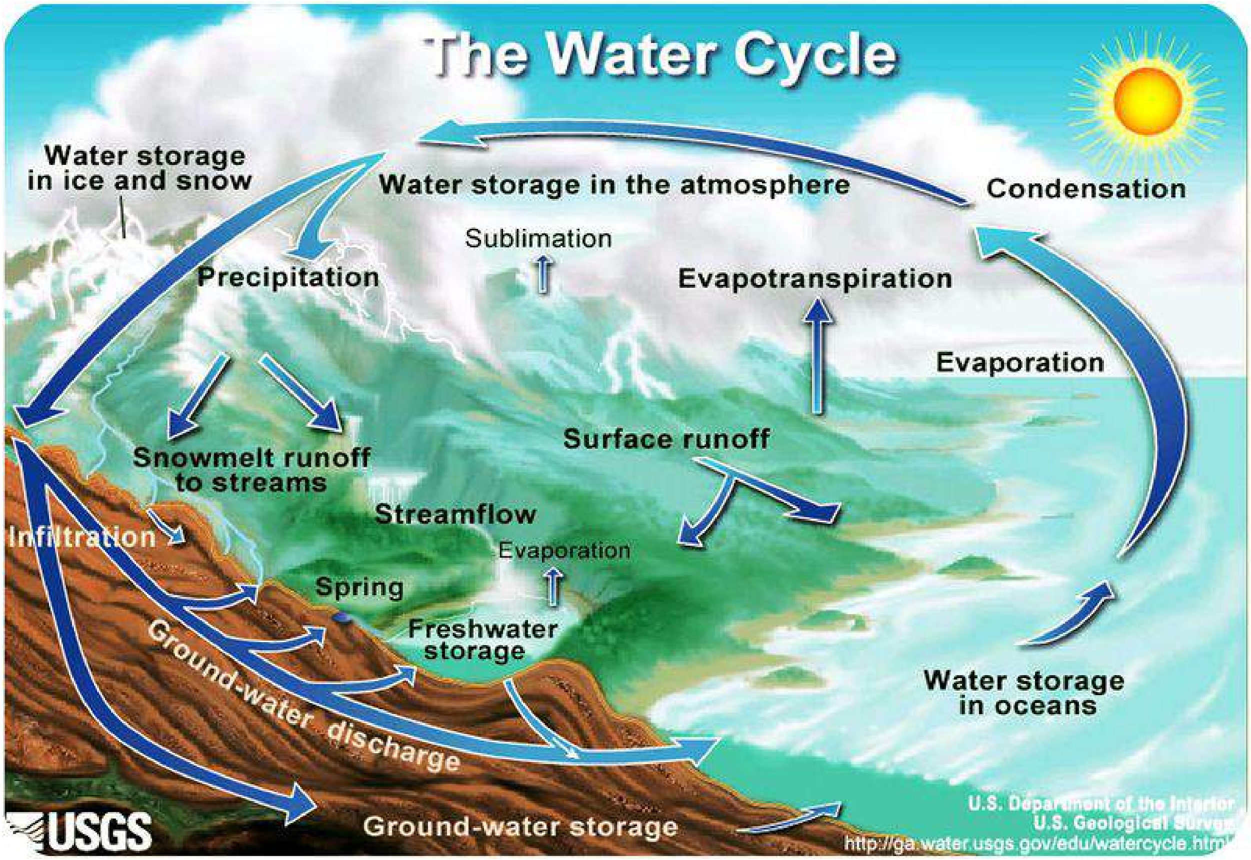


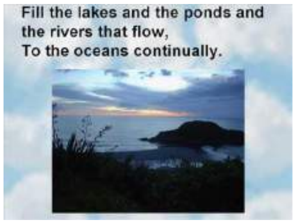
FIGURE 5.1
Because it is a cycle, the water cycle has no beginning and no end.

Atmosphere

Water changes from a liquid to a gas by **evaporation** to become water vapor. The Sun's energy can evaporate water from the ocean surface or from lakes, streams, or puddles on land. Only the water molecules evaporate; the salts remain in the ocean or a fresh water reservoir.

The water vapor remains in the atmosphere until it undergoes **condensation** to become tiny droplets of liquid. The droplets gather in clouds, which are blown about the globe by wind. As the water droplets in the clouds collide and grow, they fall from the sky as precipitation. **Precipitation** can be rain, sleet, hail, or snow. Sometimes precipitation falls back into the ocean and sometimes it falls onto the land surface.

For a little fun, watch this video. This water cycle song focuses on the role of the Sun in moving H_2O from one reservoir to another. The movement of all sorts of matter between reservoirs depends on Earth's internal or external sources of energy: http://www.youtube.com/watch?v=Zx_1g5pGFLI (2:38).



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This animation shows the annual cycle of monthly mean precipitation around the world: http://en.wikipedia.org/wiki/File:MeanMonthlyP.gif .

Streams and Lakes

When water falls from the sky as rain it may enter streams and rivers that flow downward to oceans and lakes. Water that falls as snow may sit on a mountain for several months. Snow may become part of the ice in a glacier, where it may remain for hundreds or thousands of years. Snow and ice may go directly back into the air by sublimation, the process in which a solid changes directly into a gas without first becoming a liquid. Although you probably have not seen water vapor undergoing **sublimation** from a glacier, you may have seen dry ice sublimate in air.

Snow and ice slowly melt over time to become liquid water, which provides a steady flow of fresh water to streams, rivers, and lakes below. A water droplet falling as rain could also become part of a stream or a lake. At the surface, the water may eventually evaporate and reenter the atmosphere.

Soil

A significant amount of water infiltrates into the ground. Soil moisture is an important reservoir for water (**Figure** 5.2). Water trapped in soil is important for plants to grow.

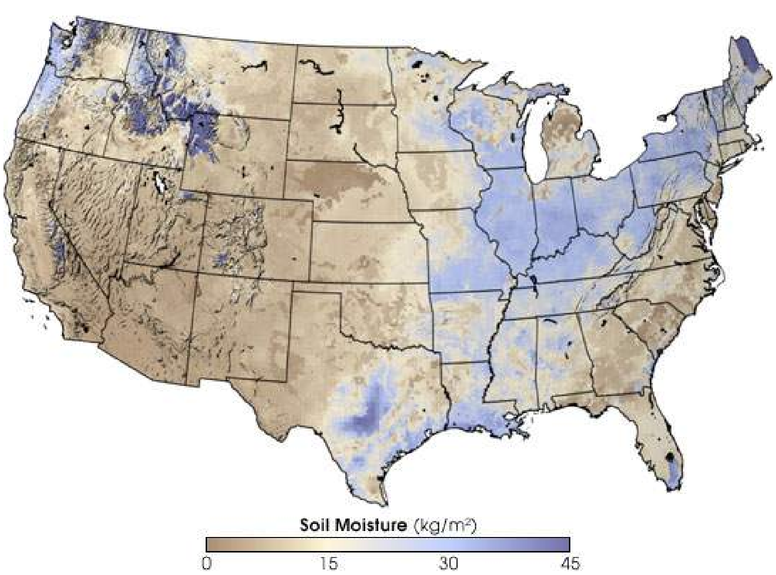


FIGURE 5.2

The moisture content of soil in the United States varies greatly.

Groundwater

Water may seep through dirt and rock below the soil and then through pores infiltrating the ground to go into Earth's groundwater system. Groundwater enters aquifers that may store fresh water for centuries. Alternatively, the water may come to the surface through springs or find its way back to the oceans.

Biosphere

Plants and animals depend on water to live. They also play a role in the water cycle. Plants take up water from the soil and release large amounts of water vapor into the air through their leaves (**Figure** 5.3), a process known as **transpiration**.

An online guide to the hydrologic cycle from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/hyd/home.rxml .

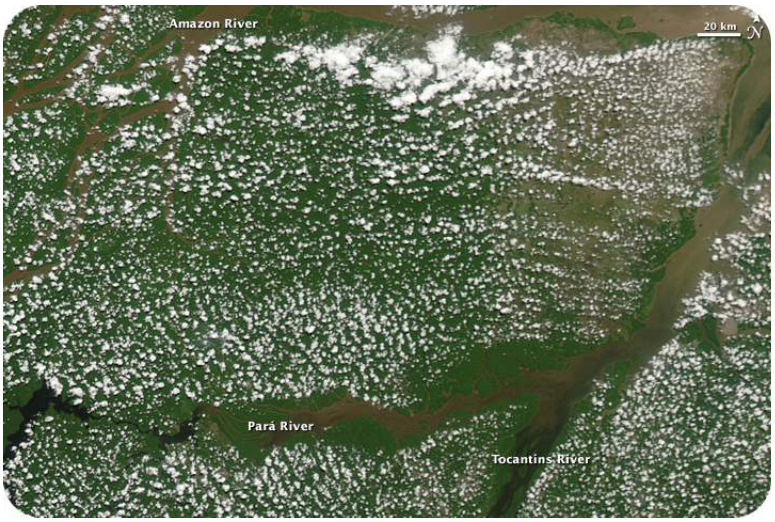


FIGURE 5.3
Clouds form above the Amazon Rainforest even in the dry season because of moisture from plant transpiration.

How the water cycle works and how rising global temperatures will affect the water cycle, especially in California, are the topics of this Quest video.

Watch it at http://www.kqed.org/quest/television/tracking-raindrops/.

Adobe Flash

MEDIA
Click image to the left for more content.

Human Uses

People also depend on water as a natural resource. Not content to get water directly from streams or ponds, humans create canals, aqueducts, dams, and wells to collect water and direct it to where they want it (**Figure** 5.4).

Summary

- The water cycle describes all of the reservoirs of water and the processes that carry it between them.
- Water changes state by evaporation, condensation, and sublimation.
- Plants release water through their leaves by transpiration.

FIGURE 5.4
Pont du Gard in France is an ancient aqueduct and bridge that was part of of a well-developed system that supplied water around the Roman empire.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Water Cycle**

1. What is condensation?
2. List the types of precipitation.
3. What is infiltration?
4. What is surface runoff?
5. Explain what happens with groundwater.
6. Explain the difference between evaporation and transpiration.

Review

1. What is transpiration?
2. Describe when and how sublimation occurs.
3. What is the role of the major reservoirs in the water cycle?

5.2 Distribution of Water on Earth

- Describe the distribution of Earth's water.
- Explain why fresh water is a scarce resource.

Water, water everywhere. But how much of it is useful?

Earth is the water planet. From space, Earth is a blue ball, unlike any of the other planets in our solar system. Life, also unique to Earth of the planets in our solar system, depends on this water. While there's a lot of salt water, a surprisingly small amount of it is fresh water.

Distribution of Water

Earth's oceans contain 97% of the planet's water. That leaves just 3% as fresh water, water with low concentrations of salts (**Figure** 5.5). Most fresh water is trapped as ice in the vast glaciers and ice sheets of Greenland.

How is the 3% of fresh water divided into different reservoirs? How much of that water is useful for living creatures? How much for people?

A storage location for water such as an ocean, glacier, pond, or even the atmosphere is known as a **reservoir**. A water molecule may pass through a reservoir very quickly or may remain for much longer. The amount of time a molecule stays in a reservoir is known as its **residence time**.

Summary

- Of Earth's water, 97% is in the oceans.
- Of the remaining 3%, much is trapped in ice and glaciers.
- A substance is stored in a reservoir and the amount of time it stays in that reservoir is its residence time.

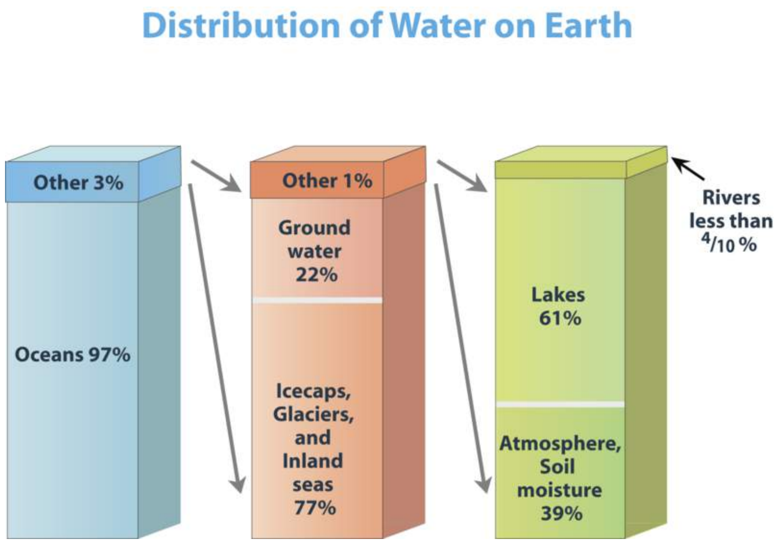


FIGURE 5.5
The distribution of Earth's water.

Practice

Use this resource to answer the questions that follow.

http://ga.water.usgs.gov/edu/earthwherewater.html

1. What percentage of Earth's water is usable for humans?
2. How much of the Earth's water is ocean water?
3. How much freshwater is in glaciers?
4. How much freshwater is groundwater?
5. How much freshwater is in lakes?

Review

1. If Earth is the water planet, why is water sometimes a scarce resource?
2. What are the reservoirs for water?
3. In which reservoirs does water have the longest residence times? The shortest?

5.3 Introduction to Groundwater

- Define aquifer and explain how aquifers form and recharge.

Is there always water flowing beneath the land surface?

Although this may seem surprising, water beneath the ground is commonplace, moving slowly and silently through an aquifer and then bubbling to the surface at a spring. Groundwater is an extremely important source of water in many parts of the world where development and agriculture outmatch the amount of water available from rainfall and streams.

Aquifer

Groundwater resides in **aquifers**, porous rock and sediment with water in between. Water is attracted to the soil particles, and **capillary action**, which describes how water moves through porous media, moves water from wet soil to dry areas.

Aquifers are found at different depths. Some are just below the surface and some are found much deeper below the land surface. A region may have more than one aquifer beneath it and even most deserts are above aquifers. The source region for an aquifer beneath a desert is likely to be far away, perhaps in a mountainous area.

Recharge

The amount of water that is available to enter groundwater in a region, called **recharge**, is influenced by the local climate, the slope of the land, the type of rock found at the surface, the vegetation cover, land use in the area, and water retention, which is the amount of water that remains in the ground. More water goes into the ground where there is a lot of rain, flat land, porous rock, exposed soil, and where water is not already filling the soil and rock.

Fossil Water

The residence time of water in a groundwater aquifer can be from minutes to thousands of years. Groundwater is often called "fossil water" because it has remained in the ground for so long, often since the end of the ice ages.

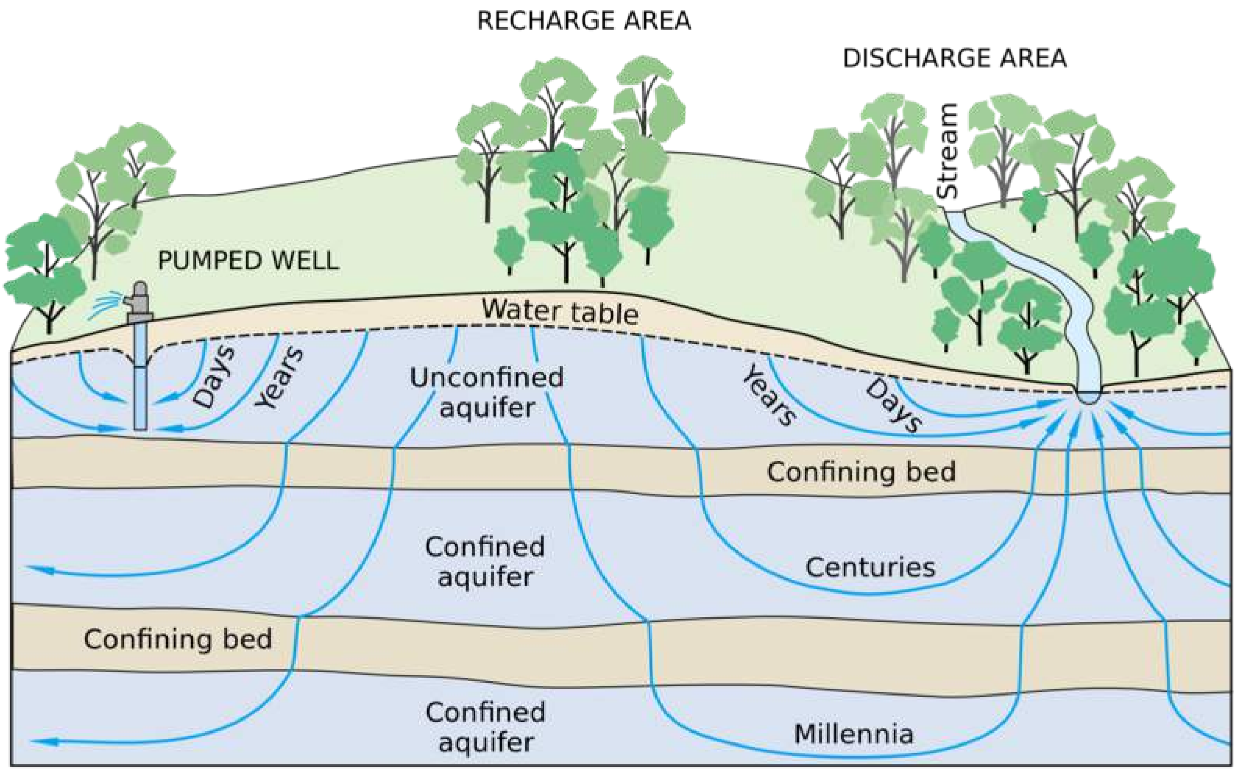


FIGURE 5.6
A diagram of groundwater flow through aquifers showing residence times. Deeper aquifers typically contain older "fossil water."

Summary

- Groundwater is in aquifers, a porous and permeable rock layer.
- Groundwater recharges in wet regions.
- Much groundwater is from the end of the ice ages, so it is called fossil water.

Practice

Use this resource to answer the questions that follow.

http://earthguide.ucsd.edu/earthguide/diagrams/groundwater/index.html

1. What is groundwater?

2. How does groundwater begin?

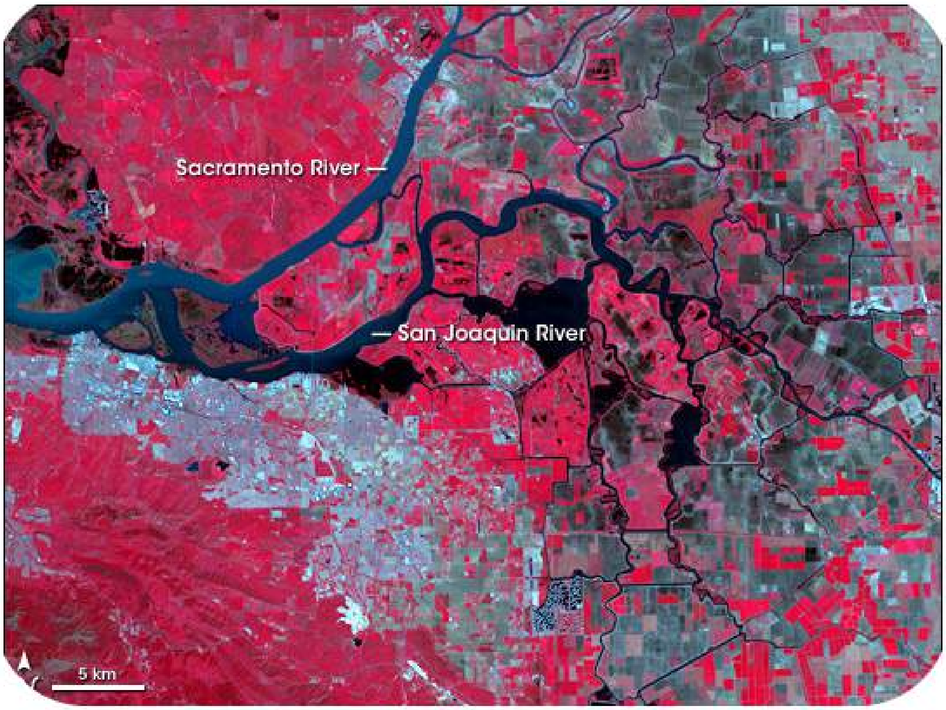
3. What is the water table?
4. What is an aquifer?
5. What is the cone of depression? How is it created?

Review

1. What effects the residence time of groundwater in a region?
2. Where does groundwater come from in a region that has very little rainfall?
3. If groundwater is used, how will there be more?

5.4 Streams and Rivers

- Define stream and describe its parts and stages.



Do you see the Sacramento and San Joaquin Rivers?

The farmland in the Central Valley of California is among the most productive in the world. Besides good soil and a mild climate, the region has a lot of water. Streams drain off of the Sierra Nevada mountains to the east and join the mighty Sacramento and San Joaquin Rivers in the Central Valley. How many of the features that are discussed below can you find in this image?

Streams

Streams are bodies of water that have a current; they are in constant motion. Geologists recognize many categories of streams depending on their size, depth, speed, and location. Creeks, brooks, tributaries, bayous, and rivers are all streams. In streams, water always flows downhill, but the form that downhill movement takes varies with rock type, topography, and many other factors. Stream erosion and deposition are extremely important creators and destroyers of landforms.

Rivers are the largest streams. People have used rivers since the beginning of civilization as a source of water, food, transportation, defense, power, recreation, and waste disposal.

With its high mountains, valleys and Pacific coastline, the western United States exhibits nearly all of the features common to rivers and streams. The photos below are from the western states of Montana, California and Colorado.

Parts of a Stream

A stream originates at its source. A source is likely to be in the high mountains where snows collect in winter and melt in summer, or a source might be a spring. A stream may have more than one source.

Two streams come together at a **confluence**. The smaller of the two streams is a **tributary** of the larger stream (**Figure** 5.7).

FIGURE 5.7
The confluence between the Yellowstone River and one of its tributaries, the Gardiner River, in Montana.

The point at which a stream comes into a large body of water, like an ocean or a lake, is called the **mouth**. Where the stream meets the ocean or lake is an **estuary** (**Figure** 5.8).

FIGURE 5.8
The mouth of the Klamath River creates an estuary where it flows into the Pacific Ocean in California.

The mix of fresh and salt water where a river runs into the ocean creates a diversity of environments where many different types of organisms create unique ecosystems.

Stages of Streams

As a stream flows from higher elevations, like in the mountains, towards lower elevations, like the ocean, the work of the stream changes. At a stream's **headwaters**, often high in the mountains, gradients are steep (**Figure** 5.9). The stream moves fast and does lots of work eroding the stream bed.

FIGURE 5.9
Headwaters of the Roaring Fork River in Colorado.

As a stream moves into lower areas, the gradient is not as steep. Now the stream does more work eroding the edges of its banks. Many streams develop curves in their channels called **meanders** (**Figure** 5.10).

FIGURE 5.10
The East River meanders through Crested Butte, Colorado.

As the river moves onto flatter ground, the stream erodes the outer edges of its banks to carve a **floodplain**, which is a flat, level area surrounding the stream channel (**Figure** 5.11).

Base level is where a stream meets a large body of standing water, usually the ocean, but sometimes a lake or pond. Streams work to down cut in their stream beds until they reach base level. The higher the elevation, the farther the stream is from where it will reach base level and the more cutting it has to do. The ultimate base level is sea level.

Divides

A **divide** is a topographically high area that separates a landscape into different water basins (**Figure** 5.12). Rain that falls on the north side of a ridge flows into the northern drainage basin and rain that falls on the south side flows into the southern drainage basin. On a much grander scale, entire continents have divides, known as **continental divides**.

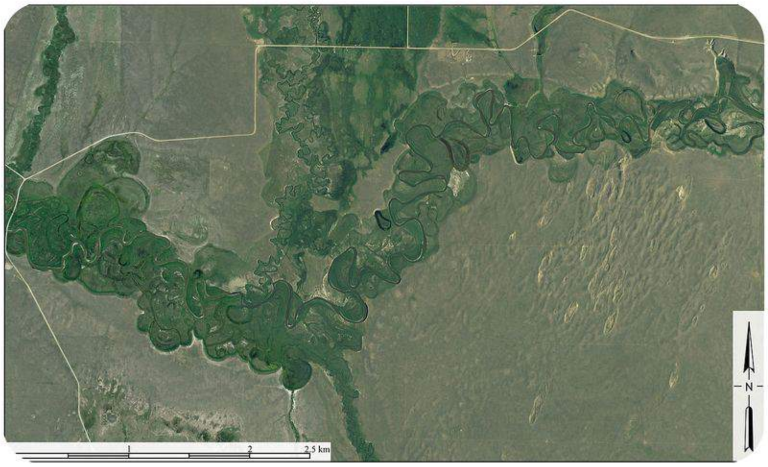


FIGURE 5.11
A green floodplain surrounds the Red Rock River as it flows through Montana.

FIGURE 5.12
(a) The divides of North America. In the Rocky Mountains in Colorado, where does a raindrop falling on the western slope end up? How about on the eastern slope? (b) At Triple Divide Peak in Montana water may flow to the Pacific, the Atlantic, or Hudson Bay depending on where it falls. Can you locate where in the map of North America this peak sits?

Summary

- A moving body of water of any size is a stream.
- A tributary begins at its headwaters on one side of a divide, comes together with another tributary at a confluence, and empties out at an estuary.
- Base level is where a large body of water is located; sea level is the ultimate base level.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=TxI9gTvNY0M

MEDIA
Click image to the left for more content.

1. Where is water speed and weight the greatest?
2. What is created by this fast moving water?
3. Explain what is occurring where the water moves slowly.

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

MEDIA
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4. What has destabilized the Minnesota River area?
5. What speeds up the water as it moves down the river?
6. What caused the ravines to form?
7. Where does most of the sediment end up?
8. List the sources of the sediment.

Review

1. Very little land is below sea level and all of it does not drain to the sea. Why not?
2. What happens to two drops of water that fall on opposite sides of a divide?
3. What happens to a river's floodplain if the river is dammed?

5.5 Fresh Water Ecosystems

- Describe the various types of freshwater ecosystems.

Why did people used to rush to fill in swamps?

People didn't know the value of wetlands. Many are in locations that might be desirable for people to live, like near a shoreline. Mosquitoes, which no one seems to like, breed there. But wetlands serve a number of valuable purposes. They are breeding grounds for many organisms and they protect inland areas from storms. Now wetlands are protected.

Freshwater Ecosystems

Organisms that live in lakes, ponds, streams, springs or wetlands are part of freshwater ecosystems. These ecosystems vary by temperature, pressure (in lakes), the amount of light that penetrates and the type of vegetation that lives there.

Lake Ecosystems

Limnology is the study of bodies of fresh water and the organisms that live there. A lake has zones just like the ocean. The ecosystem of a lake is divided into three distinct zones (**Figure** 5.13):

1. The surface (littoral) zone is the sloped area closest to the edge of the water.

2. The open-water zone (also called the photic or limnetic zone) has abundant sunlight.

3. The deep-water zone (also called the aphotic or profundal zone) has little or no sunlight.

There are several life zones found within a lake:

- In the littoral zone, sunlight promotes plant growth, which provides food and shelter to animals such as snails, insects, and fish.
- In the open-water zone, other plants and fish, such as bass and trout, live.
- The deep-water zone does not have photosynthesis since there is no sunlight. Most deep-water organisms are scavengers, such as crabs and catfish that feed on dead organisms that fall to the bottom of the lake. Fungi and bacteria aid in the decomposition in the deep zone.

Though different creatures live in the oceans, ocean waters also have these same divisions based on sunlight with similar types of creatures that live in each of the zones.

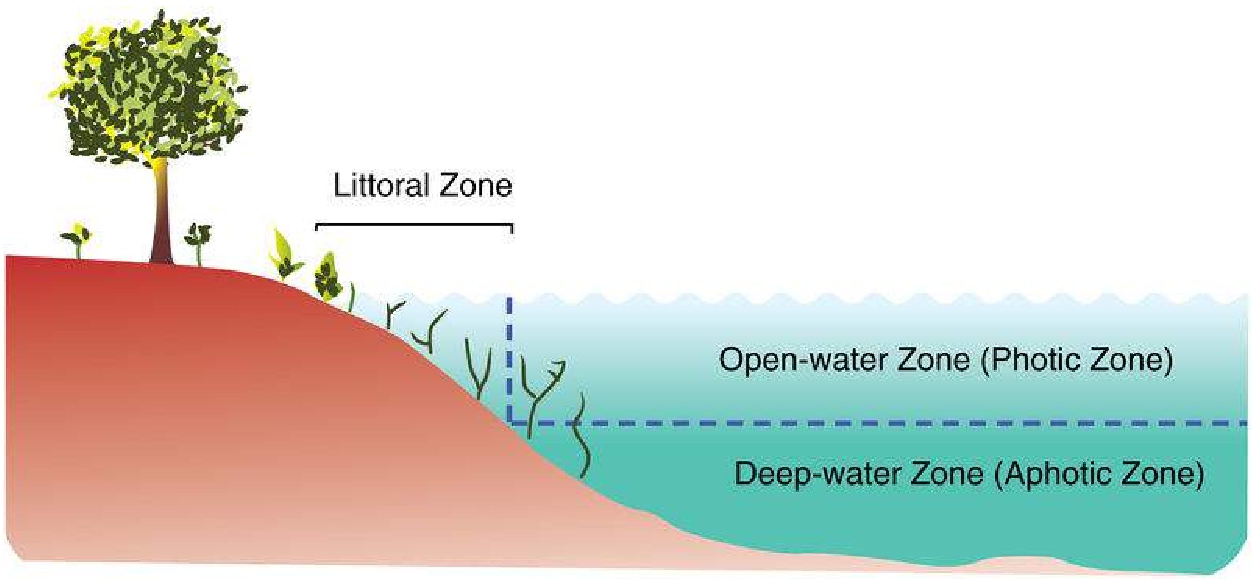

FIGURE 5.13
The three primary zones of a lake are the littoral, open-water, and deep-water zones.

Wetlands

Wetlands are lands that are wet for significant periods of time. They are common where water and land meet. Wetlands can be large flat areas or relatively small and steep areas.

Wetlands are rich and unique ecosystems with many species that rely on both the land and the water for survival. Only specialized plants are able to grow in these conditions. Wetlands tend have a great deal of biological diversity. Wetland ecosystems can also be fragile systems that are sensitive to the amount and quality of water present within them.

Marshes

Marshes are shallow wetlands around lakes, streams, or the ocean where grasses and reeds are common, but trees are not (**Figure** 5.14). Frogs, turtles, muskrats, and many varieties of birds are at home in marshes.

FIGURE 5.14
A salt marsh on Cape Cod in Massachusetts.

Swamps

A **swamp** is a wetland with lush trees and vines found in low-lying areas beside slow-moving rivers (**Figure** 5.15). Like marshes, they are frequently or always inundated with water. Since the water in a swamp moves slowly, oxygen in the water is often scarce. Swamp plants and animals must be adapted for these low-oxygen conditions. Like marshes, swamps can be fresh water, salt water, or a mixture of both.

FIGURE 5.15
A swamp is characterized by trees in still water.

Ecological Role of Wetlands

As mentioned above, wetlands are home to many different species of organisms. Although they make up only 5% of the area of the United States, wetlands contain more than 30% of the plant types. Many endangered species live in wetlands, so wetlands are protected from human use.

Wetlands also play a key biological role by removing pollutants from water. For example, they can trap and use fertilizer that has washed off a farmer's field, and therefore they prevent that fertilizer from contaminating another body of water. Since wetlands naturally purify water, preserving wetlands also helps to maintain clean supplies of water.

Summary

- The conditions that affect lake ecosystems are similar to those that affect marine ecosystems, such as light penetration, temperature and water depth.
- Wetlands are lands that are wet for a significant portion of the year.
- Wetlands are extremely important as an ecosystem and as a filter for pollutants.

Making Connections

Multimedia

MEDIA

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Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Freshwater Biomes**

1. What determines if a body of water is freshwater?
2. What percentage of the Earth's water is freshwater?
3. What are wetlands?
4. List the different types of wetlands.
5. What are ponds and lakes?
6. List and explain the three zones of lakes and ponds.
7. What are streams and rivers?

Review

1. Describe how ecological zones in lakes are similar to ecological zones in oceans.
2. For many decades, people drained wetlands. Was this a good idea or a bad idea? Why?
3. How are marshes different from swamps? How are they the same?

5.6 Flooding

- Explain the causes and effects of floods.
- Describe types of flood protection.

Why are there so many floods?

Floods are a natural part of the water cycle, but that doesn't make them any less terrifying. Put most simply, a flood is an overflow of water in one place. How can you prepare for a flood? What do you do if you're caught in one?

Causes of Floods

Floods usually occur when precipitation falls more quickly than water can be absorbed into the ground or carried away by rivers or streams. Waters may build up gradually over a period of weeks, when a long period of rainfall or snowmelt fills the ground with water and raises stream levels.

Extremely heavy rains across the Midwestern U.S. in April 2011 led to flooding of the rivers in the Mississippi River basin in May 2011 (**Figures** 5.16 and 5.17).

Flash Floods

Flash floods are sudden and unexpected, taking place when very intense rains fall over a very brief period (**Figure** 5.18). A flash flood may do its damage miles from where the rain actually falls if the water travels far down a dry streambed.

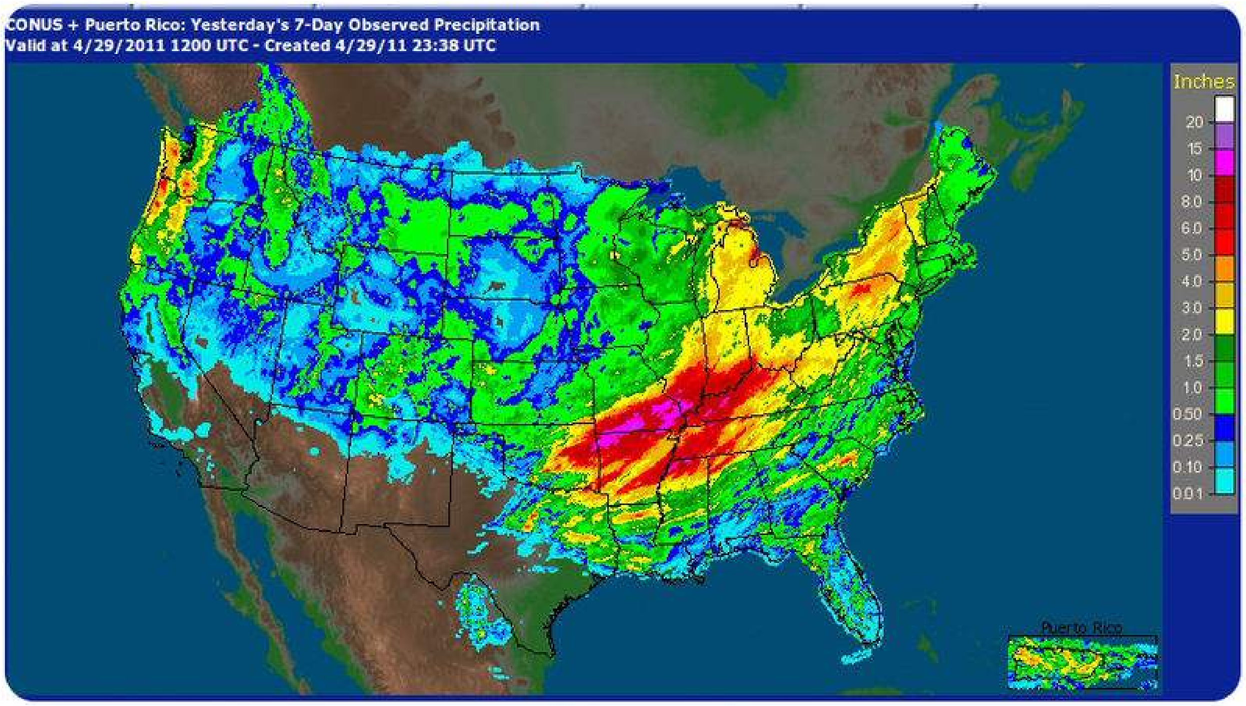


FIGURE 5.16

This map shows the accumulated rainfall across the U.S. in the days from April 22 to April 29, 2011.

FIGURE 5.17

Record flow in the Ohio and Mississippi Rivers has to go somewhere. Normal spring river levels are shown in 2010. The flooded region in the image from May 3, 2011 is the New Madrid Floodway, where overflow water is meant to go. 2011 is the first time since 1927 that this floodway was used.

FIGURE 5.18
A 2004 flash flood in England devastated two villages when 3-1/2 inches of rain fell in 60 minutes. Pictured here is some of the damage from the flash flood.

Buffers to Flooding

Heavily vegetated lands are less likely to experience flooding. Plants slow down water as it runs over the land, giving it time to enter the ground. Even if the ground is too wet to absorb more water, plants still slow the water's passage and increase the time between rainfall and the water's arrival in a stream; this could keep all the water falling over a region from hitting the stream at once. Wetlands act as a buffer between land and high water levels and play a key role in minimizing the impacts of floods. Flooding is often more severe in areas that have been recently logged.

Flood Protection

People try to protect areas that might flood with dams, and dams are usually very effective. But high water levels sometimes cause a dam to break and then flooding can be catastrophic. People may also line a river bank with **levees**, high walls that keep the stream within its banks during floods. A levee in one location may just force the high water up or downstream and cause flooding there. The New Madrid Overflow in the **Figure** 5.17 was created with the recognition that the Mississippi River sometimes simply cannot be contained by levees and must be allowed to flood.

Effects of Floods

Not all the consequences of flooding are negative. Rivers deposit new nutrient-rich sediments when they flood, so floodplains have traditionally been good for farming. Flooding as a source of nutrients was important to Egyptians along the Nile River until the Aswan Dam was built in the 1960s. Although the dam protects crops and settlements from the annual floods, farmers must now use fertilizers to feed their cops.

Floods are also responsible for moving large amounts of sediments about within streams. These sediments provide habitats for animals, and the periodic movement of sediment is crucial to the lives of several types of organisms. Plants and fish along the Colorado River, for example, depend on seasonal flooding to rearrange sand bars.

"Floods 101" is a National Geographic video found in Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/ .

FIGURE 5.19
Within the floodplain of the Nile, soils are fertile enough for productive agriculture. Beyond this, infertile desert soils prevent viable farming.

Summary

- When the amount of water in a drainage exceeds the capacity of the drainage, there is a flood.
- Floods are made worse when vegetation is cleared, when the land is already soaked, or when hillsides have been logged.
- People build dams and levees to protect from flooding.
- Floods are a source of nutrients on a floodplain.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/environment/environment-natural-disasters/landslides-and-more/floods/

1. Where are floods more likely to occur?

2. Why have farmers relied on floods?

3. What causes floods?

4. At what depth can a flood move a car? Why is this dangerous?

5. What cause the Mississippi Flood of 1993?

6. Why did Hurricane Katrina cause so much damage to New Orleans?

7. What could cause massive flooding today?

Review

1. How does a flash flood differ from another type of flood?

2. What was the role of flooding on the Nile River and what was the consequence of damming the river?

3. Why do floods still occur, even though people build dams and levees?

5.7 Glaciers

- Describe the formation, movement, and characteristics of glaciers.

Can solid ice really move?

Yes! Ice that moves downslope is called a "glacier." Glaciers move extremely slowly along the land surface. They may survive for thousands of years.

Where are the Glaciers?

Nearly all glacial ice, 99%, is contained in ice sheets in the polar regions, particularly Antarctica and Greenland.

Glaciers often form in the mountains because higher altitudes are colder and more likely to have snow that falls and collects. Every continent, except Australia, hosts at least some glaciers in the high mountains.

Types of Glaciers

The types of glaciers are:

- **Continental glaciers** are large ice sheets that cover relatively flat ground. These glaciers flow outward from where the greatest amounts of snow and ice accumulate.
- **Alpine (valley) glaciers** flow downhill from where the snow and ice accumulates through mountains along existing valleys.
- **Ice caps** are large glaciers that cover a larger area than just a valley, possibly an entire mountain range or region. Glaciers come off of ice caps into valleys.

FIGURE 5.20
The Greenland ice cap covers the entire landmass.

Glacial Growth

Formation

Glaciers grow when more snow falls near the top of the glacier, in the **zone of accumulation**, than is melted from lower down in the glacier, in the **zone of ablation**. These two zones are separated by the equilibrium line.

Snow falls and over time converts to granular ice known as firn. Eventually, as more snow and ice collect, the firn becomes denser and converts to glacial ice.

Water is too warm for a glacier to form, so they form only on land. A glacier may run out from land into water, but it usually breaks up into icebergs that eventually melt into the water.

Movement

Whether an ice field moves or not depends on the amount of ice in the field, the steepness of the slope and the roughness of the ground surface. Ice moves where the pressure is so great that it undergoes plastic flow. Ice also slides at the bottom, often lubricated by water that has melted and travels between the ground and the ice.

The speed of a glacier ranges from extremely fast, where conditions are favorable, to nearly zero.

Because the ice is moving, glaciers have **crevasses**, where cracks form in the ice as a result of movement. The large crevasse at the top of an alpine glacier where ice that is moving is separated from ice that is stuck to the mountain above is called a **bergshrund**.

FIGURE 5.21
Crevasses in a glacier are the result of movement.

Shrinking

Glaciers are melting back in many locations around the world. When a glacier no longer moves, it is called an ice sheet. This usually happens when it is less than 0.1 km2 in area and 50 m thick.

Glacier National Park

Many of the glaciers in Glacier National Park have shrunk and are no longer active. Summer temperatures have risen rapidly in this part of the country and so the rate of melting has picked up. Whereas Glacier National Park had 150 glaciers in 1850, there are only about 25 today. Recent estimates are that the park will have no active glaciers as early as 2020.

FIGURE 5.22
This satellite image shows Grinnell Glacier, Swiftcurrent Glacier, and Gem Glacier in 2003 with an outline of the extent of the glaciers as they were in 1950. Although it continues to be classified as a glacier, Gem Glacier is only 0.020 km^2 (5 acres) in area, only one-fifth the size of the smallest active glaciers.

Glaciers as a Resource

In regions where summers are long and dry, melting glaciers in mountain regions provide an important source of water for organisms and often for nearby human populations.

Summary

- Glaciers are ice that moves because the amount of snow and ice that collects in the zone of accumulation exceeds the amount that melts off in the zone of ablation.
- Continental glaciers form in a central location with ice moving outward in all directions. Alpine glaciers form in high mountains and travel through valleys.
- Because glaciers move, they have characteristic features like crevasses and bergshrunds.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=mgnzSTY5zRg

MEDIA
Click image to the left for more content.

1. Where are glaciers found?
2. What is the largest glacier in Yosemite National Park?
3. What are the dangers on glaciers?
4. What are sun cups?
5. What is a crevasse? What creates it?
6. What is a glacier?
7. Describe the bergshrund.
8. What is the challenge with glaciers?

Review

1. Compare and contrast alpine glaciers, continental glaciers, and ice caps.
2. With a glacier that is melting back, what is happening in the zone of accumulation and the zone of ablation? What is happening to the equilibrium line?
3. How do glaciers serve as a water resource for people and organisms in the summertime?

5.8 Uses of Water

- Describe how humans use water in a variety of ways.

What do you use water for?

Drinking, of course. Bathing, naturally. But what else? Growing food, producing goods, recreation, maintaining healthy ecosystems: all require lots and lots of water.

Water Consumption

Humans use six times as much water today as they did 100 years ago. People living in developed countries use a far greater proportion of the world's water than people in less developed countries. What do people use all of that water for?

Human Uses of Water

Besides drinking and washing, people need water for agriculture, industry, household uses, and recreation (**Figure** 5.23). Recreational use and environmental use average 1% each.

Water use can be consumptive or non-consumptive, depending on whether the water is lost to the ecosystem.

- **Non-consumptive** water use includes water that can be recycled and reused. For example, the water that goes down the drain and enters the sewer system is purified and then redistributed for reuse. By recycling water, the overall water consumption is reduced.
- **Consumptive** water use takes the water out of the ecosystem. Can you name some examples of consumptive water use?

Agriculture

Some of the world's farmers still farm without irrigation by choosing crops that match the amount of rain that falls in their area. But some years are wet and others are dry. For farmers to avoid years in which they produce little or

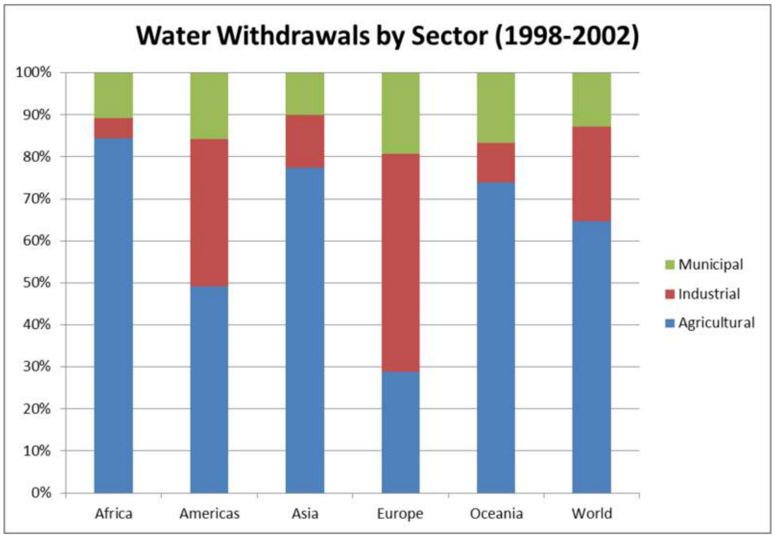


FIGURE 5.23
Water used for home, industrial, and agricultural purposes in different regions. Globally more than two-thirds of water is for agriculture.

no food, many of the world's crops are produced using irrigation.

Wasteful Methods

Three popular irrigation methods are:

- Overhead sprinklers.
- Trench irrigation: canals carry water from a water source to the fields.
- Flood irrigation: fields are flooded with water.

All of these methods waste water. Between 15% and 36% percent of the water never reaches the crops because it evaporates or leaves the fields as runoff. Water that runs off a field often takes valuable soil with it.

Non-wasteful Methods

A much more efficient way to water crops is **drip irrigation** (**Figure** 5.24). With drip irrigation, pipes and tubes deliver small amounts of water directly to the soil at the roots of each plant or tree. The water is not sprayed into the air or over the ground, so nearly all of it goes directly into the soil and plant roots.

Why Not Change?

Why do farmers use wasteful irrigation methods when water-efficient methods are available? Many farmers and farming corporations have not switched to more efficient irrigation methods for two reasons:

1. Drip irrigation and other more efficient irrigation methods are more expensive than sprinklers, trenches, and flooding.

2. In the United States and some other countries, the government pays for much of the cost of the water that is used for agriculture. Because farmers do not pay the full cost of their water use, they do not have any financial incentive to use less water.

What ideas can you come up with to encourage farmers to use more efficient irrigation systems?

FIGURE 5.24
Drip irrigation delivers water to the base of each plant so little is lost to evaporation and runoff.

Aquaculture

Aquaculture is a different type of agriculture. Aquaculture is farming to raise fish, shellfish, algae, or aquatic plants (**Figure** 5.25). As the supplies of fish from lakes, rivers, and the oceans dwindle, people are getting more fish from aquaculture. Raising fish increases our food resources and is especially valuable where protein sources are limited. Farmed fish are becoming increasingly common in grocery stores all over the world.

FIGURE 5.25
Workers at a fish farm harvest fish they will sell to stores.

Growing fish in a large scale requires that the fish stocks are healthy and protected from predators. The species raised must be hearty, inexpensive to feed, and able to reproduce in captivity. Wastes must be flushed out to keep animals healthy. Raising shellfish at farms can also be successful.

Aquaculture Problems

For some species, aquaculture is very successful and environmental harm is minimal. But for other species, aquaculture can cause problems. Natural landscapes, such as mangroves, which are rich ecosystems and also protect coastlines from storm damage, may be lost to fish farms (**Figure** 5.26). For fish farmers, keeping costs down may be a problem since coastal land may be expensive and labor costs may be high. Large predatory fish at the 4th or 5th trophic level must eat a lot, so feeding large numbers of these fish is expensive and environmentally costly. Farmed fish are genetically different from wild stocks, and if they escape into the wild they may cause problems for native fish. Because the organisms live so close together, parasites are common and may also escape into the wild.

FIGURE 5.26
Shrimp farms on the coast of Ecuador are shown as blue rectangles. Mangrove forests, salt flats, and salt marshes have been converted to shrimp farms.

Industrial Water Use

Industrial water use accounts for an estimated 15% of worldwide water use, with a much greater percentage in developed nations. Industrial uses of water include power plants that use water to cool their equipment and oil refineries that use water for chemical processes. Manufacturing is also water intensive.

Household Use

Think about all the ways you use water in a day. You need to count the water you drink, cook with, bathe in, garden with, let run down the drain, or flush down the toilet. In developed countries, people use a lot of water, while in less developed countries people use much less. Globally, household or personal water use is estimated to account for 15% of world-wide water use.

Some household water uses are non-consumptive, because water is recaptured in sewer systems, treated, and returned to surface water supplies for reuse. Many things can be done to lower water consumption at home.

- Convert lawns and gardens to drip-irrigation systems.
- Install low-flow shower heads and low-flow toilets.

In what other ways can you use less water at home?

Recreational Use

People love water for swimming, fishing, boating, river rafting, and other activates. Even activities such as golf, where there may not be any standing water, require plenty of water to make the grass on the course green. Despite its value, the amount of water that most recreational activities use is low: less than 1% of all the water we use.

Many recreational water uses are non-consumptive including swimming, fishing, and boating. Golf courses are the biggest recreational water consumer since they require large amounts for irrigation, especially because many courses are located in warm, sunny, desert regions where water is scarce and evaporation is high.

This National Geographic video chronicles the conflict between conserving the Yangtze River for recreational uses versus damming it for the clean energy China needs so badly: http://video.nationalgeographic.com/video/player/environment/energy-environment/energy-conservation.html .

Environmental Use

Environmental use of water includes creating wildlife habitat. Lakes are built to create places for fish and water birds (**Figure** 5.27). Most environmental uses are non-consumptive and account for an even smaller percentage of water use than recreational uses. A shortage of this water is a leading cause of global biodiversity loss.

FIGURE 5.27
Wetlands and other environments depend on clean water to survive.

Summary

- Consumptive water use takes water out of the ecosystem; non-consumptive water use includes water that can be recycled and reused.
- People can use less water by having efficient systems for water use and by reusing and recycling water where possible.
- Some water must remain in the environment for recreational use for humans and to support ecosystems.

Practice

Use these resources to answer the questions that follow.

http://ga.water.usgs.gov/edu/sq3.html

1. How much water is used in an average bath?

2. How much water is used in a 10 minute shower?

3. How much water is used to flush the toilet?

http://ga.water.usgs.gov/edu/sq2.html

4. What is the water distribution for your state?

http://ga.water.usgs.gov/edu/sc1.html

5. How much water does it take to produce bread?
6. How much water does it take to make a hamburger?

Review

1. Why do people use so much more water than they used to?
2. Why don't localities and people use water in the most efficient way, rather than sometimes in wasteful ways?
3. What is aquaculture and why is it going to be increasingly important in the future?

5.9 Conserving Water

- Describe ways to conserve water.

You can help to use less water by conserving in your own home. One way is to install a low-flow shower head to reduce the amount water used during showers.

How Society Can Conserve Water

Water consumption per person has been going down for the past few decades. There are many ways that water conservation can be encouraged. Charging more for water gives a financial incentive for careful water use. Water use may be restricted by time of day, season, or activity. Good behavior can be encouraged; for example, people can be given an incentive to replace grass with desert plants in arid regions.

FIGURE 5.28
This colorful adobe house in Tucson, Arizona is surrounded by native cactus, which needs little water to thrive.

How You Can Conserve Water

As human population growth continues, water conservation will become increasingly important globally, especially in developed countries where people use an enormous amount of water. What are some of the ways you can conserve water in and around your home?

- Avoid polluting water so that less is needed.
- Convert to more efficient irrigation methods on farms and in gardens.
- Reduce household demand by installing water-saving devices such as low-flow shower heads and toilets.
- Reduce personal demand by turning off the tap when water is not being used and taking shorter showers.
- Engage in water-saving practices: for instance, water lawns less and sweep rather than hose down sidewalks.

How you can conserve water at home is the subject of this National Geographic video, "Conserve Water": http://video.nationalgeographic.com/video/environment/going-green-environment/green-home-makeover/conserve-water-greenguide/ . Other videos for making your home greener are found on that page as well.

At Earth Summit 2002, many governments approved a Plan of Action to address the scarcity of water and safe drinking water in developing countries. One goal of this plan is to cut in half the number of people without access to safe drinking water by 2015. This is a very important goal and one made more difficult as population continues to grow.

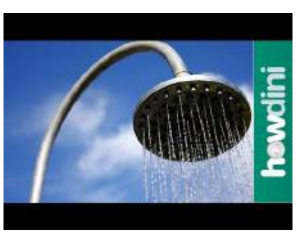
Summary

- Society can reduce water consumption by making policies that encourage or require conservation.
- People can reduce water consumption by taking shorter showers, installing water-saving devices, and many other methods.
- Financial incentives can work to encourage people to conserve water and other resources.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=4MDLpVHY8LE



MEDIA
Click image to the left for more content.

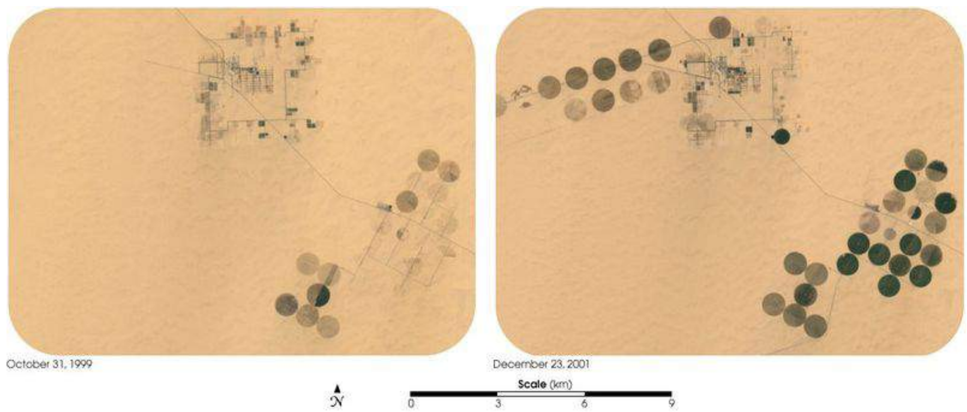
1. What percentage of water is used in the bathroom?
2. How do low-flow toilets conserve water?
3. What does an aerator do?
4. List 3 additional tips for saving water.
5. How much water does a professional car war wash use?
6. Why shouldn't you use the garden hose to wash a car?

Review

1. Why does your choice of garden plants affect the water consumption of your household?
2. How does water pollution reduce the amount of water that is available for people to use?
3. Why is providing clean water to all people so difficult? Why is it so important?

5.10 Groundwater Depletion

- Explain the causes and consequences of groundwater depletion.



Is it good to make the desert bloom?

Many sunny, arid regions are good for growing crops as long as water can be added. Some of the increase in productivity is due to farming in regions that are technically too dry. Groundwater can be used to make the desert bloom, but at what cost? And for how long? Eventually the wells will run dry.

Groundwater Overuse

Some aquifers are overused; people pump out more water than is replaced. As the water is pumped out, the water table slowly falls, requiring wells to be dug deeper, which takes more money and energy. Wells may go completely dry if they are not deep enough to reach into the lowered water table.

Other problems may stem from groundwater overuse. Subsidence and saltwater intrusion are two of them.

Ogallala Aquifer

The Ogallala Aquifer supplies about one-third of the irrigation water in the United States. The Ogallala Aquifer is widely used by people for municipal and agricultural needs. (**Figure** 5.30). The aquifer is found from 30 to 100 meters deep over an area of about 440,000 square kilometers!

The water in the aquifer is mostly from the last ice age. About eight times more water is taken from the Ogallala Aquifer each year than is replenished. Much of the water is used for irrigation (**Figure** 5.31).

Subsidence

Lowering the water table may cause the ground surface to sink. **Subsidence** may occur beneath houses and other structures (**Figure** 5.32).

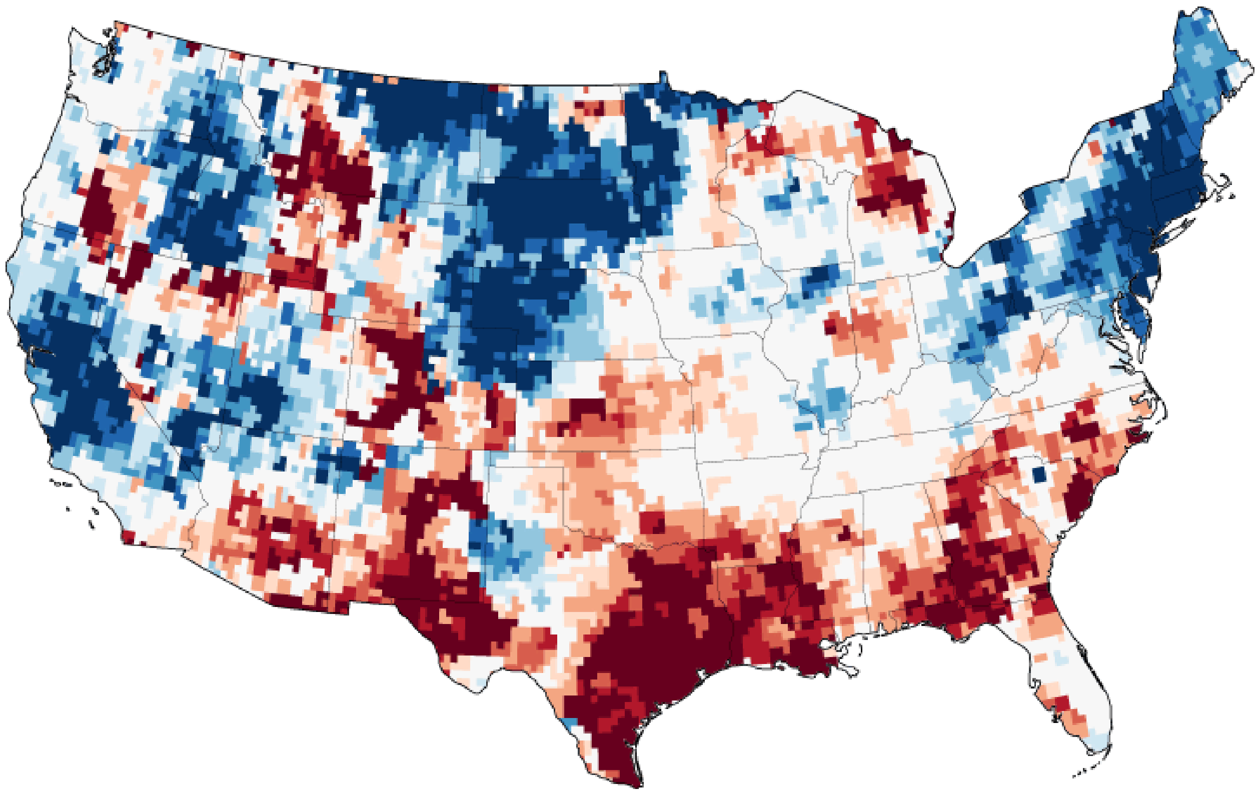


FIGURE 5.29
Intense drought has reduced groundwater levels in the southern U.S., particularly in Texas and New Mexico.

Salt Water Intrusion

When coastal aquifers are overused, salt water from the ocean may enter the aquifer, contaminating the aquifer and making it less useful for drinking and irrigation. Salt water incursion is a problem in developed coastal regions, such as on Hawaii.

Summary

- When water is pumped from an aquifer, the water table declines and wells must be drilled deeper.
- The Ogallala Aquifer was filled in the ice age but is being used to irrigate the farms of the Midwestern U.S. at a rate far greater than it is being replenished.
- Ground subsidence and saltwater intrusion are two possible consequences of groundwater overuse.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=o1QsCa7RmmU

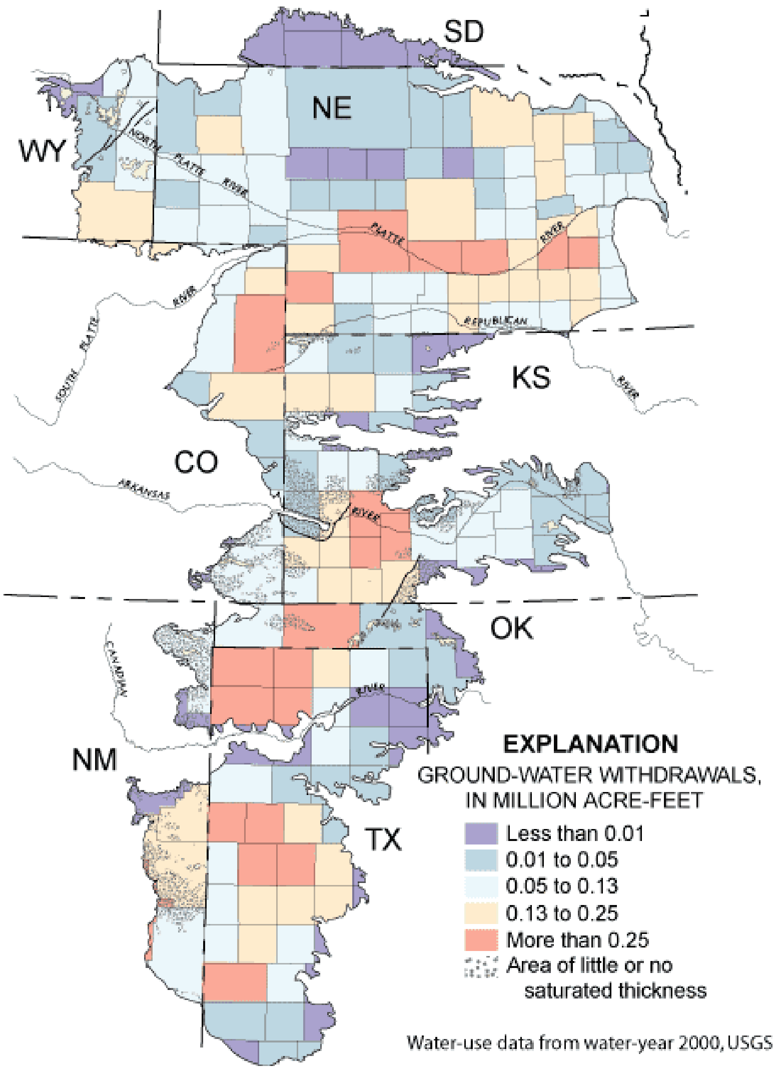


FIGURE 5.30
The Ogallala Aquifer is found beneath eight states and is heavily used.

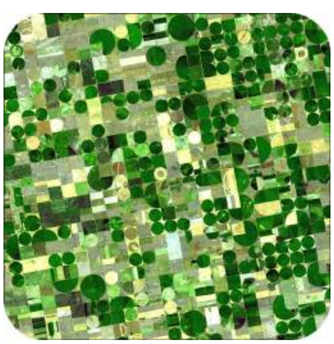
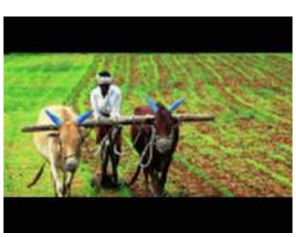


FIGURE 5.31
Farms in Kansas use central pivot irrigation, which is more efficient since water falls directly on the crops instead of being shot in the air. These fields are between 800 and 1600 meters (0.5 and 1 mile) in diameter.



MEDIA
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FIGURE 5.32

The San Joaquin Valley of California is one of the world's major agricultural areas. So much groundwater has been pumped that the land has subsided many tens of feet.

1. How has irrigation changed farming?
2. What is leading to people's demands for additional water?
3. What is the GRACE satellite doing?
4. How does GRACE find groundwater aquifers?
5. How people know the aquifers are being depleted?
6. What is the future of water?

Review

1. What are some of the problems that come from overuse of groundwater?
2. How does salt water enter an aquifer?
3. In a location where the ground has subsided due to the extraction of groundwater from an aquifer, what do you think would happen if people tried to pump water back into the aquifer?

5.11 Water Pollution

- Describe the sources of water pollution.

Is polluted water like this only seen in developing nations?

There is certainly polluted water in developed nations, but that water is cleaned and purified before it is put in taps and sent to people's homes. Pollutants come from a variety of sources.

Introduction

Freshwater and ocean pollution are serious global problems that affect the availability of safe drinking water, human health, and the environment. Waterborne diseases from water pollution kill millions of people in underdeveloped countries every year.

Sources of Water Pollution

Water pollution contributes to water shortages by making some water sources unavailable for use. In underdeveloped countries, raw sewage is dumped into the same water that people drink and bathe in. Even in developed countries, water pollution affects human and environmental health.

Water pollution includes any contaminant that gets into lakes, streams, and oceans. The most widespread source of water contamination in developing countries is raw sewage. In developed countries, the three main sources of water pollution are described below.

Municipal Pollution

Wastewater from cities and towns contains many different contaminants from many different homes, businesses, and industries (**Figure** 5.33). Contaminants come from:

- Sewage disposal (some sewage is inadequately treated or untreated).
- Storm drains.
- Septic tanks (sewage from homes).
- Boats that dump sewage.
- Yard runoff (fertilizer and herbicide waste).

FIGURE 5.33
Municipal and agricultural pollution.

Large numbers of sewage spills into San Francisco Bay are forcing cities, water agencies and the public to take a closer look at wastewater and its impacts on the health of the bay. QUEST investigates the causes of the spills and what's being done to prevent them.

Watch the investigation at http://science.kqed.org/quest/video/wastewater-woes-sewage-spills-in-sf-bay/ .

MEDIA
Click image to the left for more content.

Industrial Pollution

Factories and hospitals spew pollutants into the air and waterways (**Figure** 5.34). Some of the most hazardous industrial pollutants include:

- Radioactive substances from nuclear power plants and medical and scientific sources.
- Heavy metals, organic toxins, oils, and solids in industrial waste.
- Chemicals, such as sulfur, from burning fossil fuels.
- Oil and other petroleum products from supertanker spills and offshore drilling accidents.
- Heated water from industrial processes, such as power stations.

Agricultural Pollution

Runoff from crops, livestock, and poultry farming carries contaminants such as fertilizers, pesticides, and animal waste into nearby waterways (**Figure** 5.35). Soil and silt also run off farms. Animal wastes may carry harmful

FIGURE 5.34
Industrial Waste Water: Polluted water coming from a factory in Mexico. The different colors of foam indicate various chemicals in the water and industrial pollution.

diseases, particularly in the developing world.

FIGURE 5.35
The high density of animals in a factory farm means that runoff from the area is full of pollutants.

Fertilizers that run off of lawns and farm fields are extremely harmful to the environment. Nutrients, such as nitrates, in the fertilizer promote algae growth in the water they flow into. With the excess nutrients, lakes, rivers, and bays become clogged with algae and aquatic plants. Eventually these organisms die and decompose. Decomposition uses up all the dissolved oxygen in the water. Without oxygen, large numbers of plants, fish, and bottom-dwelling animals die.

Summary

- Municipal pollution comes from sewage, storm drains, septic tanks, boats, and runoff from yards.
- Industrial pollution, from factories and hospitals, includes radioactive substances; heavy metals and other pollutants in industrial waste; by-products of fossil fuel burning; oil and other petroleum products; and heat

from factories and power plants.
- Agricultural pollutants include wastes from animals, pesticides, herbicides, fertilizers, and soil.

Practice

Use this resource to answer the questions that follow.

http://www.watersheds.org/earth/karstmovie.htm

Click on non point pollution and the various pushpins.

1. What type of pollutants do houses create?
2. How do pollutants from cars enter the groundwater?
3. How does farming cause pollution?
4. How do towns contribute to water pollution?
5. How do sinkholes contribute to water pollution?

Review

1. How can fertilizers, which help things grow, be pollutants?
2. Why is raw sewage a major pollutant in some countries but not in developed countries?
3. How could heat be a pollutant? What damage could it cause?

5.12 Protecting Water From Pollution

- Explain how to reduce water pollution and clean up polluted water.

How do municipalities clean water?

We take clean water for granted because we have advanced wastewater treatment facilities that remove impurities with settling containers, filters, chemicals, and biological agents.

Reducing Water Pollution

Water pollution can be reduced in two ways:

- Keep the water from becoming polluted.
- Clean water that is already polluted.

Clean Water Act

Keeping water from becoming polluted often requires laws to be sure that people and companies behave responsibly. In the United States, the Clean Water Act gives the Environmental Protection Agency (EPA) the authority to set standards for water quality for industry, agriculture, and domestic uses. The law gives the EPA the authority to reduce the discharge of pollution into waterways, finance wastewater treatment plants, and manage runoff. Since its passage in 1972, more wastewater treatment plants have been constructed and the release of industrial waste into the water supply is better controlled.

The United Nations and other international groups are working to improve global water quality standards by providing the technology for treating water. These organizations also educate people in how to protect and improve the quality of the water they use (**Figure** 5.36).

FIGURE 5.36
Scientists control water pollution by sampling the water and studying the pollutants that are in the water.

Water Treatment

The goal of water treatment is to make water suitable for such uses as drinking, medicine, agriculture, and industrial processes.

People living in developed countries suffer from few waterborne diseases and illness, because they have extensive water treatment systems to collect, treat, and redeliver clean water. Many underdeveloped nations have few or no water treatment facilities.

Wastewater contains hundreds of contaminants, such as suspended solids, oxygen-demanding materials, dissolved inorganic compounds, and harmful bacteria. In a wastewater treatment plant, multiple processes must be used to produce usable water:

- **Sewage treatment** removes contaminants, such as solids and particles, from sewage.
- **Water purification** produces drinking water by removing bacteria, algae, viruses, fungi, unpleasant elements such as iron and sulfur, and man-made chemical pollutants.

The treatment method used depends on the kind of wastewater being treated and the desired end result. Wastewater is treated using a series of steps, each of which produces water with fewer contaminants.

What Can You Do?

What can individuals do to protect water quality?

- Find approved recycling or disposal facilities for motor oil and household chemicals.
- Use lawn, garden, and farm chemicals sparingly and wisely.
- Repair automobile or boat engine leaks immediately.
- Keep litter, pet waste, leaves, and grass clippings out of street gutters and storm drains.

Summary

- Keeping water from becoming polluted is easier, less expensive, and safer than cleaning it once it is polluted.
- Since the passage of the Clean Water Act, many wastewater treatment plants have been constructed and utilized.

- There are multiple levels of water treatment: some water is cleaned enough for use on lawns, while other water is cleaned enough to be safe for drinking.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=Fbmc3L9j4Os

MEDIA

Click image to the left for more content.

1. What caused people to demand action?
2. When did people protest? How many people were involved?
3. What agency was created by Nixon in response to public demand?
4. What did Nixon do to the Clean Water Act?
5. How did Congress respond?
6. What was banned during this same time?

Review

1. What is the purpose of the Clean Water Act?
2. How is wastewater treated?
3. What can the members of your household do to protect water quality?

5.13 Weathering and Erosion

- Define weathering and erosion.

What is the history of this rock face?

Walnut Canyon, just outside Flagstaff, Arizona, is a high desert landscape displaying cliff dwellings built 700 years ago by a long gone people. On the opposite side from the trail around the mesa is this incredible rock. In this rock you can see that the rock has slumped, and also see signs of mechanical weathering (fractures) and chemical weathering (dissolution). If you get a chance, go see the rock (and the cliff dwellings) for yourself.

Weathering

Weathering is the process that changes solid rock into sediments. Sediments were described in the chapter "Materials of Earth's Crust." With weathering, rock is disintegrated. It breaks into pieces. Once these sediments are separated from the rocks, **erosion** is the process that moves the sediments.

While plate tectonics forces work to build huge mountains and other landscapes, the forces of weathering gradually wear those rocks and landscapes away. Together with erosion, tall mountains turn into hills and even plains. The Appalachian Mountains along the east coast of North America were once as tall as the Himalayas.

Weathering Takes Time

No human being can watch for millions of years as mountains are built, nor can anyone watch as those same mountains gradually are worn away. But imagine a new sidewalk or road. The new road is smooth and even. Over hundreds of years, it will completely disappear, but what happens over one year? What changes would you see? (**Figure** 5.37). What forces of weathering wear down that road, or rocks or mountains over time?

- Animations of different types of weathering processes can be found here: http://www.geography.ndo.co.uk/animationsweathering.htm# .

FIGURE 5.37
A once smooth road surface has cracks and fractures, plus a large pothole.

Summary

- Weathering breaks down Earth materials into smaller pieces.
- Erosion transports those pieces to other locations.
- Weathering and erosion modify Earth's surface landscapes over time.

Practice

Use this resource to answer the questions that follow.

http://www.ux1.eiu.edu/~cfjps/1300/weathering.html

1. What is weathering?
2. What is mechanical weathering?
3. What is chemical weathering?
4. What is erosion?
5. Describe frost wedging.
6. What is abrasion?
7. List the types of chemical weathering.
8. What factors can influence weathering?

Review

1. What is weathering?
2. How is weathering different from erosion?
3. Why does weathering take so much time?

5.14 Influences on Weathering

- Identify and explain factors that influence the rate and intensity of weathering.

What circumstances allow for the most intense weathering?

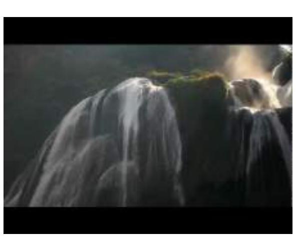
The rate and intensity of weathering depend on the climate of a region and the rocks materials that are being weathered. Material in Baraboo, Wisconsin weathers a lot more readily than similar material in Sedona, Arizona.

Rock and Mineral Type

Different rock types weather at different rates. Certain types of rock are very resistant to weathering. Igneous rocks, especially intrusive igneous rocks such as granite, weather slowly because it is hard for water to penetrate them. Other types of rock, such as limestone, are easily weathered because they dissolve in weak acids.

Rocks that resist weathering remain at the surface and form ridges or hills. Shiprock in New Mexico is the throat of a volcano that's left after the rest of the volcano eroded away. The rock that's left behind is magma that cooled relatively slowly and is harder than the rock that had surrounded it.

Different minerals also weather at different rates. Some minerals in a rock might completely dissolve in water, but the more resistant minerals remain. In this case, the rock's surface becomes pitted and rough. When a less resistant mineral dissolves, more resistant mineral grains are released from the rock. A beautiful example of this effect is the "Stone Forest" in China, see the video below:



MEDIA

Click image to the left for more content.

FIGURE 5.38
The Shiprock formation in northwest New Mexico is the central plug of resistant lava from which the surrounding rock weathered and eroded away.

Climate

A region's **climate** strongly influences weathering. Climate is determined by the temperature of a region plus the amount of precipitation it receives. Climate is weather averaged over a long period of time. Chemical weathering increases as:

- Temperature increases: Chemical reactions proceed more rapidly at higher temperatures. For each 10^{o}C increase in average temperature, the rate of chemical reactions doubles.
- Precipitation increases: More water allows more chemical reactions. Since water participates in both mechanical and chemical weathering, more water strongly increases weathering.

So how do different climates influence weathering? A cold, dry climate will produce the lowest rate of weathering. A warm, wet climate will produce the highest rate of weathering. The warmer a climate is, the more types of vegetation it will have and the greater the rate of biological weathering (**Figure** 5.39). This happens because plants and bacteria grow and multiply faster in warmer temperatures.

Resources from Weathering

Some resources are concentrated by weathering processes. In tropical climates, intense chemical weathering carries away all soluble minerals, leaving behind just the least soluble components. The aluminum oxide, bauxite, forms this way and is our main source of aluminum ore.

Summary

- Different materials weather at different rates and intensities under the same conditions.
- Different climate conditions cause the same materials to weather different intensities.

Practice

Use this resource to answer the questions that follow.

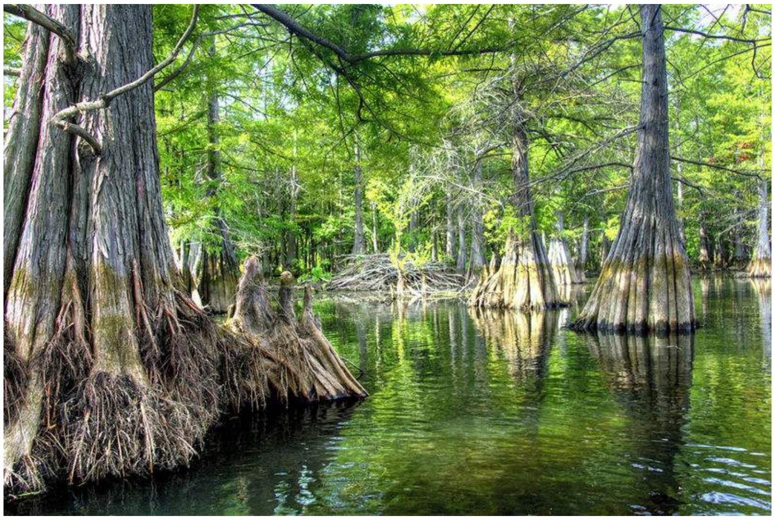


FIGURE 5.39
Wet, warm tropical areas have the most weathering.

Rock types on the Isle of Sky - Geological Landforms

http://www.youtube.com/watch?v=l-Y6588DnQg

MEDIA
Click image to the left for more content.

1. What type of rocks make up most of the Isle of Skye?
2. What other types of rocks are found on the island?
3. What two processes shape the landscape of the island?
4. What are the primary sources of weathering on Skye?
5. How is scree produced?
6. How does weathering effect granite?
7. What is responsible for the topography of the island?
8. Which rocks are more resistant to weathering?

Review

1. What types of rocks weather most readily? What types weather least readily?
2. What climate types cause more intense weathering? What climate types cause less intense weathering?
3. How does bauxite form?

5.15 Mechanical Weathering

- Define mechanical weathering.
- Describe the various processes of mechanical weathering.

Who broke those rocks?

In extreme environments, where there is little moisture and soil development, it's possible to see rocks that have broken by mechanical weathering. This talus in Colorado's Indian Peaks broke from the jointed rock that is exposed.

Mechanical Weathering

Mechanical weathering (also called physical weathering) breaks rock into smaller pieces. These smaller pieces are just like the bigger rock, but smaller. That means the rock has changed physically without changing its composition. The smaller pieces have the same minerals, in just the same proportions as the original rock.

Ice Wedging

There are many ways that rocks can be broken apart into smaller pieces. **Ice wedging** is the main form of mechanical weathering in any climate that regularly cycles above and below the freezing point (**Figure** 5.40). Ice wedging works quickly, breaking apart rocks in areas with temperatures that cycle above and below freezing in the day and night, and also that cycle above and below freezing with the seasons.

Ice wedging breaks apart so much rock that large piles of broken rock are seen at the base of a hillside, as rock fragments separate and tumble down. Ice wedging is common in Earth's polar regions and mid latitudes, and also at higher elevations, such as in the mountains.

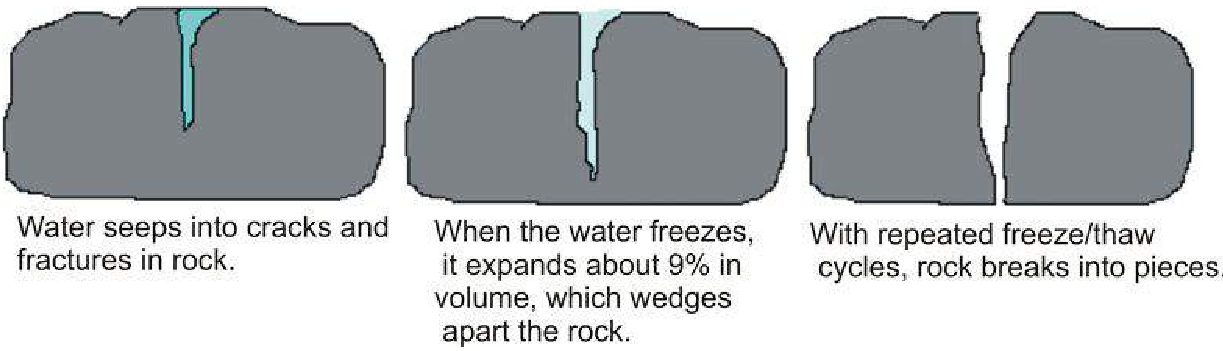


FIGURE 5.40
Ice wedging.

Abrasion

Abrasion is another form of mechanical weathering. In abrasion, one rock bumps against another rock.

- Gravity causes abrasion as a rock tumbles down a mountainside or cliff.
- Moving water causes abrasion as particles in the water collide and bump against one another.
- Strong winds carrying pieces of sand can sandblast surfaces.
- Ice in glaciers carries many bits and pieces of rock. Rocks embedded at the bottom of the glacier scrape against the rocks below.

Abrasion makes rocks with sharp or jagged edges smooth and round. If you have ever collected beach glass or cobbles from a stream, you have witnessed the work of abrasion (**Figure** 5.41).

FIGURE 5.41
Rocks on a beach are worn down by abrasion as passing waves cause them to strike each other.

Organisms

Now that you know what mechanical weathering is, can you think of other ways it could happen? Plants and animals can do the work of mechanical weathering (**Figure** 5.42). This could happen slowly as a plant's roots grow into a crack or fracture in rock and gradually grow larger, wedging open the crack. Burrowing animals can also break apart rock as they dig for food or to make living spaces for themselves.

Humans

Human activities are responsible for enormous amounts of mechanical weathering, by digging or blasting into rock to build homes, roads, and subways, or to quarry stone.

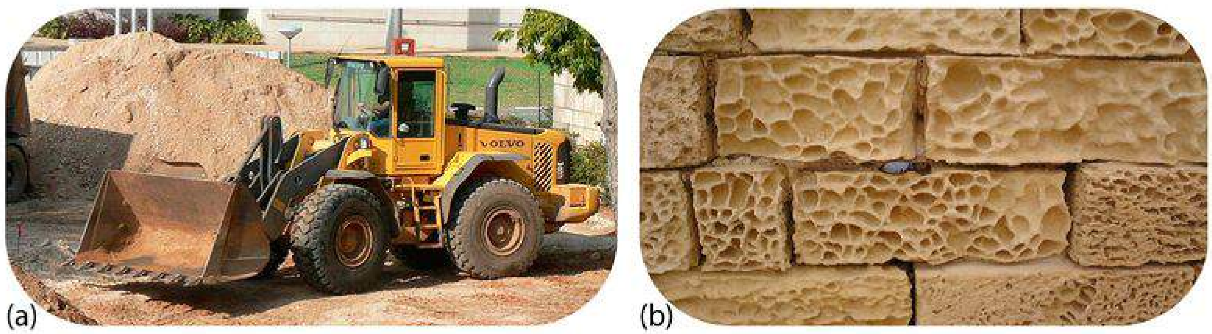


FIGURE 5.42

(a) Humans are tremendous agents of mechanical weathering. (b) Salt weathering of building stone on the island of Gozo, Malta.

Summary

- Mechanical weathering breaks down existing rocks and minerals without changing them chemically.
- Ice wedging, abrasion, and some actions of living organisms and humans are some of the agents of mechanical weathering.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What is weathering?
2. What are the agents of weathering?
3. What is mechanical weathering?
4. Explain frost wedging.
5. Explain root wedging.
6. What is abrasion?
7. Explain the two types of abrasion.
8. What is exfoliation? What is it unique to?
9. What is differential weathering? What can be created with differential weathering?
10. What role does climate play in physical weathering?

Review

1. Describe the process of ice wedging.
2. Describe the process of abrasion.
3. How do plants and animals cause mechanical weathering?

5.16 Chemical Weathering

- Define chemical weathering.
- Describe the various processes of chemical weathering.

How do rocks turn red?

In the desert Southwest, red rocks are common. Tourists flock to Sedona, Arizona to see the beautiful red rocks, which are set off very nicely by the snow in this photo. What makes the rocks red? The same process that makes rust red!

Chemical Weathering

Chemical weathering is the other important type of weathering. Chemical weathering may change the size of pieces of rock materials, but definitely changes the composition. So one type of mineral changes into a different mineral. Chemical weathering works through chemical reactions that cause changes in the minerals.

No Longer Stable

Most minerals form at high pressure or high temperatures deep in the crust, or sometimes in the mantle. When these rocks are uplifed onto Earth's surface, they are at very low temperatures and pressures. This is a very different environment from the one in which they formed and the minerals are no longer stable. In chemical weathering, minerals that were stable inside the crust must change to minerals that are stable at Earth's surface.

Clay

Remember that the most common minerals in Earth's crust are the silicate minerals. Many silicate minerals form in igneous or metamorphic rocks. The minerals that form at the highest temperatures and pressures are the least stable at the surface. Clay is stable at the surface and chemical weathering converts many minerals to clay (**Figure** 5.43).

There are many types of chemical weathering because there are many agents of chemical weathering.

FIGURE 5.43
Deforestation in Brazil reveals the underlying clay-rich soil.

Chemical Weathering by Water

A water molecule has a very simple chemical formula, H_2O, two hydrogen atoms bonded to one oxygen atom. But water is pretty remarkable in terms of all the things it can do. Remember that water is a polar molecule. The positive side of the molecule attracts negative ions and the negative side attracts positive ions. So water molecules separate the ions from their compounds and surround them. Water can completely dissolve some minerals, such as salt.

FIGURE 5.44
Weathered rock in Walnut Canyon near Flagstaff, Arizona.

- Check out this animation of how water dissolves salt: http://www.northland.cc.mn.us/biology/Biology1111/animations/dissolve.html .

Hydrolysis is the name of the chemical reaction between a chemical compound and water. When this reaction takes place, water dissolves ions from the mineral and carries them away. These elements have been **leached**. Through hydrolysis, a mineral such as potassium feldspar is leached of potassium and changed into a clay mineral. Clay minerals are more stable at the Earth's surface.

Chemical Weathering by Carbonic Acid

Carbon dioxide (CO_2) combines with water as raindrops fall through the atmosphere. This makes a weak acid, called carbonic acid. Carbonic acid is a very common in nature, where it works to dissolve rock. Pollutants, such as sulfur and nitrogen from fossil fuel burning, create sulfuric and nitric acid. Sulfuric and nitric acids are the two main components of **acid rain**, which accelerates chemical weathering (**Figure** 5.45). Acid rain is discussed in the chapter Human Impacts on Earth's Systems.

FIGURE 5.45
This statue at Washington Square Arch in New York City exhibits damage from acid rain.

Chemical Weathering by Oxygen

Oxidation is a chemical reaction that takes place when oxygen reacts with another element. Oxygen is very strongly chemically reactive. The most familiar type of oxidation is when iron reacts with oxygen to create rust (**Figure** 5.46). Minerals that are rich in iron break down as the iron oxidizes and forms new compounds. Iron oxide produces the red color in soils.

FIGURE 5.46
When iron-rich minerals oxidize, they produce the familiar red color found in rust.

Plants and Animals

Now that you know what chemical weathering is, can you think of some other ways chemical weathering might occur? Chemical weathering can also be contributed to by plants and animals. As plant roots take in soluble ions as nutrients, certain elements are exchanged. Plant roots and bacterial decay use carbon dioxide in the process of respiration.

Mechanical and Chemical Weathering

Mechanical weathering increases the rate of chemical weathering. As rock breaks into smaller pieces, the surface area of the pieces increases **Figure** 5.47. With more surfaces exposed, there are more surfaces on which chemical weathering can occur.

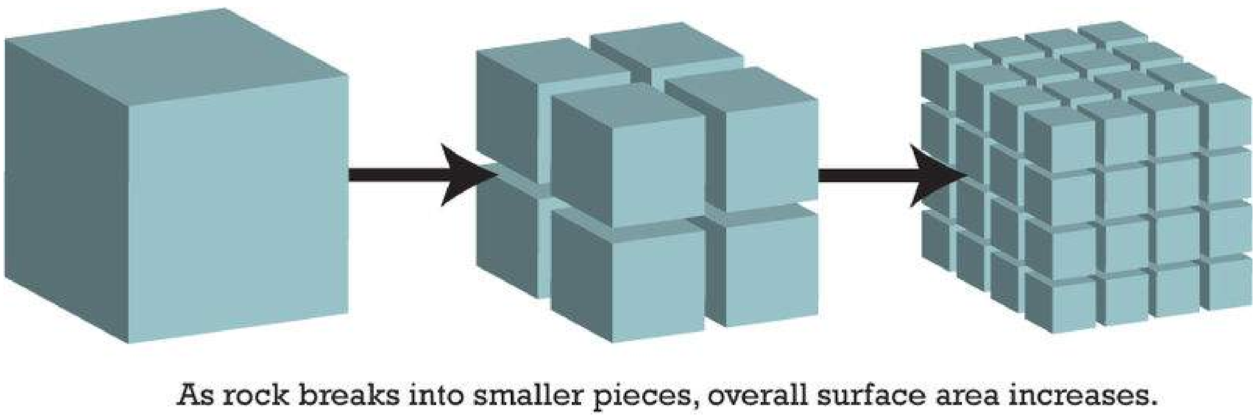


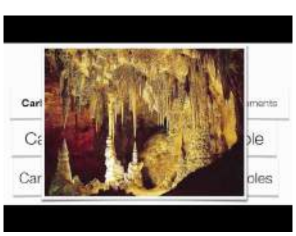
FIGURE 5.47
Mechanical weathering may increase the rate of chemical weathering.

Summary

- Chemical weathering changes the composition of a mineral to break it down.
- The agents of chemical weathering include water, carbon dioxide, and oxygen.
- Living organisms and humans can contribute to chemical weathering.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What is chemical weathering?
2. What are the three ways chemical weathering occurs?
3. What is oxidation? What does it produced?
4. What is carbonation? What does it create?
5. What is hydration? What does it do?

Review

1. How does the structure of the water molecule lead to chemical weathering?
2. Describe how carbon dioxide and oxygen cause chemical weathering.
3. How does mechanical weathering increase the effectiveness of chemical weathering processes?

5.17 Landforms from Wind Erosion and Deposition

- Describe how wind erodes and deposits sediments.

What are the effects of sandblasting?

If you've ever been in a sand storm, you've felt the power of the wind blasting at your skin. Over time, this natural sand blasting can be a tremendous erosional force on rocks or buildings. Hopefully, you won't stay out long enough to experience permanent damage.

Transport of Particles by Wind

Wind transports small particles, such as silt and clay, over great distances, even halfway across a continent or an entire ocean basin. Particles may be suspended for days. Wind more easily picks up particles on ground that has been disturbed, such as a construction site or a sand dune. Just like flowing water, wind transports particles as both bed load and suspended load. For wind, bed load is made of sand-sized particles, many of which move by saltation (**Figure** 5.48). The suspended load is very small particles of silt and clay.

Wind Erosion

Wind is a stronger erosional force in arid regions than it is in humid regions because winds are stronger. In humid areas, water and vegetation bind the soil so it is harder to pick up. In arid regions, small particles are selectively picked up and transported.

Deflation

As small particles are removed, the ground surface gets lower and rockier, causing **deflation**. What is left is **desert pavement** (**Figure** 5.49), a surface covered by gravel-sized particles that are not easily moved by wind.

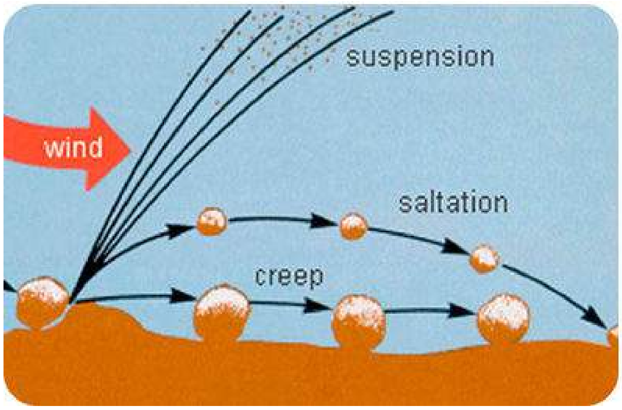


FIGURE 5.48

(a) Wind transport is by suspension, saltation, and creep (bed load). (b) In a sandstorm, sand is usually within a meter of the ground. A dust storm's smaller particles can travel higher. A dust storm as it approaches Al Asad, Iraq.

FIGURE 5.49

This desert pavement formed in the Mojave Desert as a result of deflation.

Abrasion

Particles moved by wind do the work of abrasion. As a grain strikes another grain or surface it erodes that surface. Abrasion by wind may polish natural or human-made surfaces, such as buildings. Stones that have become polished and faceted due to abrasion by sand particles are called **ventifacts** (**Figure** 5.50).

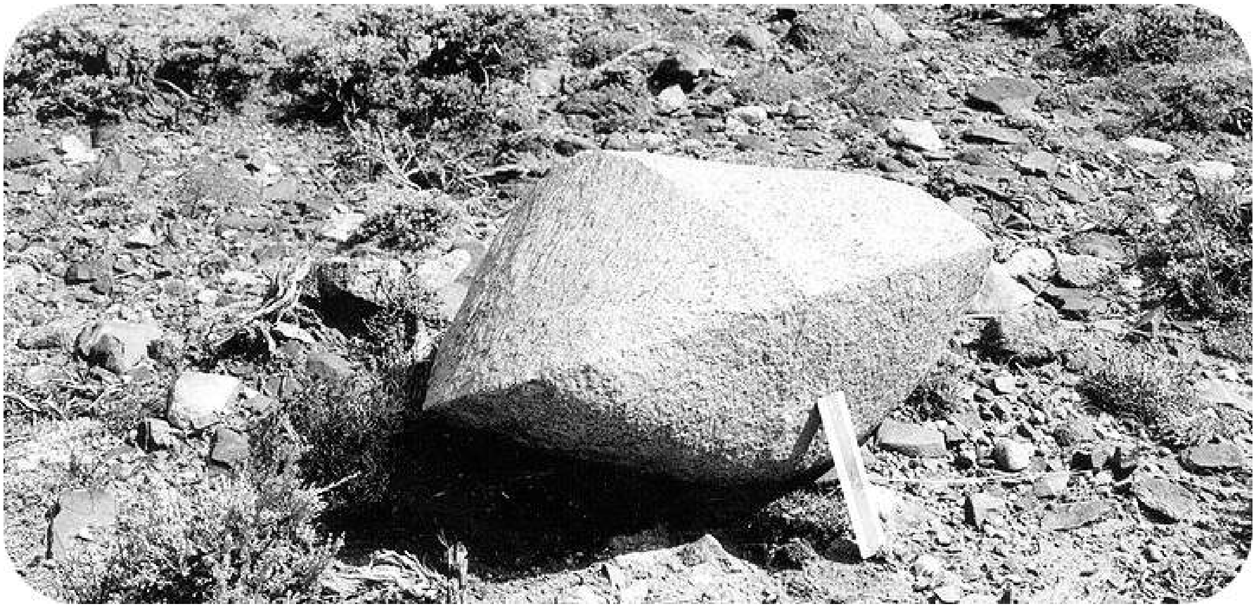


FIGURE 5.50
As wind blows from different direction, polished flat surfaces create a ventifact.

Desert Varnish

Exposed rocks in desert areas often develop a dark brown or black coating called **desert varnish**. Wind transports clay-sized particles that chemically react with other substances at high temperatures. The coating is formed of iron and manganese oxides (**Figure** 5.51).

FIGURE 5.51
Ancient people carved these petroglyphs into desert varnish near Canyonlands National Park in Utah.

Wind Deposition

The main features deposited by wind are sand dunes. Loess are wind deposits of finer sediments.

Sand Dunes

Deserts and seashores sometimes have **sand dunes** (**Figure** 5.52). Beach dunes are usually made of quartz because quartz is what's left in humid areas as other minerals weather into clays. Sand dunes may be composed of calcium carbonate in tropical areas. But in deserts, sand dunes are composed of a variety of minerals because there is little weathering.

Dune sands are usually very uniform in size and shape. Larger particles are too heavy for the wind to transport by suspension and smaller particles can't be picked up. Particles are rounded, since rounded grains roll more easily than angular grains.

FIGURE 5.52
This sand dune in Death Valley, California shows secondary sand ripples along its slip face.

For sand dunes to form there must be an abundant supply of sand and steady winds. A strong wind slows down, often over some type of obstacle, such as a rock or some vegetation, and drops its sand. As the wind moves up and over the obstacle, it increases in speed. It carries the sand grains up the gently sloping, upwind side of the dune by saltation. As the wind passes over the dune, its speed decreases. Sand cascades down the crest, forming the **slip face** of the dune. The slip face is steep because it is at the angle of repose for dry sand, about 34^o (**Figure** 5.53).

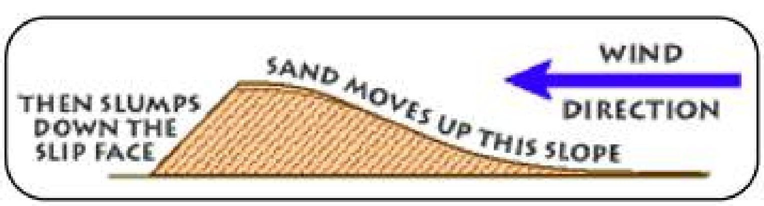


FIGURE 5.53
Sand dunes slope gently in the upwind direction. Downwind, a steeper slip face forms.

Wind deposits dune sands layer by layer. If the wind changes directions, cross beds form. Cross beds are named for the way each layer is formed at an angle to the ground (**Figure** 5.54).

The type of sand dune that forms depends on the amount of sand available, the character and direction of the wind,

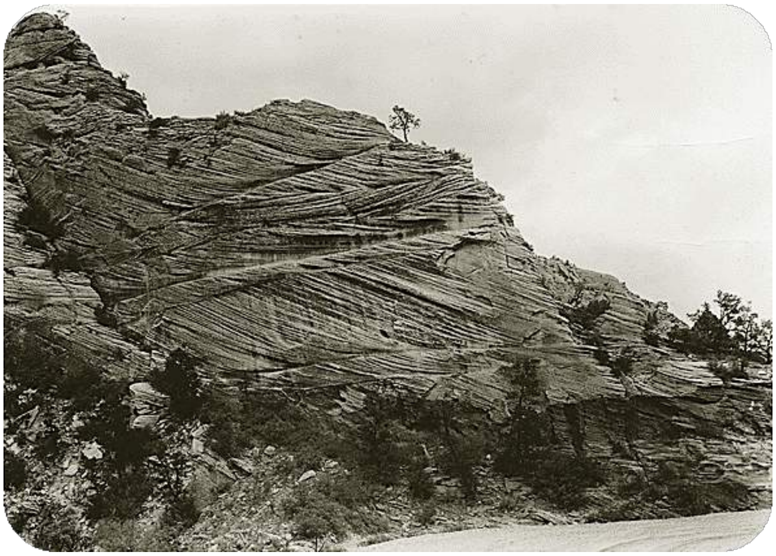


FIGURE 5.54
This sandstone in Zion National Park, Utah, shows crossbedding.

and the type of ground the sand is moving over. Dunes may be crescent-shaped, star-shaped, parabolic, linear, or barchan.

- An animation of the formation of the dunes at Great Sand Dunes National Park is seen on this website: http://www.nps.gov/grsa/naturescience/sanddunes.htm .

Loess

Windblown silt and clay deposited layer on layer over a large area form **loess** (**Figure** 5.55). Loess deposits form downwind of glacial outwash or desert, where fine particles are available. Loess deposits make very fertile soils in many regions of the world.

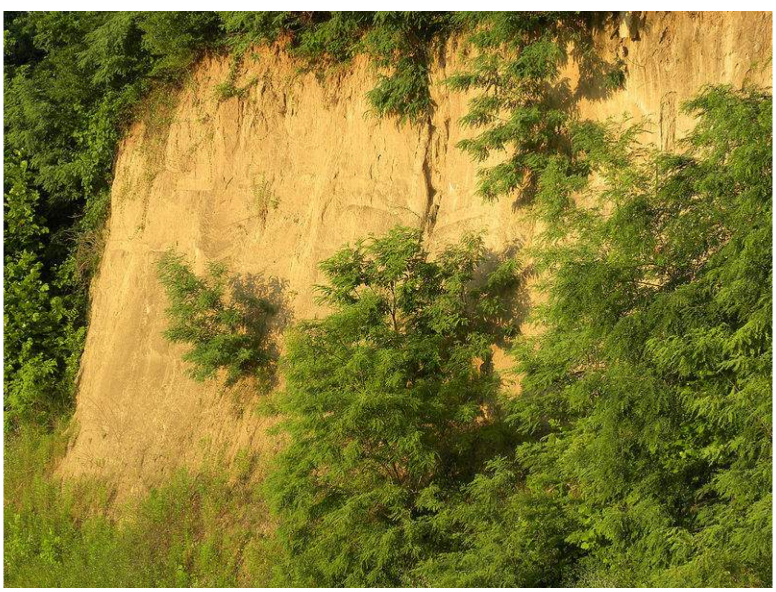


FIGURE 5.55
Loess deposits form nearly vertical cliffs, without grains sliding down the face.

Seafloor Mud

Fine-grained mud in the deep ocean is formed from silts and clays brought from the land by wind. The particles are deposited on the sea surface, then slowly settle to the deep ocean floor, forming brown, greenish, or reddish clays. Volcanic ash may also settle on the seafloor.

Summary

- In deserts, wind picks up small particles and leaves behind larger rocks to form desert pavement.
- Moving sand may sand blast rocks and other features to create ventifacts.
- The sand is transported until it is deposited in a sand dune.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What causes erosion?
2. Why is soil erosion a problem?
3. How does wind erosion occur?
4. What are the 3 types of wind erosion?
5. What type of wind erosion moves 50% of the soil?
6. What is creep?
7. What is saltation?
8. What is suspension?
9. When is suspension easily seen?
10. What has accelerated erosion?

Review

1. How does desert varnish form?
2. Describe how sand dunes form and move.
3. Why is loess a non-renewable resource?

5.18 Landforms from Stream Erosion and Deposition

- Describe how streams erode and deposit sediments.

What on Earth are 'goosenecks'?

In Southeastern Utah, stream meanders have been immortalized by erosion into the Goosenecks of the San Juan River. This satellite image shows the amazing path the river has cut. Even better is to stand at the edge and look into one of the meanders. Goosenecks State Park is in the southeastern corner of Utah.

Erosion by Streams

Flowing streams pick up and transport weathered materials by eroding sediments from their banks. Streams also carry ions and ionic compounds that dissolve easily in the water.

Sediment Transport

Sediments are carried as:

- **Dissolved load**: Dissolved load is composed of ions in solution. These ions are usually carried in the water all the way to the ocean.
- **Suspended load**: Sediments carried as solids as the stream flows are suspended load. The size of particles that can be carried is determined by the stream's velocity (**Figure** 5.56). Faster streams can carry larger particles. Slower streams can only carry smaller particles. Streams with a steep **gradient** (slope) have a faster velocity and can carry larger particles.

FIGURE 5.56
The Amazon River appears brown when carrying a large sediment load.

- **Bed load**: Some particles are too large to be carried as suspended load. These particles bumped and pushed along the stream bed as bed load. Bed load sediments do not move continuously. This intermittent movement is called **saltation**. Streams with high velocities and steep gradients cut down into the stream bed. This type of erosion is primarily by movement of particles that make up the bed load.

- An animation of saltation is found here: http://www.weru.ksu.edu/new_weru/multimedia/movies/dust003.mpg .
- A video of bedload transport is found here: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/bdld.mov .

Stream Deposition

A stream is at its **base level** where it meets a large body of water. As a stream gets closer to base level, its gradient lowers. The stream deposits more material than it erodes. On flatter ground, streams deposit material on the inside of meanders. Meanders are bends in the stream's path. Placer mineral deposits are often deposited on the inside of meanders.

A stream's **floodplain** is much broader and shallower than its channel. When a stream flows onto its floodplain, its velocity slows. The stream deposits much of its load. Stream sediments are rich in nutrients and make excellent farmland. The Mississippi River floodplain is heavily farmed. Flooding can wipe out farms and towns, but the stream also deposits nutrient-rich sediments that enrich the floodplain (**Figure** 5.57).

A stream at flood stage carries lots of sediments. When its gradient decreases, the stream overflows its banks and broadens its channel. The decrease in gradient causes the stream to deposit its sediments. The largest sediments are deposited first. These large sediments build a higher area around the edges of the stream channel. This creates a **natural levee**.

When a river enters standing water, its velocity slows to a stop. The stream moves back and forth across the region. The stream drops its sediments in a wide triangular-shaped deposit called a **delta** (**Figure** 5.58).

If a stream falls down a steep slope onto a broad flat valley, an **alluvial fan** develops (**Figure** 5.59). Alluvial fans generally form in arid regions.

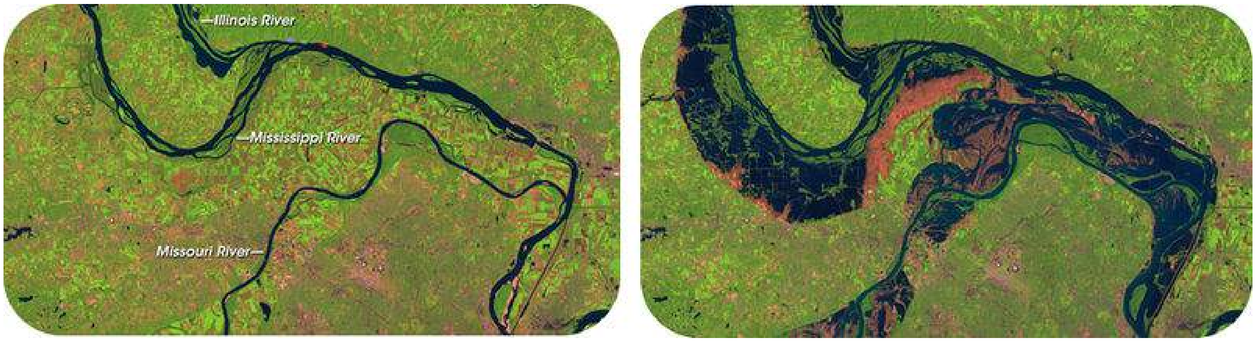


FIGURE 5.57
The Mississippi River floodplain at normal flow and during flood.

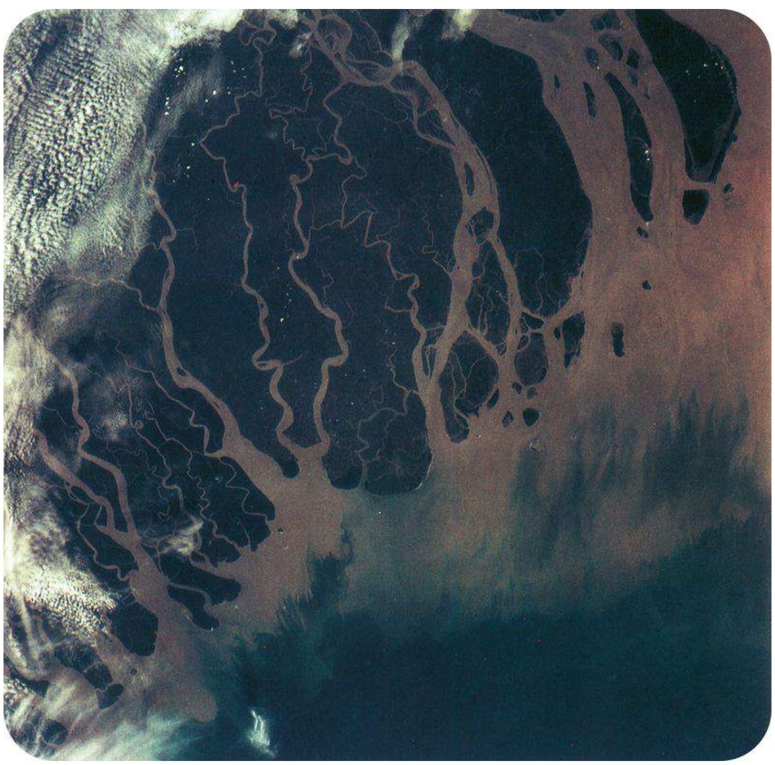


FIGURE 5.58
The Ganges River forms an enormous delta in Bangladesh.

Summary

- Streams carry dissolved ions and sediments. The sizes of the sediments a stream can carry depend on the stream's velocity.
- Particles that are too large to be suspended move along the stream bed by saltation.
- Rivers deposit sediments on levees, floodplains, and in deltas and alluvial fans.

FIGURE 5.59
A series of alluvial fans spread out from mountains along the Badwater Basin in Death Valley, California.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is laminar flow?
2. What is turbulent flow?
3. What is jet flow?
4. Where does jet flow occur?
5. What is water velocity?
6. What factors can influence the stream velocity?

Review

1. If flood waters decrease, what will happen to the size of particle the stream can carry? What will be deposited and where?
2. Under what conditions do streams cut down into their beds? Under what conditions do they erode their banks?
3. Deserts are extremely dry, yet alluvial fans are said to be deposited by stream flow. Describe how this occurs.

5.19 Landforms from Erosion and Deposition by Gravity

- Describe how gravity erodes and deposits sediments.

Would you live here?

La Conchita, California is in a beautiful location, nestled between a Southern California beach and a hillside. That hillside, though, is prone to landslides, and the town has lost several homes, a banana plantation, and 10 residents to landslides in 1995 and 2005. Despite these problems people stay in the community. Would you?

Landforms and Gravity

Gravity shapes the Earth's surface by moving weathered material from a higher place to a lower one. This occurs in a variety of ways and at a variety of rates, including sudden, dramatic events as well as slow, steady movements that happen over long periods of time. The force of gravity is constant and it is changing the Earth's surface right now.

Downslope Movement by Gravity

Erosion by gravity is called **mass wasting**. Mass wasting can be slow and virtually imperceptible, or rapid, massive, and deadly.

Weathered material may fall away from a cliff because there is nothing to keep it in place. Rocks that fall to the base of a cliff make a **talus slope**. Sometimes as one rock falls, it hits another rock, which hits another rock, and begins a landslide.

Landslides

Landslides are the most dramatic, sudden, and dangerous examples of Earth materials moved by gravity. Landslides are sudden falls of rock; by contrast, avalanches are sudden falls of snow.

When large amounts of rock suddenly break loose from a cliff or mountainside, they move quickly and with tremendous force (**Figure** 5.60). Air trapped under the falling rocks acts as a cushion that keeps the rock from slowing down. Landslides can move as fast as 200 to 300 km/hour.

FIGURE 5.60
This landslide in California in 2008 blocked Highway 140.

Landslides are exceptionally destructive. Homes may be destroyed as hillsides collapse. Landslides can even bury entire villages. Landslides may create lakes when the rocky material dams a stream. If a landslide flows into a lake or bay, they can trigger a tsunami.

Landslides often occur on steep slopes in dry or semi-arid climates. The California coastline, with its steep cliffs and years of drought punctuated by seasons of abundant rainfall, is prone to landslides.

- Rapid downslope movement of material is seen in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/dflows.mov .

Mudflows and Lahars

Added water creates natural hazards produced by gravity (**Figure** 5.61). On hillsides with soils rich in clay, little rain, and not much vegetation to hold the soil in place, a time of high precipitation will create a **mudflow**. Mudflows follow river channels, washing out bridges, trees, and homes that are in their path.

- A debris flow is seen in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/Moscardo.mov .

A lahar is mudflow that flows down a composite volcano (**Figure** 5.62). Ash mixes with snow and ice melted by the eruption to produce hot, fast-moving flows. The lahar caused by the eruption of Nevado del Ruiz in Columbia in 1985 killed more than 23,000 people.

FIGURE 5.61
Mudflows are common in southern California.

FIGURE 5.62
A lahar is a mudflow that forms from volcanic ash and debris.

Slump and Creep

Less dramatic types of downslope movement move Earth materials slowly down a hillside. **Slump** moves materials as a large block along a curved surface (**Figure** 5.63). Slumps often happen when a slope is undercut, with no support for the overlying materials, or when too much weight is added to an unstable slope.

Creep is the extremely gradual movement of soil downhill. Curves in tree trunks indicate creep because the base of the tree is moving downslope while the top is trying to grow straight up (**Figure** 5.64). Tilted telephone or power company poles are also signs of creep.

Contributing Factors

There are several factors that increase the chance that a landslide will occur. Some of these we can prevent and some we cannot.

FIGURE 5.63
Slump material moves as a whole unit, leaving behind a crescent shaped scar.

FIGURE 5.64
The trunks of these trees near Mineral King, California, were bent by snow creeping downhill when the trees were saplings.

Water

A little bit of water helps to hold grains of sand or soil together. For example, you can build a larger sand castle with slightly wet sand than with dry sand. However, too much water causes the sand to flow quickly away. Rapid snow melt or rainfall adds extra water to the soil, which increases the weight of the slope and makes sediment grains lose contact with each other, allowing flow.

Rock Type

Layers of weak rock, such as clay, also allow more landslides. Wet clay is very slippery, which provides an easy surface for materials to slide over.

Undercutting

If people dig into the base of a slope to create a road or a homesite, the slope may become unstable and move downhill. This is particularly dangerous when the underlying rock layers slope towards the area.

- Ocean waves undercut cliffs and cause landslides on beaches, as in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/Cliff_retreat.mov .

When construction workers cut into slopes for homes or roads, they must stabilize the slope to help prevent a landslide (**Figure** 5.65). Tree roots or even grasses can bind soil together. It is also a good idea to provide drainage so that the slope does not become saturated with water.

FIGURE 5.65
A rock wall stabilizes a slope that has been cut away to make a road.

Ground Shaking

An earthquake, volcanic eruption, or even just a truck going by can shake unstable ground loose and cause a slide. Skiers and hikers may disturb the snow they travel over and set off an avalanche.

A very good introduction to the topic, "Landslide 101," is a video seen on National Geographic Videos, Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/ .

Prevention and Awareness

Landslides cause $1 billion to $2 billion damage in the United States each year and are responsible for traumatic and sudden loss of life and homes in many areas of the world.

Some at-risk communities have developed landslide warning systems. Around San Francisco Bay, the National Weather Service and the U.S. Geological Survey use rain gauges to monitor soil moisture. If soil becomes saturated, the weather service issues a warning. Earthquakes, which may occur on California's abundant faults, can also trigger landslides.

To be safe from landslides:

- Be aware of your surroundings and notice changes in the natural world.
- Look for cracks or bulges in hillsides, tilting of decks or patios, or leaning poles or fences when rainfall is heavy. Sticking windows and doors can indicate ground movement as soil pushes slowly against a house and knocks windows and doors out of alignment.
- Look for landslide scars because landslides are most likely to happen where they have occurred before.
- Plant vegetation and trees on the hillside around your home to help hold soil in place.
- Help to keep a slope stable by building retaining walls. Installing good drainage in a hillside may keep the soil from getting saturated.

Hillside properties in the San Francisco Bay Area and elsewhere may be prone to damage from landslides. Geologists are studying the warning signs and progress of local landslides to help reduce risks and give people adequate warnings of these looming threats.

See more at http://science.kqed.org/quest/video/landslide-detectives/.

Adobe Flash

MEDIA

Click image to the left for more content.

Summary

- Landslides are sudden and massive falls of rock down a slope that may be very destructive or even deadly. Mudflows or lahars, which are volcanic mudflows, are mass movements that contain a lot of water. Slump and creep are slower types of mass wasting.
- Mass movements are more likely to occur on slopes that are wet, have weak rock, or are undercut. An earthquake or other ground shaking can trigger a landslide.
- To avoid being in a landslide, be aware of signs in a hillside, such as cracks or bulges and old landslide scars.
- To keep a slope stable, install good drainage or build retaining walls.

Practice

Use these resources to answer the questions that follow.

http://video.nationalgeographic.com/video/environment/environment-natural-disasters/landslides-and-more/landslides/

1. Where do landslides occur?

2. How many people are killed by landslides each year?

3. What can cause landslides to become more frequent?

MEDIA

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4. What is creep?

5. How do trees compensate for creep?

Review

1. How would installing drainage pipes in a slope change that slope's chance of a landslide?
2. If you look at a hillside, how can you tell that it's vulnerable to landslides? How can you tell that it's vulnerable to creep?
3. What is the scenario that creates a mudflow that kills 23,000 people?

5.20 Soil Formation

- Identify the factors that influence soil formation and explain how they work.

What do different types of soil feel like?

Did you ever plant a garden? Even if you live in an area with poor soil you can buy some dirt and put in some seeds. The type of soil that forms in an area depends on many factors. Some regions produce soil that are not good for crops, but may be good for something else, like cactus!

Soil Formation

How well soil forms and what type of soil forms depends on several different factors, which are described below.

- An animation of how weathering makes soil is found here: http://courses.soil.ncsu.edu/resources/soil_classification_genesis/mineral_weathering/mineral_weathering.swf .

Climate

Scientists know that climate is the most important factor determining soil type because, given enough time, different rock types in a given climate will produce a similar soil (**Figure** 5.66). Even the same rock type in different climates will not produce the same type of soil. This is true because most rocks on Earth are made of the same eight elements and when the rock breaks down to become soil, those elements dominate.

The same factors that lead to increased weathering also lead to greater soil formation.

- More rain equals more chemical reactions to weather minerals and rocks. Those reactions are most efficient in the top layers of the soil, where the water is fresh and has not yet reacted with other materials.

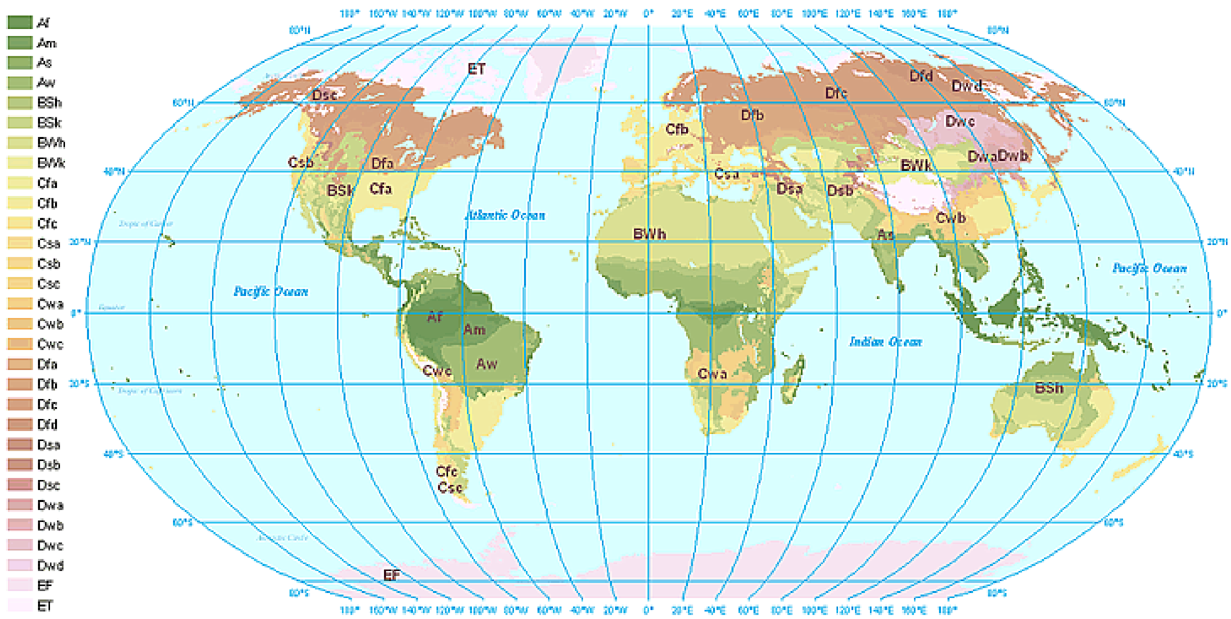


FIGURE 5.66

Climate is the most important factor in determining the type of soil that will form in a particular area.

- Increased rainfall increases the amount of rock that is dissolved as well as the amount of material that is carried away by moving water. As materials are carried away, new surfaces are exposed, which also increases the rate of weathering.
- Increased temperature increases the rate of chemical reactions, which also increases soil formation.
- In warmer regions, plants and bacteria grow faster, which helps to weather material and produce soils. In tropical regions, where temperature and precipitation are consistently high, thick soils form. Arid regions have thin soils.

Soil type also influences the type of vegetation that can grow in the region. We can identify climate types by the types of plants that grow there.

Rock Type

The original rock is the source of the inorganic portion of the soil. The minerals that are present in the rock determine the composition of the material that is available to make soil. Soils may form in place or from material that has been moved.

- **Residual soils** form in place. The underlying rock breaks down to form the layers of soil that reside above it. Only about one-third of the soils in the United States are residual.
- **Transported soils** have been transported in from somewhere else. Sediments can be transported into an area by glaciers, wind, water, or gravity. Soils form from the loose particles that have been transported to a new location and deposited.

Slope

The steeper the slope, the less likely material will be able to stay in place to form soil. Material on a steep slope is likely to go downhill. Materials will accumulate and soil will form where land areas are flat or gently undulating.

Time

Soils thicken as the amount of time available for weathering increases. The longer the amount of time that soil remains in a particular area, the greater the degree of alteration.

Biological Activity

The partial decay of plant material and animal remains produces the organic material and nutrients in soil. In soil, decomposing organisms breakdown the complex organic molecules of plant matter and animal remains to form simpler inorganic molecules that are soluble in water. Decomposing organisms also create organic acids that increase the rate of weathering and soil formation. Bacteria in the soil change atmospheric nitrogen into nitrates.

The decayed remains of plant and animal life are called **humus**, which is an extremely important part of the soil. Humus coats the mineral grains. It binds them together into clumps that then hold the soil together, creating its structure. Humus increases the soil's porosity and water-holding capacity and helps to buffer rapid changes in soil acidity. Humus also helps the soil to hold its nutrients, increasing its fertility. Fertile soils are rich in nitrogen, contain a high percentage of organic materials, and are usually black or dark brown in color. Soils that are nitrogen poor and low in organic material might be gray or yellow or even red in color. Fertile soils are more easily cultivated.

- An animation of how different types of weathering affect different minerals in soil: http://courses.soil.ncsu.edu/resources/soil_classification_genesis/mineral_weathering/elemental_change.swf .

Summary

- The factors that affect soil formation are climate, rock type, slope, time, and biological activity. Differences in these factors will produce different types of soil.
- Soil type determines what can grow in a region.
- Humus, the decayed remains of living organisms, is essential for soils to be fertile.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What two features do parent material have on soil formation?
2. What are the physical properties that contribute to soil formation?
3. How does relief effect soil formation?

4. What is seen on slopes?

5. How does climate determine soil formation?

6. How does time effect soil formation?

7. How are humans changing soil formation?

Review

1. How does climate affect soil type? Why is climate the most important factor in developing the characteristics of a soil?

2. How does time affect soil formation in an arid environment versus in a warm, humid environment?

3. What is the role of partially decayed plant and animal remains in a soil?

5.21 Types of Soils

- Describe the characteristics of types of soil and where each is found.

What makes soil good?

Some types of soils are good for growing crops and some are not. When good soils are found in good climates where water is available, a variety of crops will grow. If one of these things is missing, the possibilities are much more limited.

Types of Soils

Although soil scientists recognize thousands of types of soil –each with its own specific characteristics and name - let's consider just three soil types. This will help you to understand some of the basic ideas about how climate produces a certain type of soil, but there are many exceptions to what we will learn right now (**Figure** 5.67).

FIGURE 5.67
Just some of the thousands of soil types.

Pedalfer

Deciduous trees, the trees that lose their leaves each winter, need at least 65 cm of rain per year. These forests produce soils called **pedalfers**, which are common in many areas of the temperate, eastern part of the United States (**Figure** 5.68). The word pedalfer comes from some of the elements that are commonly found in the soil. The "Al" in ped **al**fer is the chemical symbol of the element aluminum, and the "Fe" in pedal **fe**r is the chemical symbol for iron. Pedalfers are usually a very fertile, dark brown or black soil. Not surprisingly, they are rich in aluminum clays and iron oxides. Because a great deal of rainfall is common in this climate, most of the soluble minerals dissolve and are carried away, leaving the less soluble clays and iron oxides behind.

Pedocal

Pedocal soils form in drier, temperate areas where grasslands and brush are the usual types of vegetation (**Figure** 5.69). The climates that form pedocals have less than 65 cm rainfall per year. Compared to pedalfers there is less chemical weathering and less water to dissolve away soluble minerals, so more soluble minerals are present and fewer clay minerals are produced. It is a drier region with less vegetation, so the soils have lower amounts of organic material and are less fertile.

A pedocal is named for the calcite enriched layer that forms. Water begins to move down through the soil layers, but before it gets very far, it begins to evaporate. Soluble minerals, like calcium carbonate, concentrate in a layer that marks the lowest place that water was able to reach. This layer is called caliche.

FIGURE 5.68
A pedalfer is the dark, fertile type of soil that will form in a forested region.

FIGURE 5.69
A lizard on soil typical of an arid region in Mexico.

Laterite

In tropical rainforests where it rains literally every day, **laterite** soils form (**Figure** 5.70). In these hot, wet, tropical regions, intense chemical weathering strips the soils of their nutrients. There is practically no humus. All soluble minerals are removed from the soil and all plant nutrients are carried away. All that is left behind are the least soluble materials, like aluminum and iron oxides. These soils are often red in color from the iron oxides. Laterite soils bake as hard as a brick if they are exposed to the Sun.

Many climate types have not been mentioned here. Each produces a distinctive soil type that forms in the particular circumstances found there. Where there is less weathering, soils are thinner but soluble minerals may be present. Where there is intense weathering, soils may be thick but nutrient-poor. Soil development takes a very long time, it may take hundreds or even thousands of years for a good fertile topsoil to form. Soil scientists estimate that in the very best soil-forming conditions, soil forms at a rate of about 1mm/year. In poor conditions, soil formation may take thousands of years!

Summary

- Pedalfer is the soil common in deciduous forests and is rich in aluminum and iron. Pedalfers are dark brown and fertile.

FIGURE 5.70
A laterite is the type of thick, nutrient-poor soil that forms in the rainforest.

- Pedocal is the soil common in grasslands where the climate is drier and is rich in calcium.
- Laterite forms in tropical rain forests. Chemical weathering strips the soils of their nutrients, so when the forest is removed the soil is not very fertile.

Practice

Use these resources to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What are the three most common types of soil?
2. Where are pedalfers found?
3. Where are pedocals found?
4. Where is laterite found?

MEDIA
Click image to the left for more content.

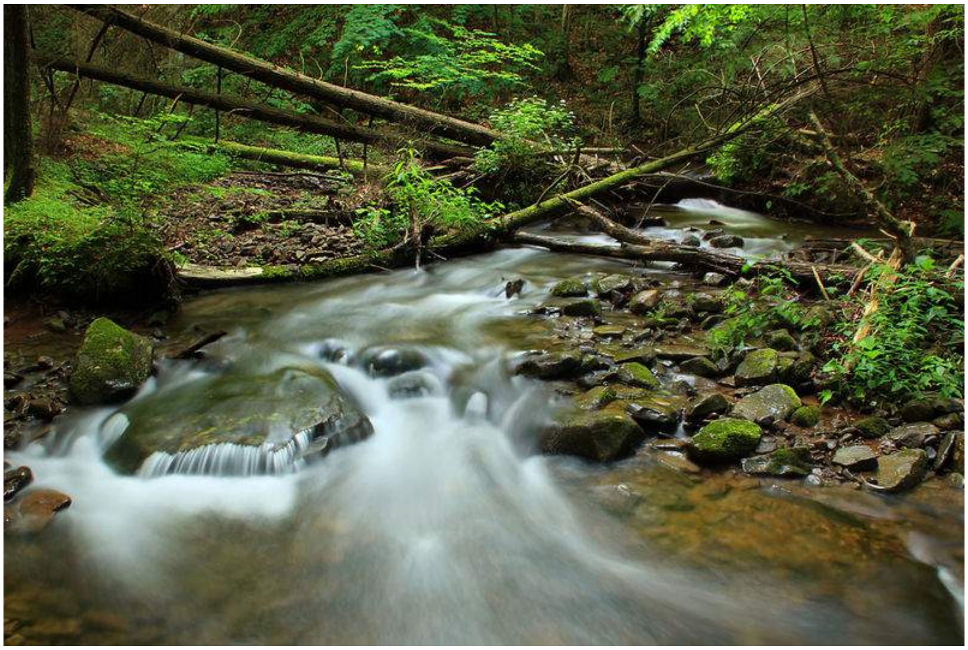
5. What is laterite?
6. Where is it found?
7. What zones are in laterite?

Review

1. What is pedocal and under what conditions does it form?
2. What is pedalfer and under what conditions does it form?
3. What is laterite and under what conditions does it form?

5.22 Soil Characteristics

- Describe the characteristics of soil.



"Land, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals." —Aldo Leopold, *A Sand County Almanac*, 1949

Even though soil is only a very thin layer on Earth's surface over the solid rocks below, it is the where the atmosphere, hydrosphere, biosphere, and lithosphere meet. We should appreciate soil more.

Characteristics of Soil

Soil is a complex mixture of different materials.

- About half of most soils are **inorganic** materials, such as the products of weathered rock, including pebbles, sand, silt, and clay particles.
- About half of all soils are **organic** materials, formed from the partial breakdown and decomposition of plants and animals. The organic materials are necessary for a soil to be fertile. The organic portion provides the nutrients, such as nitrogen, needed for strong plant growth.
- In between the solid pieces, there are tiny spaces filled with air and water.

Within the soil layer, important reactions between solid rock, liquid water, air, and living things take place.

In some soils, the organic portion could be missing, as in desert sand. Or a soil could be completely organic, such as the materials that make up peat in a bog or swamp (**Figure** 5.71).

Soil Texture

The inorganic portion of soil is made of many different size particles, and these different size particles are present in different proportions. The combination of these two factors determines some of the properties of the soil.

FIGURE 5.71
Peat is so rich in organic material, it can be burned for energy.

- A **permeable** soil allows water to flow through it easily because the spaces between the inorganic particles are large and well connected. Sandy or silty soils are considered "light" soils because they are permeable, water-draining types of soils.
- Soils that have lots of very small spaces are water-holding soils. For example, when clay is present in a soil, the soil is heavier, holds together more tightly, and holds water.
- When a soil contains a mixture of grain sizes, the soil is called a **loam** (**Figure** 5.72).

FIGURE 5.72
A loam field.

Classification

When soil scientists want to precisely determine soil type, they measure the percentage of sand, silt, and clay. They plot this information on a triangular diagram, with each size particle at one corner (**Figure** 5.73). The soil type can then be determined from the location on the diagram. At the top, a soil would be clay; at the left corner, it would be sand; at the right corner, it would be silt. Soils in the lower middle with less than 50% clay are loams.

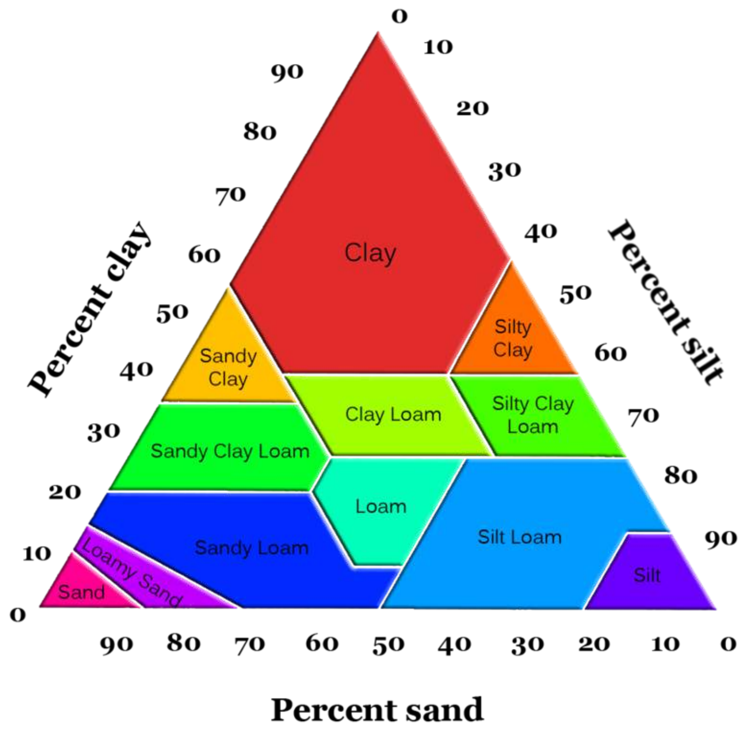


FIGURE 5.73
Soil types by particle size.

Soil, the Ecosystem

Soil is an ecosystem unto itself. In the spaces of soil, there are thousands or even millions of living organisms. Those organisms could include earthworms, ants, bacteria, or fungi (**Figure** 5.74).

FIGURE 5.74
Earthworms and insects are important residents of soils.

Summary

- Soil reflects the interactions between the lithosphere, atmosphere, hydrosphere and biosphere.

- Permeable soils allow water to flow through.
- The proportions of silt, clay, and sand allow scientists to classify soil type.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. Why is soil important?
2. How many different types of soils are there?
3. Explain the composition of average soil.
4. What is humus?
5. What does the amount of humus determine?
6. What is texture?
7. How can texture effect plant growth?
8. What type of soil do farmers prefer?
9. How is soil being lost each year?
10. List the different types of erosion.

Review

1. What is the inorganic material that makes up a soil?
2. What is the organic material that makes up a soil?
3. If a soil has equal amounts of silt, clay, and sand, what type of soil is it?

5.23 Soil Horizons and Profiles

- Define soil horizon and soil profile.
- Describe the characteristics of the three major types of soil horizon, and explain the relationship of each to weathering processes.

What conditions would create so much clay?

Soils are so different. In the desert there's a very thin layer and then bedrock. The quarry in the photo is of clay. A thick, thick layer of clay is found in this area. The area must be quite moist for so much rock material to have weathered to clays.

Soil Horizons and Profiles

A residual soil forms over many years, as mechanical and chemical weathering slowly change solid rock into soil. The development of a residual soil may go something like this.

1. The bedrock fractures because of weathering from ice wedging or another physical process.
2. Water, oxygen, and carbon dioxide seep into the cracks to cause chemical weathering.
3. Plants, such as lichens or grasses, become established and produce biological weathering.
4. Weathered material collects until there is soil.
5. The soil develops **soil horizons**, as each layer becomes progressively altered. The greatest degree of weathering is in the top layer. Each successive, lower layer is altered just a little bit less. This is because the first place where water and air come in contact with the soil is at the top.

A cut in the side of a hillside shows each of the different layers of soil. All together, these are called a **soil profile** (**Figure** 5.75).

The simplest soils have three horizons.

FIGURE 5.75
Soil is an important resource. Each soil horizon is distinctly visible in this photograph.

Topsoil

Called the **A-horizon**, the **topsoil** is usually the darkest layer of the soil because it has the highest proportion of organic material. The topsoil is the region of most intense biological activity: insects, worms, and other animals burrow through it and plants stretch their roots down into it. Plant roots help to hold this layer of soil in place.

In the topsoil, minerals may dissolve in the fresh water that moves through it to be carried to lower layers of the soil. Very small particles, such as clay, may also get carried to lower layers as water seeps down into the ground.

Subsoil

The **B-horizon** or **subsoil** is where soluble minerals and clays accumulate. This layer is lighter brown and holds more water than the topsoil because of the presence of iron and clay minerals. There is less organic material. **Figure** 5.76.

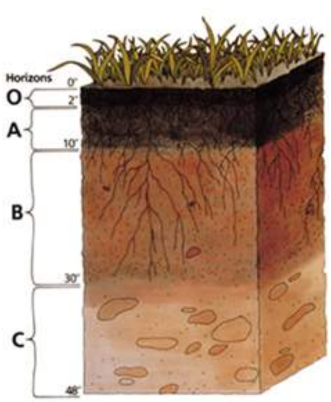


FIGURE 5.76
A soil profile is the complete set of soil layers. Each layer is called a horizon.

C horizon

The **C-horizon** is a layer of partially altered bedrock. There is some evidence of weathering in this layer, but pieces of the original rock are seen and can be identified.

Not all climate regions develop soils, and not all regions develop the same horizons. Some areas develop as many as five or six distinct layers, while others develop only very thin soils or perhaps no soils at all.

- An animation of soil profile development can be viewed here: http://courses.soil.ncsu.edu/resources/soil_classification_genesis/soil_formation/soil_transform.swf .

Summary

- Soil horizons are layers within a soil showing different amounts of alteration.
- Soil profiles show the layers of soil, which include topsoil, subsoil and the C horizon.
- Topsoil has the highest proportion of organic material and is very important for agriculture.

Practice

Use this resource to answer the questions that follow.

http://uccpbank.k12hsn.org/courses/APEnvironmentalScience/course%20files/multimedia/lesson51/animations/4c_soil_profile.html

1. What is a horizon?
2. How many horizons does typical soil contain?
3. What does the O-horizon contain?
4. What is duff?
5. What is the A-horizon? What does it contain?
6. What are the characteristics of the B-horizon?
7. What is the C-horizon? How does it differ from the other horizons?

Review

1. Describe topsoil. Why is loss of topsoil a very large problem when it happens?
2. Describe the weathering processes that go into producing soil.
3. What is the C horizon?

5.24 Soil Erosion

- Explain how human activities cause soil erosion.

What would cause such a tremendous dust storm?

Farmers were forced off their lands during the Dust Bowl in the 1930s when the rains stopped and the topsoil blew off these former grasslands. A wind storm blew huge amounts of soil into the air in Texas on April 14, 1935. This scene was repeated throughout the central United States.

Causes of Soil Erosion

The agents of soil erosion are the same as the agents of all types of erosion: water, wind, ice, or gravity. Running water is the leading cause of soil erosion, because water is abundant and has a lot of power. Wind is also a leading cause of soil erosion because wind can pick up soil and blow it far away.

Activities that remove vegetation, disturb the ground, or allow the ground to dry are activities that increase erosion. What are some human activities that increase the likelihood that soil will be eroded?

Farming

Agriculture is probably the most significant activity that accelerates soil erosion because of the amount of land that is farmed and how much farming practices disturb the ground (**Figure** 5.77). Farmers remove native vegetation and then plow the land to plant new seeds. Because most crops grow only in spring and summer, the land lies fallow during the winter. Of course, winter is also the stormy season in many locations, so wind and rain are available to wash soil away. Tractor tires make deep grooves, which are natural pathways for water. Fine soil is blown away by wind.

The soil that is most likely to erode is the nutrient-rich topsoil, which degrades the farmland.

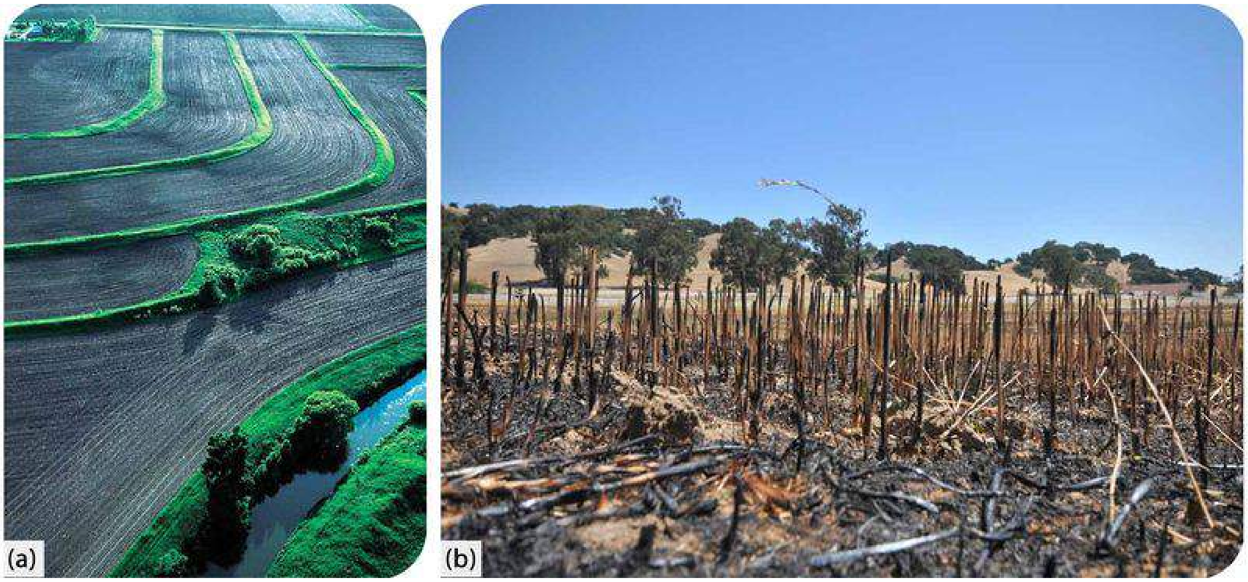


FIGURE 5.77
(a) The bare areas of farmland are especially vulnerable to erosion. (b) Slash-and-burn agriculture leaves land open for soil erosion and is one of the leading causes of soil erosion in the world.

Grazing

Grazing animals (**Figure** 5.78) wander over large areas of pasture or natural grasslands eating grasses and shrubs. Grazers expose soil by removing the plant cover for an area. They also churn up the ground with their hooves. If too many animals graze the same land area, the animals' hooves pull plants out by their roots. A land is overgrazed if too many animals are living there.

FIGURE 5.78
Grazing animals can cause erosion if they are allowed to overgraze and remove too much or all of the vegetation in a pasture.

Logging and Mining

Logging removes trees that protect the ground from soil erosion. The tree roots hold the soil together and the tree canopy protects the soil from hard falling rain. Logging results in the loss of **leaf litter**, or dead leaves, bark, and branches on the forest floor. Leaf litter plays an important role in protecting forest soils from erosion (**Figure** 5.79).

FIGURE 5.79
Logging exposes large areas of land to erosion.

Much of the world's original forests have been logged. Many of the tropical forests that remain are currently the site of logging because North America and Europe have already harvested many of their trees (**Figure** 5.80). Soils eroded from logged forests clog rivers and lakes, fill estuaries, and bury coral reefs.

Surface mining disturbs the land (**Figure** 5.81) and leaves the soil vulnerable to erosion.

Construction

Constructing buildings and roads churns up the ground and exposes soil to erosion. In some locations, native landscapes, such as forest and grassland, are cleared, exposing the surface to erosion (in some locations the land that will be built on is farmland). Near construction sites, dirt, picked up by the wind, is often in the air. Completed construction can also contribute to erosion (**Figure** 5.82).

Recreational Activities

Recreational activities may accelerate soil erosion. Off-road vehicles disturb the landscape and the area eventually develops bare spots where no plants can grow. In some delicate habitats, even hikers' boots can disturb the ground, so it's important to stay on the trail (**Figure** 5.83).

Soil erosion is as natural as any other type of erosion, but human activities have greatly accelerated soil erosion. In some locations soil erosion may occur about 10 times faster than its natural rate. Since Europeans settled in North America, about one-third of the topsoil in the area that is now the United States has eroded away.

FIGURE 5.80
Deforested swatches in Brazil show up as gray amid the bright red tropical rainforest.

FIGURE 5.81
(a) Disturbed land at a coal mine pit in Germany. (b) This coal mine in West Virginia covers more than 10,000 acres (15.6 square miles). Some of the exposed ground is being reclaimed by planting trees.

Summary

- Although soil erosion is a natural process, human activities have greatly accelerated it.
- The agents of soil erosion are the same as of other types of erosion: water, ice, wind, and gravity.
- Soil erosion is more likely where the ground has been disturbed by agriculture, grazing animals, logging, mining, construction, and recreational activities.

FIGURE 5.82
Urban areas and parking lots result in less water entering the ground. Water runs off the parking lot onto nearby lands and speeds up erosion in those areas.

FIGURE 5.83
(a) ATV'S churn up the soil, accelerating erosion. (b) Hiking trails may become eroded.

Practice

Use this resource to answer the questions that follow.

http://www.scalloway.org.uk/phye6.htm

1. What is soil erosion?
2. Where is soil erosion common?
3. How can soil erosion be reduced?
4. What are good farming techniques?
5. What are some natural causes for soil erosion?

Review

1. What is soil erosion? Why did soil erosion accelerate so greatly during the Dust Bowl?
2. How do human activities accelerate soil erosion? Since soil erosion is a natural process, is this bad?
3. What is the consequence of the acceleration of soil erosion?

5.25 Avoiding Soil Loss

- Describe steps that can be taken to minimize soil loss.

How does the terracing shown in this photo prevent soil erosion?

Terracing keeps the soil from moving very far downhill since it will only get as far as the next terrace downhill. Water will also be slowed by the terraces and so will be less able to carry tremendous amounts of soil downhill. Terracing is a great way to preserve soil when farming is being done on hillsides.

Soil Erosion

Bad farming practices and a return to normal rainfall levels after an unusually wet period led to the Dust Bowl. In some regions more than 75% of the topsoil blew away. This is the most extreme example of soil erosion the United States has ever seen.

Still, in many areas of the world, the rate of soil erosion is many times greater than the rate at which it is forming. Drought, insect plagues, or outbreaks of disease are natural cycles of events that can negatively impact ecosystems and the soil, but there are also many ways in which humans neglect or abuse this important resource. Soils can also be contaminated if too much salt accumulates in the soil or where pollutants sink into the ground.

One harmful practice is removing the vegetation that helps to hold soil in place. Sometimes just walking or riding your bike over the same place will kill the grass that normally grows there. Land is also deliberately cleared or deforested for wood. The loose soils then may be carried away by wind or running water.

Soil Conservation

Soil is only a renewable resource if it is carefully managed. There are many practices that can protect and preserve soil resources.

FIGURE 5.84
A farmer and his sons walk through a dust storm in Cimarron County, Oklahoma in 1936.

Organic Material

Adding organic material to the soil in the form of plant or animal waste, such as compost or manure, increases the fertility of the soil and improves its ability to hold on to water and nutrients (**Figure** 5.85). Inorganic fertilizer can also temporarily increase the fertility of a soil and may be less expensive or time consuming, but it does not provide the same long-term improvements as organic materials.

FIGURE 5.85
Organic material can be added to soil to help increase its fertility.

Preventing Soil Erosion

Soil is a natural resource that is vitally important for sustaining natural habitats and for growing food. Although soil is a renewable resource, it is renewed slowly, taking hundreds or thousands of years for a good fertile soil to develop.

Most of the best land for farming is already being cultivated. With human populations continuing to grow, it is extremely important to protect our soil resources. Agricultural practices such as rotating crops, alternating the types of crops planted in each row, and planting nutrient-rich cover crops all help to keep soil more fertile as it is used season after season. Planting trees as windbreaks, plowing along contours of the field, or building terraces into steeper slopes will all help to hold soil in place (**Figure** 5.86). No-till or low-tillage farming helps to keep soil in place by disturbing the ground as little as possible when planting.

FIGURE 5.86
Steep slopes can be terraced to make level planting areas and decrease surface water runoff and erosion.

The rate of topsoil loss in the United States and other developed countries has decreased recently as better farming practices have been adopted. Unfortunately, in developing nations, soil is often not protected.

Table 5.1 shows some steps that we can take to prevent erosion. Some are things that can be done by farmers or developers. Others are things that individual homeowners or community members can implement locally.

TABLE 5.1: **Erosion**

Source of Erosion	Strategies for Prevention
Agriculture	• Leave leaf litter on the ground in the winter. • Grow cover crops, special crops grown in the winter to cover the soil. • Plant tall trees around fields to buffer the effects of wind. • Drive tractors as little as possible. • Use drip irrigation that puts small amounts of water in the ground frequently. • Avoid watering crops with sprinklers that make big water drops on the ground. • Keep fields as flat as possible to avoid soil eroding down hill.

TABLE 5.1: (continued)

Source of Erosion	Strategies for Prevention
Grazing Animals	• Move animals throughout the year, so they don't consume all the vegetation in one spot. • Keep animals away from stream banks, where hills are especially prone to erosion.
Logging and Mining	• Reduce the amount of land that is logged and mined. • Reduce the number of roads that are built to access logging areas. • Avoid logging and mining on steep lands. • Cut only small areas at one time and quickly replant logged areas with new seedlings.
Development	• Reduce the amount of land area that is developed into urban areas, parking lots, etc. • Keep as much "green space" in cities as possible, such as parks or strips where plants can grow. • Invest in and use new technologies for parking lots that make them permeable to water in order to reduce runoff of water.
Recreational Activities	• Avoid using off-road vehicles on hilly lands. • Stay on designated trails.
Building Construction	• Avoid building on steep hills. • Grade surrounding land to distribute water rather than collecting it in one place. • Where water collects, drain to creeks and rivers. • Landscape with plants that minimize erosion.

Summary

- Soil is a renewable resource, but sometimes it is lost faster than it can be replaced.
- Soil resources must be preserved because there are many more people on Earth who need to eat and a great deal of topsoil has already been lost in many regions.
- There are many techniques available for preventing soil loss in agriculture, grazing, logging, mining, and recreation.
- Soil conservation is extremely important. Some helpful practices include adding organic material, terracing,

and no-till farming.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Erosion Control**

1. Describe contour farming.
2. What is terracing?
3. How does strip cropping work?
4. What is agroforestry?
5. How does tree litter help crops?

Review

1. Why is it so important for strategies that prevent soil erosion to be understood and used?
2. Which agricultural techniques are better that preserving soils?
3. How do recreational activities exacerbate soil erosion and how can this be lessened?
4. Why does the addition of organic material to soil help with its conservation?
5. What are a few agricultural practices that make conserving soil a priority?

5.26 Growth of Human Populations

- Describe the rate of current human population growth.

What will stop population growth?

It took all of human history until 1802 for the human population to reach its first billion. It took just 12 years for it to acquire its most recent billion. Although the growth rate is predicted to slow later this century, there's no end to population growth in sight. Yet, the population can't continue to grow forever. How will it stop?

Human Population Numbers

Human population growth over the past 10,000 years has been tremendous (**Figure** 5.87). The entire human population was estimated to be

- 5 million in 8000 B.C.
- 300 million in A.D. 1
- 1 billion in 1802
- 3 billion in 1961
- 7 billion in 2011

As the human population continues to grow, different factors limit population in different parts of the world. What might be a limiting factor for human population in a particular location? Space, clean air, clean water, and food to feed everyone are limiting in some locations.

An interactive map of where human population growth has been over time: http://www.pbs.org/wgbh/nova/worldbalance/numbers.html .

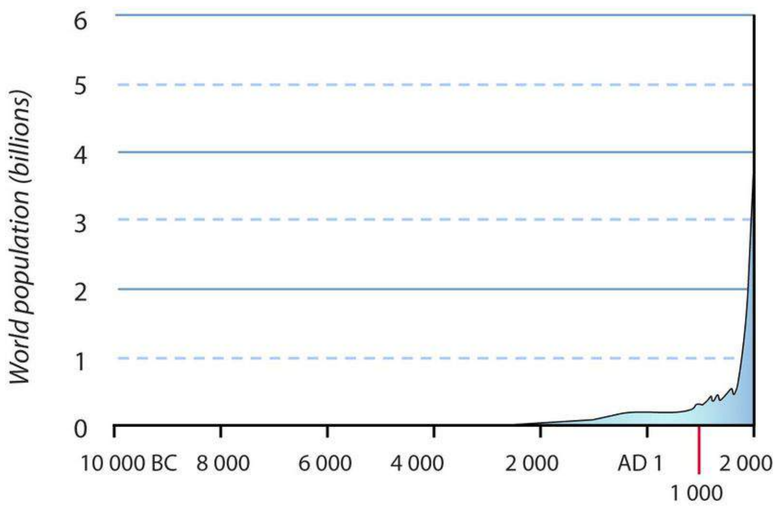


FIGURE 5.87
Human population from 10,000 BC through 2000 AD, showing the exponential increase in human population that has occurred in the last few centuries.

The Rate of Growth

Not only has the population increased, but the rate of population growth has increased (**Figure** 5.88). The population was estimated to reach 7 billion in 2012, but it did so in 2011, just 12 years after reaching 6 billion.

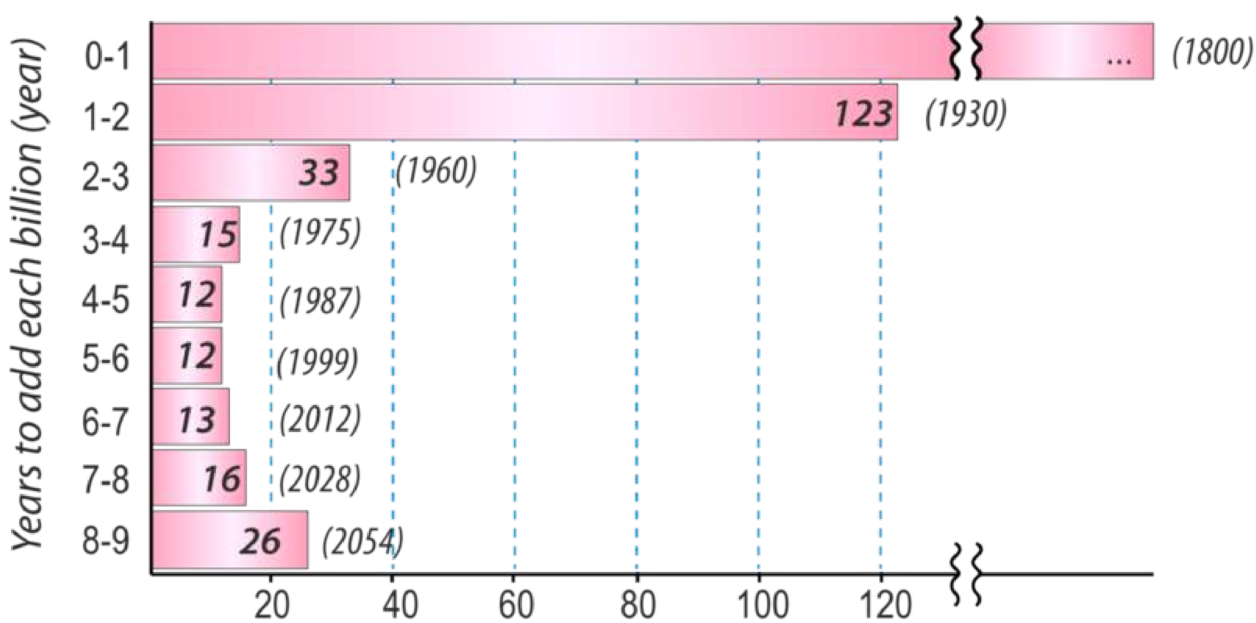


FIGURE 5.88
The amount of time between the addition of each one billion people to the planet's population, including speculation about the future.

Although population continues to grow rapidly, the rate that the growth rate is increasing has declined. Still, a recent estimate by the United Nations estimates that 10.1 billion people will be sharing this planet by the end of the century.

The total added will be about 3 billion people, which is more than were even in existence as recently as 1960.

Summary

- The human population is growing more than exponentially.
- The human population is increasing, the rate of human population growth is increasing, but the rate at which the rate of growth is increasing has declined.
- The United Nations estimates a population of 10.1 billion by the end of the century yet that is much less than the number we would expect if 1 billion people were being added every 12 years.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=sc4HxPxNrZ0

MEDIA

Click image to the left for more content.

1. What was the population in 1800?
2. What was the population in 1930?
3. What could the population be in 2045?
4. What is the average lifespan of people today?
5. What was the average lifespan of people in 1960?
6. What is a megacity?
7. How many megacities were there in 1975?
8. How many megacities are there now?
9. Explain what the world needs.
10. How much of the population lacks adequate sanitation?

Review

1. What does it mean that the human population growth rate is increasing?
2. What does it mean that the rate that the growth rate is increasing has declined?
3. What factors may someday limit human population growth?

5.27 Agriculture and Human Population Growth

- Explain how advances in agriculture have led to leaps in population numbers.

What's your vision of a chicken farm?

In many nations, farming today is industrial, growing the maximum amount of food for the minimum price, often without much thought as to the long-term social or environmental consequences. These industrial food production plants are a long way from the farms of the past.

Advances in Agriculture and Population

Every major advance in agriculture has allowed global population to increase. Early farmers could settle down to a steady food supply. Irrigation, the ability to clear large swaths of land for farming efficiently, and the development of farm machines powered by fossil fuels allowed people to grow more food and transport it to where it was needed.

Hunters and Gatherers

What is Earth's carrying capacity for humans? Are humans now exceeding Earth's carrying capacity for our species? Many anthropologists say that the carrying capacity of humans on the planet without agriculture is about 10 million (**Figure** 5.89). This population was reached about 10,000 years ago. At the time, people lived together in small bands of hunters and gatherers. Typically men hunted and fished; women gathered nuts and vegetables.

Obviously, human populations have blown past this hypothetical carrying capacity. By using our brains, our erect posture, and our hands, we have been able to manipulate our environment in ways that no other species has ever done. What have been the important developments that have allowed population to grow?

FIGURE 5.89
In a hunter-gatherer society, people relied on the resources they could find where they lived.

Farming

About 10,000 years ago, we developed the ability to grow our own food. Farming increased the yield of food plants and allowed people to have food available year round. Animals were domesticated to provide meat. With agriculture, people could settle down, so that they no longer needed to carry all their possessions (**Figure** 5.90). They could develop better farming practices and store food for when it was difficult to grow. Agriculture allowed people to settle in towns and cities.

FIGURE 5.90
More advanced farming practices allowed a single farmer to grow food for many more people.

When advanced farming practices allowed farmers to grow more food than they needed for their families (**Figure** 5.91), some people were then able to do other types of work, such as crafts or shop keeping.

FIGURE 5.91
Farming has increasingly depended on machines. Such advanced farming practices allow one farmer to feed many more people than in the past.

The Industrial Revolution

The next major stage in the growth of the human population was the **Industrial Revolution**, which started in the late 1700s (**Figure** 5.92). This major historical event marks when products were first mass-produced and when fossil fuels were first widely used for power.

FIGURE 5.92
Early in the Industrial Revolution, large numbers of people who had been freed from food production were available to work in factories.

The Green Revolution

The **Green Revolution** has allowed the addition of billions of people to the population in the past few decades. The Green Revolution has improved agricultural productivity by:

- Improving crops by selecting for traits that promote productivity; recently, genetically engineered crops have been introduced.

- Increasing the use of artificial fertilizers and chemical **pesticides**. About 23 times more fertilizer and 50 times more pesticides are used around the world than were used just 50 years ago (**Figure** 5.93).
- Agricultural machinery: plowing, tilling, fertilizing, picking, and transporting are all done by machines. About 17% of the energy used each year in the United States is for agriculture.
- Increasing access to water. Many farming regions depend on groundwater, which is not a renewable resource. Some regions will eventually run out of this water source. Currently about 70% of the world's fresh water is used for agriculture.

FIGURE 5.93
Rows of a single crop and heavy machinery are normal sights for modern day farms.

The Green Revolution has increased the productivity of farms immensely. A century ago, a single farmer produced enough food for 2.5 people, but now a farmer can feed more than 130 people. The Green Revolution is credited for feeding 1 billion people that would not otherwise have been able to live.

The Future

The flip side to this is that for the population to continue to grow, more advances in agriculture and an ever increasing supply of water will be needed. We've increased the carrying capacity for humans by our genius: growing crops, trading for needed materials, and designing ways to exploit resources that are difficult to get at, such as groundwater. And most of these resources are limited.

The question is, even though we have increased the carrying capacity of the planet, have we now exceeded it (**Figure** 5.94)? Are humans on Earth experiencing **overpopulation**?

There is not yet an answer to that question, but there are many different opinions. In the eighteenth century, Thomas Malthus predicted that human population would continue to grow until we had exhausted our resources. At that point, humans would become victims of famine, disease, or war. This has not happened, at least not yet. Some scientists think that the carrying capacity of the planet is about 1 billion people, not the 7 billion people we have today. The limiting factors have changed as our intelligence has allowed us to expand our population. Can we continue to do this indefinitely into the future?

Summary

- Hunters and gatherers lived off the land, with no agriculture, and reached a total population of no more than around 10 million.
- Farming allowed people to settle down and allowed populations to grow.

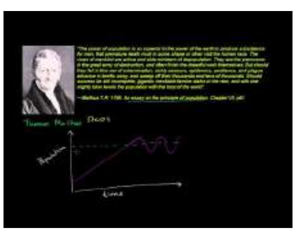
FIGURE 5.94
Manhattan is one of the most heavily populated regions in the world.

- The Green Revolution and the Industrial Revolution are heavily dependent on fossil fuels.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=r1ywppAJ1xs



MEDIA
Click image to the left for more content.

1. Who was Thomas Malthus?
2. What did Malthus think would happen as population increased?
3. What did Malthus think would limit population?
4. What is the Malthusian limit?
5. What is happening to population growth in some developed countries today?
6. Malthus didn't account for what in his theory?
7. What country is close to the Malthusian limit today?

Review

1. Link major advances in agriculture and industry with changes in the human population.

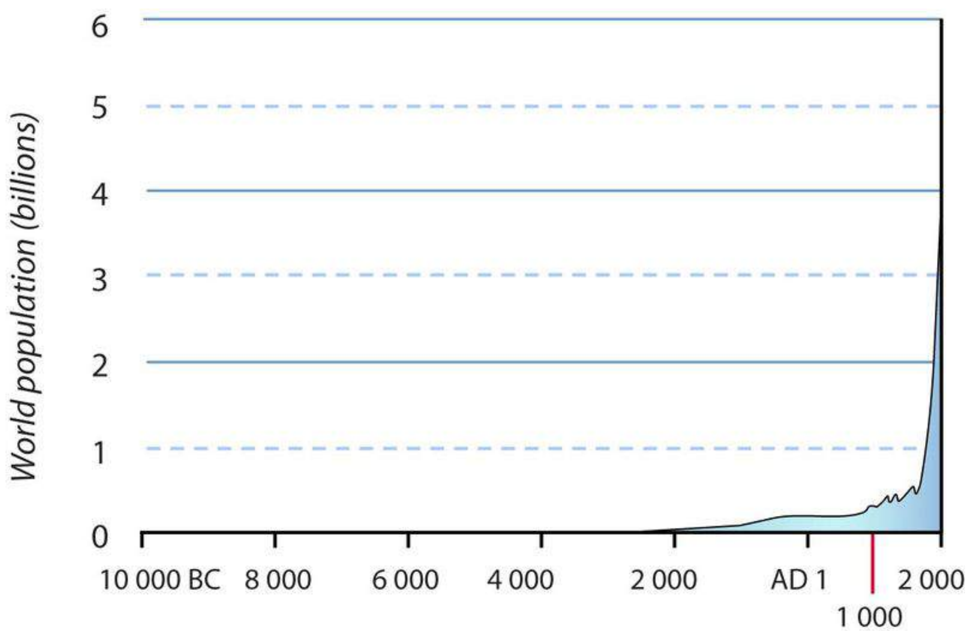
2. What is carrying capacity? Has the human population exceeded Earth's carrying capacity for humans? If so, how could this have happened?

3. What is the Green Revolution? How has it affected human population?

4. What do you think of Thomas Malthus' prediction? Have we proven Malthus wrong or have we just not gotten to that point yet?

5.28 Revolutions in Human Population Growth

- Explain what has caused the rises in human population numbers.



Where on the graph are the major population changes?

Let's look at this graph again. It shows human population from 10,000 BC through 2000 AD. Where are the big changes in slope of the line? Can you identify them? In this concept, we'll learn what causes them.

What Causes Human Populations to Grow?

Look at the graph above. Human population increased dramatically at certain times. The graph begins 10,000 BC, although you can't really see the line. Population starts to rise perceptibly at around 1800 BC. The numbers begin to rise dramatically about 200 years ago. What causes these changes?

Agricultural Revolution

Farming was developed about 10,000 years ago. Farming meant a steady supply of food. People could settle in villages. The rise at around 1800 BC is due to increased farming and the rise of cities and towns. The population rises steadily until around 1800 AD. At that time it shoots up dramatically. Really dramatically. What happened?

Industrial Revolution

The **Industrial Revolution** is what happened. The Industrial Revolution began in the late 1700s in Europe, North America, and a few other places. Before the Industrial Revolution, most labor was done by people. The Industrial Revolution changed the source of power from humans to fossil fuels. This allowed more work to be done and more food to be grown. People began to move into cities.

Where the Industrial Revolution was taking place, the human population started to grow really fast. The birth rate was always high. What changed was the death rate. The population grew because more people stayed alive. The death rate fell for several reasons:

1. New farm machines were invented. They increased the amount of food that could be produced. With more food, people were healthier and could live longer.
2. Steam engines and railroads were built. These machines could quickly carry food long distances. This made food shortages less likely.
3. Sanitation was improved. Sewers were dug to carry away human wastes (**Figure** 5.95). This helped reduce the spread of disease.

FIGURE 5.95

Digging a London sewer (1840s). Before 1800, human wastes were thrown into the streets of cities such as London. In the early 1800s, sewers were dug to carry away the wastes.

With better food and less chance of disease, the death rate fell. More children lived long enough to reach adulthood and have children of their own. As the death rate fell, the birth rate stayed high for awhile. This caused rapid population growth.

The Green Revolution

The most recent increase in the slope of the population line is because of another advance in agriculture. The **Green Revolution** began in the mid-1900s. The Green Revolution has allowed billions of people to be added to the population in the past few decades. New methods and products increased how much food could be grown. These advances include:

- Improving crops by selecting for certain genetic traits. The desired traits promote productivity. Recently, genetically engineered crops have been introduced.
- Increasing the use of artificial fertilizers and chemical **pesticides**.
- Increasing the use of agricultural machinery: plowing, tilling, fertilizing, picking, and transporting. These machines are powered by fossil fuels, rather than humans.
- Increasing access to water. Many rivers have been dammed. Wells tap into many groundwater aquifers.

The Green Revolution has increased the productivity of farms immensely. A century ago, a single farmer produced enough food for 2.5 people, but now a farmer can feed more than 130 people. The Green Revolution is credited for feeding 1 billion people that would not otherwise have been able to live.

The Health Revolution

Health care has been improving over the most recent centuries. **Vaccines** were developed that could prevent many diseases (**Figure** 5.96). **Antibiotics** were discovered that could cure most infections caused by bacteria. Together, these two advances saved countless lives.

FIGURE 5.96
This child is getting a polio vaccine. She will never get sick with polio, which could save her life or keep her from becoming crippled.

Vocabulary

- **antibiotics**: Medications that kill or slow down the growth of harmful bacteria.
- **Green Revolution**: Changes in the way food is produced since World War II that have resulted in enormous increases in production.
- **Industrial Revolution**: Time when mass production and fossil fuel use started to grow explosively.
- **pesticides**: Chemical that kills a certain pest that would otherwise eat or harm plants that humans want to grow.
- **vaccines**: Medication that increases the immune system's response to a disease.

Summary

- Farming allowed people to have a steady food source and settle down. The Green Revolution has dramatically increased agricultural productivity.
- The Industrial Revolution brought new machinery, increased the food supply, and improved sanitation.
- Vaccinations and antibiotics have greatly improved human health.
- With a dramatically lower death rate, human populations have grown.

Practice

Use the resources below to answer the questions that follow.

- **Turning Points in History - Industrial Revolution** at http://www.youtube.com/watch?v=3Efq-aNBkvc (3:31)

MEDIA
Click image to the left for more content.

1. Where did most people work in the late 1700s? Who did they work for?
2. What did the new machines do?
3. What became more affordable?
4. Why did families move? Where did they move from and to?
5. Who were the workers? Who did they work for?
6. What problems did industrialization cause?

7. Where were the worst conditions?
8. Why were unions formed?

Review

1. What caused the first rise in human population?
2. Why has the Industrial Revolution altered human population numbers?
3. How has the Green Revolution increased agricultural productivity?
4. If the birth rate doesn't change but the death rate goes down, what happens to population?

5.29 Overpopulation and Over-Consumption

- Describe the consequences of the Green Revolution on Earth's systems.
- Define over-consumption and explain its impact on Earth's systems.

How many people could live in this house?

The amount of space and resources used by each resident of this house far exceeds the average for a single person on Earth and even more for a person in a poor country in sub-Saharan Africa.

Consequences of the Green Revolution

The Green Revolution has brought enormous impacts to the planet.

Land Loss

Natural landscapes have been altered to create farmland and cities. Already, half of the ice-free lands have been converted to human uses. Estimates are that by 2030, that number will be more than 70%. Forests and other landscapes have been cleared for farming or urban areas. Rivers have been dammed and the water is transported by canals for irrigation and domestic uses. Ecologically sensitive areas have been altered: wetlands are now drained and coastlines are developed.

Pollution

Modern agricultural practices produce a lot of pollution (**Figure** 5.97). Some pesticides are toxic. Dead zones grow as fertilizers drain off farmland and introduce nutrients into lakes and coastal areas. Farm machines and vehicles used to transport crops produce air pollutants. Pollutants enter the air, water, or are spilled onto the land. Moreover, many types of pollution easily move between air, water, and land. As a result, no location or organism —not even polar bears in the remote Arctic —is free from pollution.

FIGURE 5.97
Pesticides are hazardous in large quantities and some are toxic in small quantities.

Consequences for Other Resources

The increased numbers of people have other impacts on the planet. Humans do not just need food. They also need clean water, secure shelter, and a safe place for their wastes. These needs are met to different degrees in different nations and among different socioeconomic classes of people. For example, about 1.2 billion of the world's people do not have enough clean water for drinking and washing each day (**Figure** 5.98).

Over-Consumption

The addition of more people has not just resulted in more poor people. A large percentage of people expect much more than to have their basic needs met. For about one-quarter of people there is an abundance of food, plenty of water, and a secure home. Comfortable temperatures are made possible by heating and cooling systems, rapid transportation is available by motor vehicles or a well-developed public transportation system, instant communication takes place by phones and email, and many other luxuries are available that were not even dreamed of only a few

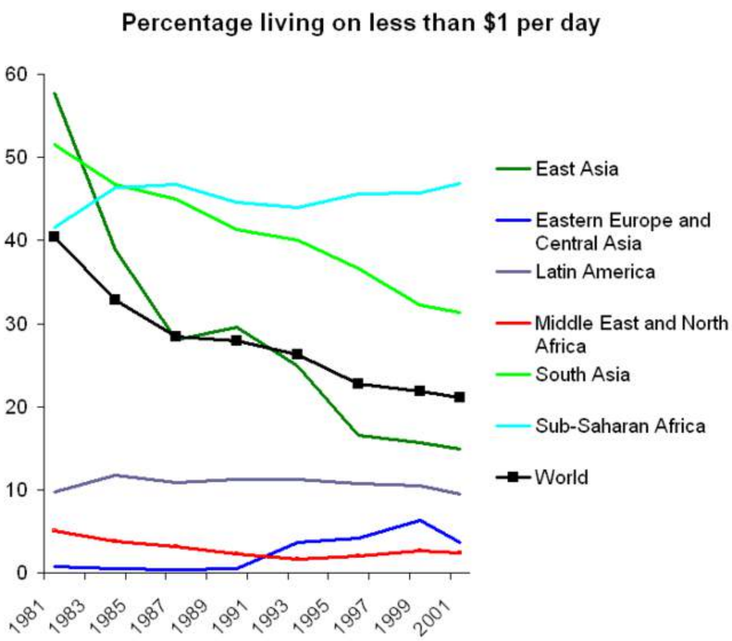


FIGURE 5.98
The percentage of people in the world that live in abject poverty is decreasing somewhat globally, but increasing in some regions, such as Sub-Saharan Africa.

decades ago. All of these require resources in order to be produced, and fossil fuels in order to be powered (**Figure** 5.99). Their production, use, and disposal all produce wastes.

Many people refer to the abundance of luxury items in these people's lives as **over-consumption**. People in developed nations use 32 times more resources than people in the developing countries of the world.

Summary

- The Green Revolution has allowed more people to be fed and the human population to increase. The consequences are land loss, pollution, and a tremendous use of fossil fuels.
- By keeping more people alive, the Green Revolution has put a strain on other needed resources like water and materials.
- Overpopulation is a big problem, but over-consumption is also depleting Earth's resources as some people in the world use far more materials than others.

Practice

Use these resources to answer the questions that follow.

http://www.nationalgeographic.com/eye/ozone/ozone.html

1. What happened in London in 1952?

2. What are the air pollutants?

3. What problems does acid rain cause?

4. How much of the emissions come from transportation?

5. What is ozone?

6. What is affecting the ozone?

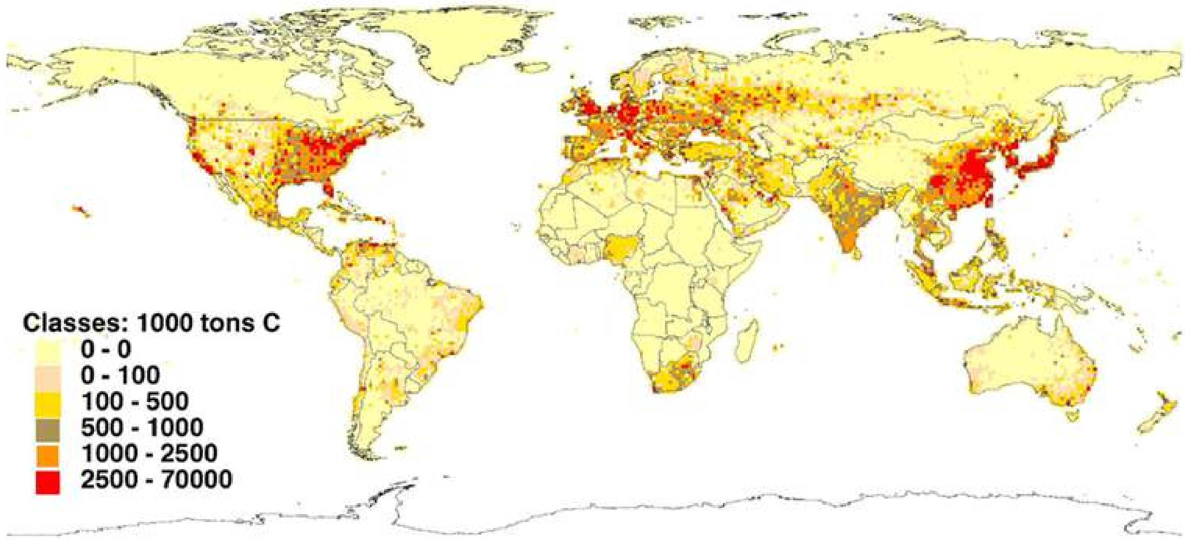


FIGURE 5.99
Since CO_2 is a waste product from fossil fuel burning, CO_2 emissions tell which countries are using the most fossil fuels, which means that the population has a high standard of living.

http://www.nationalgeographic.com/eye/deforestation/deforestation.html

7. How much of the Earth's forests have been destroyed?

8. Why might deforestation have devastating effects globally?

9. What is the Sahel and what happened to it?

10. Why is desertification called a runaway phenomenon?

11. What are the solutions for deforestation and desertification?

http://www.nationalgeographic.com/eye/overpopulation/overpopulation.html

12. Which areas have the highest population growth?

13. Why does the United States have positive population growth?

14. What has happened to population in Asia and Africa since 1960?

15. What can be done to help with the population growth?

Review

1. Why has so much natural land been converted to human uses? What happens to the ecosystems that are affected?

2. What causes pollution and why is it so widespread?

3. What do you use in your daily life that would be inconceivable for a poor teenager in sub-Saharan Africa? What about contrasting yourself with a poor teen living in an urban ghetto in the U.S.?

5.30 Sustainable Development

- Define sustainable development.
- Describe forms of sustainable development and explain how they conserve energy and natural resources.

Is there another way?

Visibility in Beijing is sometimes so bad that the airport must be closed due to smog. In their rush to develop, many nations are making the same mistakes that the developed nations have already made. Can everyone find a more sustainable path?

Sustainable Development

FIGURE 5.100

A topic generating a great deal of discussion these days is **sustainable development**. The goals of sustainable development are to:

- help people out of poverty.
- protect the environment.
- use resources no faster than the rate at which they are regenerated.

One of the most important steps to achieving a more sustainable future is to reduce human population growth. This has been happening in recent years. Studies have shown that the birth rate decreases as women become educated, because educated women tend to have fewer, and healthier, children.

Science can be an important part of sustainable development. When scientists understand how Earth's natural systems work, they can recognize how people are impacting them. Scientists can work to develop technologies that can be used to solve problems wisely. An example of a practice that can aid sustainable development is fish farming, as long as it is done in environmentally sound ways. Engineers can develop cleaner energy sources to reduce pollution and greenhouse gas emissions.

Citizens can change their behavior to reduce the impact they have on the planet by demanding products that are produced sustainably. When forests are logged, new trees should be planted. Mining should be done so that the landscape is not destroyed. People can consume less and think more about the impacts of what they do consume.

And what of the waste products of society? Will producing all that we need to keep the population growing result in a planet so polluted that the quality of life will be greatly diminished? Will warming temperatures cause problems for human populations? The only answer to all of these questions is, time will tell.

Summary

- Sustainable development tries to bring people up to certain minimum living conditions without doing further damage to the environment.
- To develop sustainably, the human population must stabilize.
- Resources must be developed and used consciously and in environmentally sound ways.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=eEFwaQej_0E

MEDIA
Click image to the left for more content.

1. Explain sustainable development.
2. How can we achieve sustainable development?
3. What are renewable energy sources?
4. What are fossil fuels?
5. Why didn't the United States sign the Kyoto treaty?
6. List examples of renewable energy sources.
7. What can we do to reduce our carbon footprint?

8, How can we reduce the demand for fossil fuels?

Review

1. Why does the status of women help decrease population growth?

2. What is sustainable development? Do you think that it be achieved in your lifetime?

3. How can environmental protections be enacted and people be helped out of poverty at the same time? Are those goals conflicting?

5.31 References

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CHAPTER 6 Oceanography

Chapter Outline

6.1 Landforms from Wave Erosion and Deposition

- Describe how waves erode and deposit sediments.

How is surfing like erosion?

Have you ever surfed or even body surfed? Have you felt a wave crash onto your body and then try to drag you offshore? Surfers use the power of waves for a wild ride. But that power can also be used to create landforms along a shoreline.

Wave Erosion

Wave energy does the work of erosion at the shore. Waves approach the shore at some angle so the inshore part of the wave reaches shallow water sooner than the part that is further out. The shallow part of the wave "feels" the bottom first. This slows down the inshore part of the wave and makes the wave "bend." This bending is called **refraction**.

- In this animation, notice how the wave refracts as it comes into the beach. http://www.grossmont.edu/garyjacobson/Oceanography%20112/Wave%20Model.htm

Wave refraction either concentrates wave energy or disperses it. In quiet water areas, such as bays, wave energy is dispersed, so sand is deposited. Areas that stick out into the water are eroded by the strong wave energy that concentrates its power on the **wave-cut cliff** (**Figure** 6.1).

Other features of wave erosion are pictured and named in **Figure** 6.2. A **wave-cut platform** is the level area formed by wave erosion as the waves undercut a cliff. An **arch** is produced when waves erode through a cliff. When a sea arch collapses, the isolated towers of rocks that remain are known as **sea stacks**.

Wave Deposition

Rivers carry sediments from the land to the sea. If wave action is high, a delta will not form. Waves will spread the sediments along the coastline to create a **beach**. Waves also erode sediments from cliffs and shorelines and transport

FIGURE 6.1

These colorful cliffs on Martha's Vineyard are eroded by wave action. Note that the topsoil and vegetation at the top of the cliff are undercut by the falling sand and clay beneath.

FIGURE 6.2

(a) The high ground is a large wave-cut platform formed from years of wave erosion. (b) A cliff eroded from two sides produces an arch. (c) The top of an arch erodes away, leaving behind a tall sea stack.

them onto beaches. Beaches can be made of mineral grains like quartz, rock fragments, and also pieces of shell or coral (**Figure** 6.3).

Waves continually move sand along the shore. Waves also move sand from the beaches on shore to bars of sand offshore as the seasons change. In the summer, waves have lower energy so they bring sand up onto the beach. In the winter, higher energy waves bring the sand back offshore.

Some of the features formed by wave-deposited sand are in **Figure** 6.4. These features include barrier islands and spits. A **spit** is sand connected to land and extending into the water. A spit may hook to form a tombolo.

Shores that are relatively flat and gently sloping may be lined with long, narrow **barrier islands** (**Figure** 6.5). Most barrier islands are a few kilometers wide and tens of kilometers long.

In its natural state, a barrier island acts as the first line of defense against storms such as hurricanes. When barrier islands are urbanized, hurricanes damage houses and businesses rather than vegetated sandy areas in which sand can move. A large hurricane brings massive problems to the urbanized area.

FIGURE 6.3
Quartz, rock fragments, and shell make up the sand along a beach.

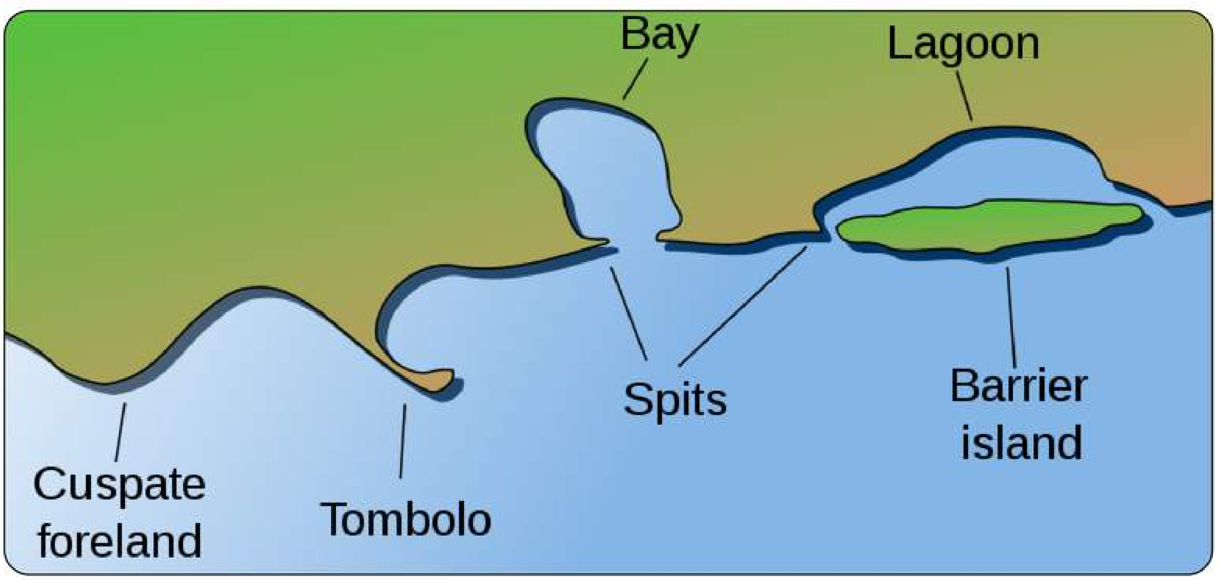


FIGURE 6.4
Examples of features formed by wave-deposited sand.

Protecting Shorelines

Intact shore areas protect inland areas from storms that come off the ocean. Where the natural landscape is altered or the amount of development makes damage from a storm too costly to consider, people use several types of structures to attempt to slow down wave erosion. A few are pictured below (**Figure** 6.6). A **groin** is a long, narrow pile of rocks built perpendicular to the shoreline to keep sand at that beach. A **breakwater** is a structure built in the water

FIGURE 6.5
Much of North Carolina's coast is protected by barrier islands that enclose Pamlico Sound. The thin white strips on the outer edges of the islands are beach sand.

parallel to the shore in order to protect the shore from strong incoming waves. A **seawall** is also parallel to the shore, but it is built onshore.

FIGURE 6.6
(a) Groins trap sand on the up-current side so then people down current build groins to trap sand too. (b) Breakwaters are visible in this satellite image parallel to the shoreline. (c) Seawalls are similar to breakwaters except built onshore. Extremely large storm waves may destroy the sea wall, leaving the area unprotected.

People do not always want to choose safe building practices, and instead choose to build a beach house right on the beach. Protecting development from wave erosion is difficult and expensive.

Protection does not always work. The northeastern coast of Japan was protected by anti-tsunami seawalls. Yet waves from the 2011 tsunami that resulted from the Tohoku earthquake washed over the top of some seawalls and caused others to collapse. Japan is now planning to build even higher seawalls to prepare for any future (and inevitable) tsunami.

Summary

- Ocean waves have a tremendous amount of energy and so they may do a great deal of erosion. Some landforms created by erosion are platforms, arches, and sea stacks.

- Transported sand will eventually be deposited on beaches, spits, or barrier islands.
- People love the shore, so they develop these regions and then must build groins, breakwaters, and seawalls to protect them.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What are the two methods to stop coastal erosion?
2. What is a sea wall?
3. What is a jetty?
4. What is a groynes?
5. What are breakwaters?
6. Why don't people like most of the methods to prevent coastal erosion?
7. What is beach nourishment?
8. What problems does beach nourishment cause?

Review

1. Describe how a set of waves erodes a rocky headland.
2. What processes cause spits and barrier islands to form?
3. How do barrier islands and mangroves protect beaches? What happens when these natural barriers are destroyed?

6.2 Protecting Shorelines

- Describe the barriers humans construct to protect beaches.

Why do you see man-made structures on some beaches?

When you go to a beach, you may see man-made structures like these. Most attempt to keep the sand where people want the sand to be. A smaller number keep the sand from coming into an area where it is not wanted.

Protecting Shorelines

Shores are attractive places to live and vacation. But development at the shore is at risk of damage from waves. Wave erosion threatens many homes and beaches on the ocean. This is especially true during storms, when waves may be much larger than normal. People build several types of structures to protect beaches.

Breakwaters

Barrier islands provide natural protection to shorelines. Storm waves strike the barrier island before they reach the shore. People also build artificial barriers, called **breakwaters**. Breakwaters also protect the shoreline from incoming waves. The breakwater pictured below (**Figure** 6.7) runs parallel to the coast like a barrier island.

Groins

Longshore drift can erode the sediment from a beach. To keep this from happening, people may build a series of groins. A **groin** (**Figure** 6.8) is wall of rocks or concrete. The structure juts out into the ocean perpendicular to the shore. A groin stops the longshore movement of sand. Sand collects on the up-current side of the groin. Sand on opposite of side of the groin erodes. This reduces beach erosion.

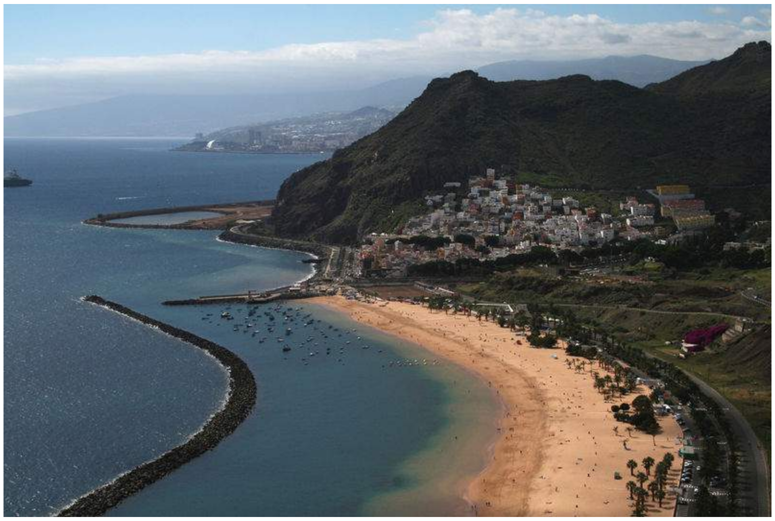


FIGURE 6.7
This rocky breakwater protects the beach at Tenerife in the Canary Islands, Spain.

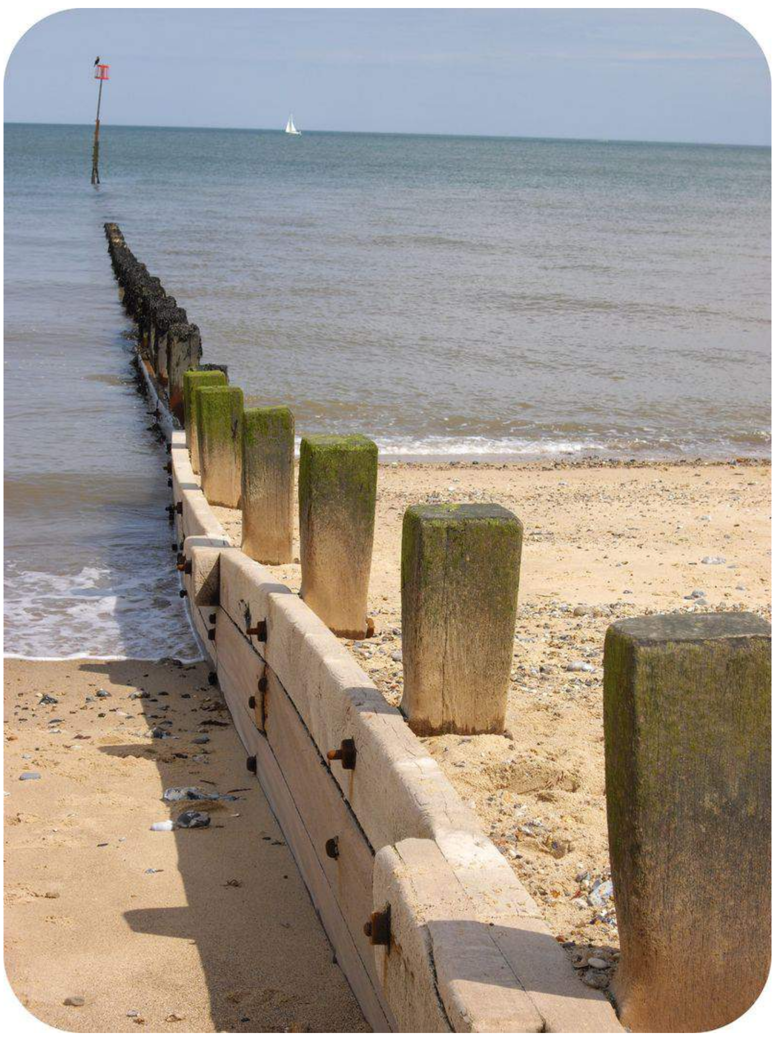


FIGURE 6.8
This groin slows sand on the up-current side. Can you determine which way the water is moving based on where the sand is collecting?

Seawalls

A seawall is also parallel to the shore. However, a seawall is built onshore. **Seawalls** (**Figure** 6.9) protect the shore from incoming waves.

FIGURE 6.9
This seawall protects a shore in Vancouver.

Does Protection Work?

People do not always want to choose safe building practices, and instead choose to build a beach house right on the beach. Protecting development from wave erosion is difficult and expensive.

Protection does not always work. The northeastern coast of Japan was protected by anti-tsunami seawalls. Yet waves from the 2011 tsunami that resulted from the Tōhoku earthquake washed over the top of some seawalls and caused others to collapse. Japan is now planning to build even higher seawalls to prepare for any future (and inevitable) tsunami.

Vocabulary

- **breakwater**: Structure built in the water parallel to the shore to protect from strong incoming waves.
- **groin**: Long, narrow piles of stone or timbers built perpendicular to the shore; a groin will trap sand.
- **seawall**: Structure built parallel to the shore on the beach to protect against strong waves.

Summary

- People love the shore, so they develop these regions and then must protect them.
- Seawalls and breakwaters are built parallel to the shore.
- Groins are built perpendicular to the shore. They trap sand.

Practice

Use the resource below to answer the questions that follow.

- **Methods Used to Slow Down Coastal Erosion** at http://www.youtube.com/watch?v=nujYG_b8lI8 (1:52)

MEDIA

Click image to the left for more content.

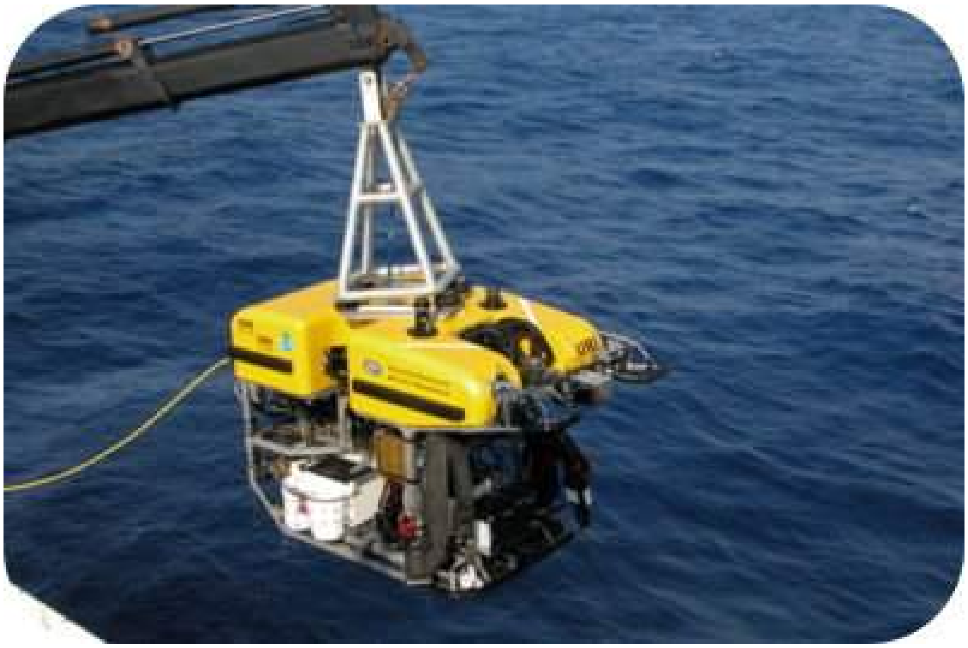
1. What are the two methods to slow down coastal erosion?
2. What is a sea wall? What does it protect the shore from?
3. What is a jetty? What does it protect the shore from?
4. What is a groin? What does it protect the shore from?
5. What are breakwaters? What do they protect the shore from?
6. Why don't people like most of the methods to prevent coastal erosion?
7. What is beach nourishment?
8. What problems does beach nourishment cause?

Review

1. How does a groin protect a beach?
2. How does a seawall protect a beach?
3. How does a breakwater protect a beach?
4. What are the downsides of protecting beaches with engineering solutions?

6.3 Seafloor

- Describe ways scientists learn about the deep ocean.



Is it true that we know more about the dark side of the Moon than we do about the oceans?

It's true! Why do you think so? The oceans are deep, dark, frigid, and under extraordinarily high pressure at all but the surface. It's hard to imagine an environment that's less hospitable to human life! Yet, as you will see, we know quite a bit about the oceans and this is due mostly to technology. Rovers, like the one pictured, allow scientists to go to places that are too inhospitable or dangerous for human life.

Studying the Seafloor

Scuba divers can only dive to about 40 meters, and they cannot stay down there for very long. Although this is good for researching the organisms and ecosystems very near a coast, most oceanic research requires accessing greater depths.

Seafloor Bathymetry

How do scientists create bathymetric maps like the one of Loihi volcano in Hawaii shown in the concept "Maps"? Early explorers mapped a small amount of the seafloor by painstakingly dropping a line over the side of a ship to measure the depth at one tiny spot at a time. Then, during World War II, battleships and submarines carried **echo sounders** to locate enemy submarines (**Figure** 6.10). Echo sounders produce sound waves that travel outward in all directions, bounce off the nearest object, and then return to the ship. By knowing the speed of sound in seawater, scientists calculate the distance to the object based on the time it takes for the wave to make a round trip.

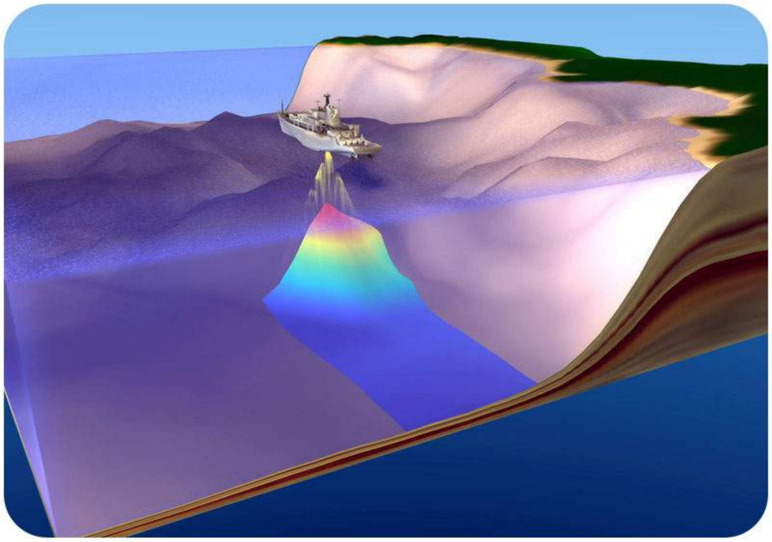


FIGURE 6.10
This echo sounder has many beams and creates a three dimensional map of the seafloor. Early echo sounders had a single beam and created a line of depth measurements.Echo sounders now have many beams to get a more detailed and more rapid picture of the seafloor.

Sampling Remotely

Samples of seawater from different depths in the water column are needed to understand ocean chemistry. To do this, bottles are placed along a cable at regular depths and closed as a weight is dropped down the cable. The water trapped in the bottle can be analyzed later in a laboratory (**Figure** 6.11).

Scientists are also interested in collecting rock and sediment samples from the seafloor. A dredge is a giant rectangular bucket that is dragged along behind a ship to collect loose rocks. Gravity corers are metal tubes that fall to the seafloor and slice into the sediments to collect a sample. The research vessel, the *Joides Resolution*, drills deep into the seafloor to collect samples of the sediment and ocean crust. Scientists analyze the samples for chemistry and paleomagnetism.

Submersibles

Samples of seawater and rocks can be collected directly by scientists in a **submersible**. These subs can take scientists down to make observations. The subs have arms for collecting samples. The human operated vehicle Alvin can dive up to 4,500 m beneath the ocean surface and has made more than 4,400 dives since 1964 (**Figure** 6.12).

Remotely Operated Vehicles

To avoid the expense, dangers, and limitations of human missions under the sea, **remotely operated vehicles**, or ROVs, allow scientists to study the ocean's depths by using small vehicles carrying cameras and scientific instruments. ROVs were used to study the *Titanic*, which would have been far too dangerous for a manned sub to enter. Scientists control ROVs electronically with sophisticated operating systems.

Footage of the NOAA *Titanic* Expedition of 2004 is visible in this video: http://www.youtube.com/watch?v=6Z7REEnwKOQ .

Summary

- Most of the ocean is less well known than the dark side of the Moon because it is inhospitable and inaccessible.
- Echo sounders use sound waves to make bathymetric maps.

FIGURE 6.11
A Niskin bottle being deployed off the side of a research ship.

- Submersibles and ROVs allow scientists to view otherwise inhospitable regions either directly or remotely.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is the only truly uncharted area of Earth?
2. How were soundings taken in the past?
3. List the advantages of using multi-beam sonar.
4. How is texture captured?
5. What is groundtruthing and why is it necessary?
6. Why is this project important?

FIGURE 6.12
Alvin allows two people and a pilot to make a nine hour dive.

Review

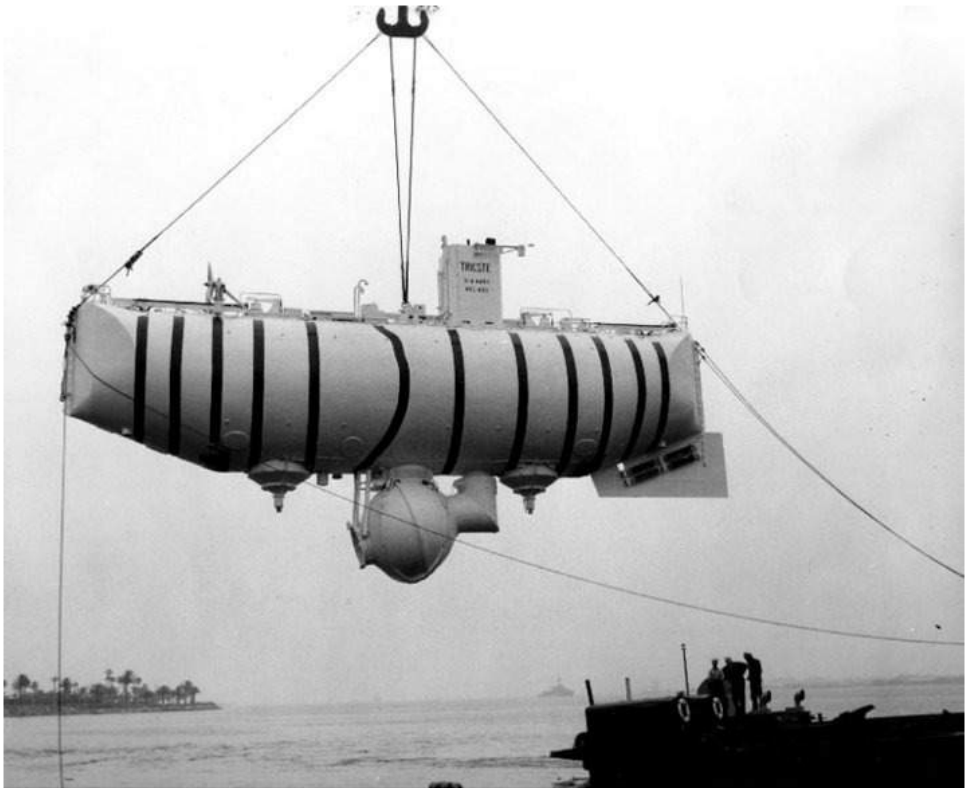
1. How does an echo sounder work?

2. Why is an ROV better for some tasks than a submersible? Why is a submersible better for some tasks than an ROV?

3. How do marine geologists collect rock and sediment samples?

6.4 Ocean Zones

- Identify and describe the vertical and horizontal ocean zones.



There's a trench in the bottom of the sea. Would you like to visit it?

In 1960, two men in a specially designed submarine called the Trieste descended into a submarine trench called the Challenger Deep (10,910 meters). The depth of this dive remains a record. No craft exists today that can reach that depth. Would you like to go to the bottom of the ocean in that vessel?

Divisions of the Ocean

Oceanographers divide the ocean into zones both vertically and horizontally.

Vertical Divisions

To better understand regions of the ocean, scientists define the **water column** by depth. They divide the entire ocean into two zones vertically, based on light level. Large lakes are divided into similar regions.

- Sunlight only penetrates the sea surface to a depth of about 200 m, creating the **photic zone** ("photic" means light). Organisms that photosynthesize depend on sunlight for food and so are restricted to the photic zone. Since tiny photosynthetic organisms, known as phytoplankton, supply nearly all of the energy and nutrients to the rest of the marine food web, most other marine organisms live in or at least visit the photic zone.

- In the **aphotic zone** there is not enough light for photosynthesis. The aphotic zone makes up the majority of the ocean, but has a relatively small amount of its life, both in diversity of type and in numbers. The aphotic zone is subdivided based on depth (**Figure** 6.13).

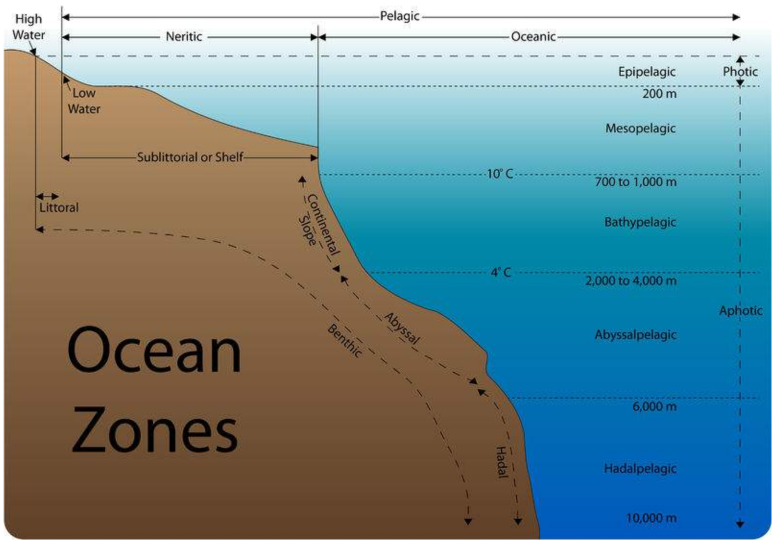


FIGURE 6.13
Vertical and horizontal ocean zones.

The average depth of the ocean is 3,790 m, a lot more shallow than the deep trenches but still an incredible depth for sea creatures to live in. What makes it so hard to live at the bottom of the ocean? The three major factors that make the deep ocean hard to inhabit are the absence of light, low temperature, and extremely high pressure.

Horizontal Divisions

The seabed is divided into the zones described above, but ocean itself is also divided horizontally by distance from the shore.

- Nearest to the shore lies the **intertidal zone** (also called the littoral zone), the region between the high and low tidal marks. The hallmark of the intertidal is change: water is in constant motion in the form of waves, tides, and currents. The land is sometimes under water and sometimes exposed.
- The **neritic zone** is from low tide mark and slopes gradually downward to the edge of the seaward side of the continental shelf. Some sunlight penetrates to the seabed here.
- The **oceanic zone** is the entire rest of the ocean from the bottom edge of the neritic zone, where sunlight does not reach the bottom. The sea bed and water column are subdivided further, as seen in the **Figure** 6.13.

Summary

- The most important vertical distinction in the oceans is between the small surface zone that has light, the photic zone, and the entire rest of the ocean without light, the aphotic zone.
- The ocean is divided into horizontal zones based on the depth of water beneath: the intertidal, neritic, and oceanic.
- Why does most of the life in the oceans live in or at least visit the surface?

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

The Layers of the Ocean: http://www.youtube.com/watch?v=UEh9cx-b8Og

MEDIA
Click image to the left for more content.

1. Where can 90% of the of the ocean's life be found?
2. What is the twilight zone?
3. What is the dark zone?
4. Why is little life found in the dark zone?
5. What is the abyss?
6. What are trenches?

Review

1. Why is there so little life at the bottom of the ocean?
2. Compare and contrast the intertidal, neritic, and oceanic zones.
3. Do you think that the line between the photic and aphotic zones is solid and that life is either in one or the other, or do you think the divisions are more gradational? Why?

6.5 Wind Waves

- Describe the characteristics of ocean waves.
- Explain how wind forms ocean waves.

If ocean waves are caused by wind, how can there be strong waves on calm days?

Waves form where there are winds. Energy from the wind is transferred to the water and then that is transferred to nearby water molecules. The wave moves as a transfer of energy across the sea. Once the wave starts, it doesn't need more wind to keep it going.

Ocean Waves

Waves have been discussed in previous concepts in several contexts: seismic waves traveling through the planet, sound waves traveling through seawater, and ocean waves eroding beaches. Waves transfer energy, and the size of a wave and the distance it travels depends on the amount of energy that it carries. This concept studies the most familiar waves, those on the ocean's surface.

Building Big Waves

Ocean waves originate from wind blowing –steady winds or high storm winds –over the water. Sometimes these winds are far from where the ocean waves are seen. What factors create the largest ocean waves?

The largest wind waves form when the wind

- is very strong
- blows steadily for a long time
- blows over a long distance

The wind could be strong, but if it gusts for just a short time, large waves won't form.

Wind blowing across the water transfers energy to that water. The energy first creates tiny ripples, which make an uneven surface for the wind to catch so that it may create larger waves. These waves travel across the ocean out of the area where the wind is blowing.

Remember that a wave is a transfer of energy. Do you think the same molecules of water that start out in a wave in the middle of the ocean later arrive at the shore? The molecules are not the same, but the energy is transferred across the ocean.

Shape of a Wave

Water molecules in waves make circles or ellipses (**Figure** 6.14). Energy transfers between molecules, but the molecules themselves mostly bob up and down in place.

In this animation, a water bottle bobs in place like a water molecule: http://www.onr.navy.mil/Focus/ocean/motion/waves1.htm .

An animation of motion in wind waves from the Scripps Institution of Oceanography: http://earthguide.ucsd.edu/earthguide/diagrams/waves/swf/wave_wind.html .

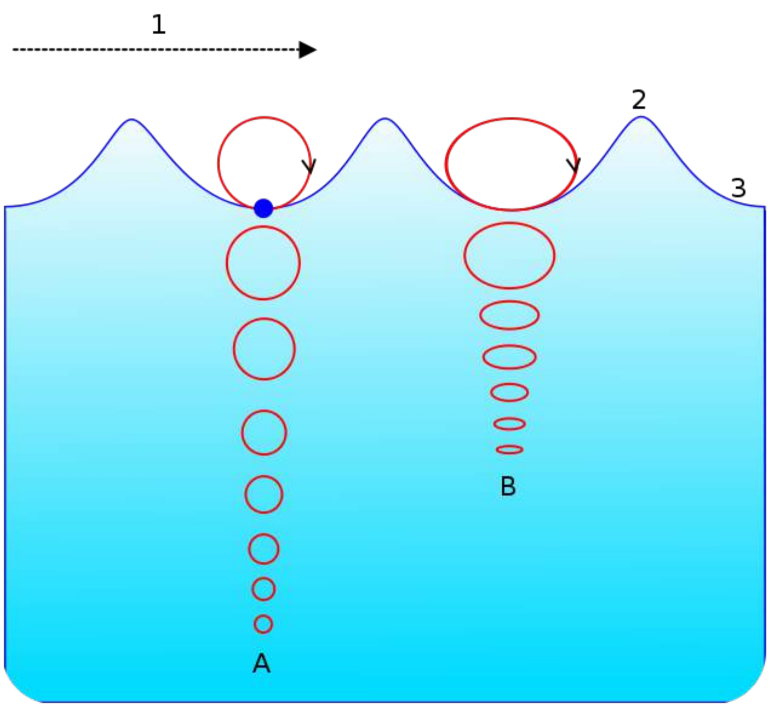


FIGURE 6.14
The circles show the motion of a water molecule in a wind wave. Wave energy is greatest at the surface and decreases with depth. "A" shows that a water molecule travels in a circular motion in deep water. "B" shows that molecules in shallow water travel in an elliptical path because of the ocean bottom.

An animation of a deep water wave is seen here: http://en.wikipedia.org/wiki/File:Deep_water_wave.gif .

An animation of a shallow water wave is seen here: http://commons.wikimedia.org/wiki/File:Shallow_water_wave.gif .

Waves Break

When does a wave break? Do waves only break when they reach shore? Waves break when they become too tall to be supported by their base. This can happen at sea but happens predictably as a wave moves up a shore. The energy at the bottom of the wave is lost by friction with the ground, so that the bottom of the wave slows down but the top of the wave continues at the same speed. The crest falls over and crashes down.

Storm Surge

Some of the damage done by storms is from **storm surge**. Water piles up at a shoreline as storm winds push waves into the coast. Storm surge may raise sea level as much as 7.5 m (25 ft), which can be devastating in a shallow land area when winds, waves, and rain are intense.

A wild video of "Storm Surge" can be seen on National Geographic Videos, Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/ .

Maverick waves are massive. Learning how they are generated can tell scientists a great deal about how the ocean creates waves and especially large waves.

Learn more by watching this video at http://www.kqed.org/quest/television/science-of-big-waves.

MEDIA
Click image to the left for more content.

Summary

- The largest wind waves are built when a strong wind blows for a long time over a large area.
- When a wave breaks onshore it is not the water but the energy that has traveled from where the wave formed.
- A wave breaks when it is too tall to be supported by its base, which is common as a wave moves up the shore.

Practice

Use these resources to answer the questions that follow.

http://www.ehow.com/video_4908368_causes-waves_.html

MEDIA
Click image to the left for more content.

1. What can cause waves?

2. What three factors effect the size and strength of waves?

3. How can large waves be created?

http://www.youtube.com/watch?v=ouoodQg3XD0

MEDIA

Click image to the left for more content.

4. What causes the overturning of wave?

Review

1. Do waves break in the oceans or do waves only break when they reach shore?

2. When a hurricane reaches land, the damage done to coastal development often depends on how high the tide is. Why would this make a difference?

3. Describe how a wave that forms in the central Pacific travels to and breaks at the beach in San Diego, California.

6.6 Surface Ocean Currents

- Define major and local surface currents.
- Explain how major and local surface currents are created.

Why is so much trash so far from land?

The Great Pacific Garbage Patch is a region in the center of the north Pacific Ocean where plastic bits and chemicals are concentrated. Trash from the countries bordering the region enters the oceans and is transported into the center of the North Pacific Gyre, where it remains. Seabirds may get sick from ingesting so much plastic instead of food. More about the patch can be found in the chapter Human Impacts on Earth's Systems.

Surface Currents

Ocean water moves in predictable ways along the ocean surface. **Surface currents** can flow for thousands of kilometers and can reach depths of hundreds of meters. These surface currents do not depend on weather; they remain unchanged even in large storms because they depend on factors that do not change.

Surface currents are created by three things:

- global wind patterns
- the rotation of the Earth
- the shape of the ocean basins

Surface currents are extremely important because they distribute heat around the planet and are a major factor influencing climate around the globe.

Global Wind Patterns

Winds on Earth are either global or local. Global winds blow in the same directions all the time and are related to the unequal heating of Earth by the Sun —that is, more solar radiation strikes the Equator than the polar regions —and the rotation of the Earth —that is, the **Coriolis effect**. Coriolis was described in the chapter Earth as a Planet. The causes of the global wind patterns will be described in detail in the chapter Atmospheric Processes.

Water in the surface currents is pushed in the direction of the major wind belts:

- trade winds: east to west between the Equator and 30^oN and 30^oS
- westerlies: west to east in the middle latitudes
- polar easterlies: east to west between 50^o and 60^o north and south of the Equator and the north and south pole

Shape of the Ocean Basins

When a surface current collides with land, the current must change direction. In the **Figure** 6.15, the Atlantic South Equatorial Current travels westward along the Equator until it reaches South America. At Brazil, some of it goes north and some goes south. Because of Coriolis effect, the water goes right in the Northern Hemisphere and left in the Southern Hemisphere.

Gyres

You can see on the map of the major surface ocean currents that the surface ocean currents create loops called **gyres** (**Figure** 6.16). The Antarctic Circumpolar Current is unique because it travels uninhibited around the globe. Why is it the only current to go all the way around?

This video shows the surface ocean currents set by global wind belts: http://www.youtube.com/watch?v=Hu_Ga0JYFNg (1:20).

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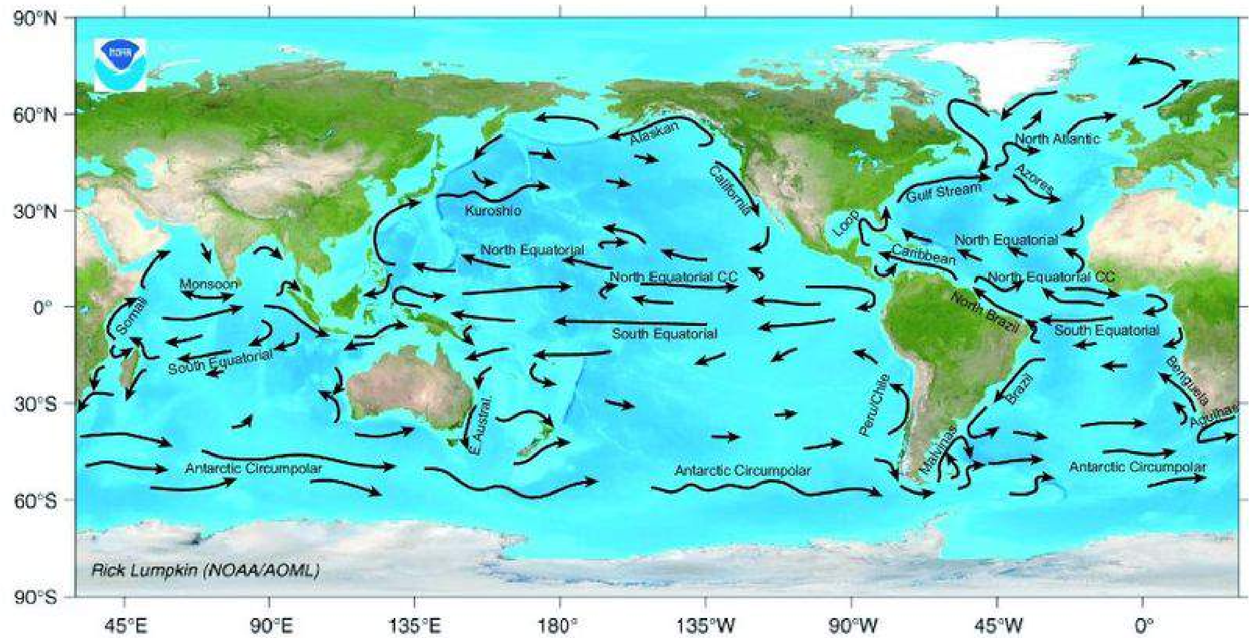

FIGURE 6.15

The major surface ocean currents.

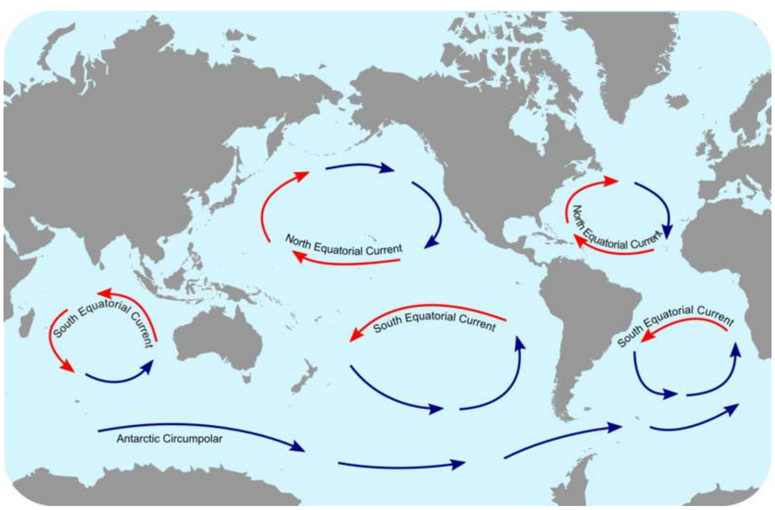

FIGURE 6.16

The ocean gyres. Why do the Northern Hemisphere gyres rotate clockwise and the Southern Hemisphere gyres rotate counterclockwise?

Local Surface Currents

The surface currents described above are all large and unchanging. Local surface currents are also found along shorelines (**Figure** 6.17). Two are **longshore currents** and **rip currents**.

Rip currents are potentially dangerous currents that carry large amounts of water offshore quickly. Look at the rip-current animation to determine what to do if you are caught in a rip current: http://www.onr.navy.mil/Focus/ocean/motion/currents2.htm . Each summer in the United States at least a few people die when they are caught in rip

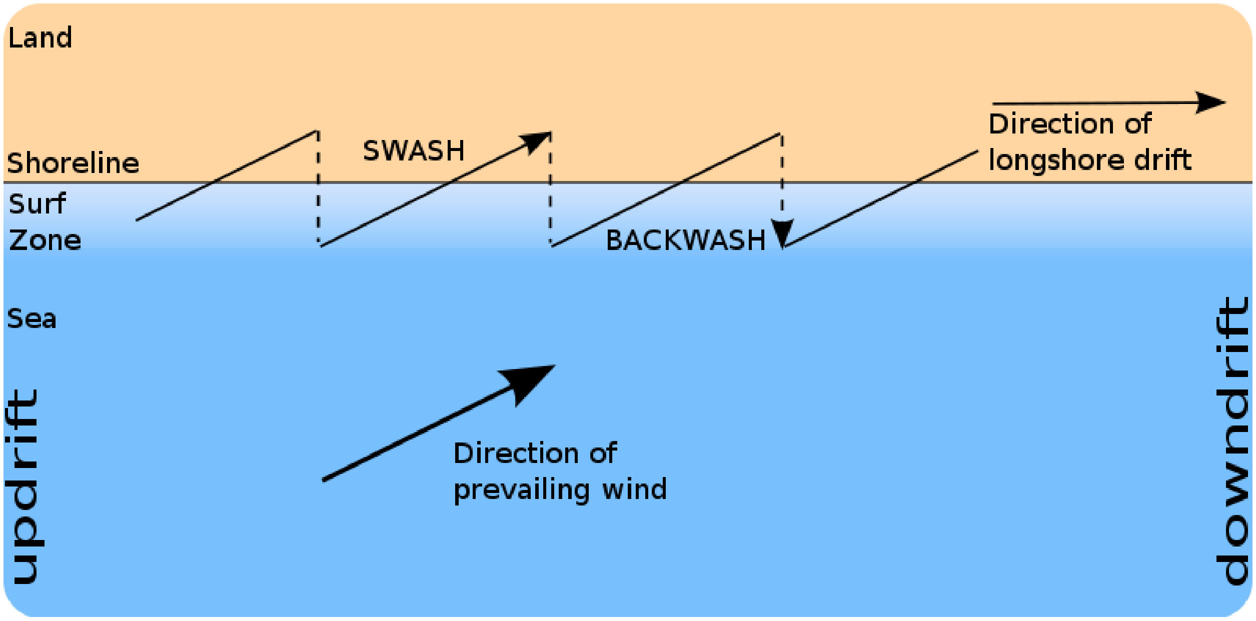

FIGURE 6.17
Longshore currents move water and sediment parallel to the shore in the direction of the prevailing local winds.

currents.

This animation shows the surface currents in the Caribbean, the Gulf of Mexico, and the Atlantic Ocean off of the southeastern United States: http://polar.ncep.noaa.gov/ofs/viewer.shtml?-gulfmex-cur-0-large-rundate=latest .

Summary

- Major surface ocean currents are the result of global wind patterns, Earth's rotation, and the shape of the ocean basins.
- Major surface currents circle the oceans in five gyres.
- Local surface currents, like longshore and rip currents, move near shorelines.

Making Connections

MEDIA
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Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=YCorkyBe66o

MEDIA
Click image to the left for more content.

1. What is a surface current?
2. What is a thermocline?
3. Where is the thermocline?
4. How do surface currents form?
5. What factors determine the movement of surface currents?
6. Why are currents different temperatures?
7. How are the currents monitored?

Review

1. Describe the motion of a water particle that is stuck in a gyre in the North Pacific.
2. What should you do if you get stuck in a rip current?
3. What would happen if a major surface current did not run into a continent? Note that this is what happens with the Antarctic Circumpolar Current.

6.7 Deep Ocean Currents

- Describe the processes that drive deep ocean currents.

How are ocean currents like a conveyor belt?

Seawater doesn't just circulate around the surface, it moves through the deep sea. Just like at the surface, normal circulation patterns transport much of the water. Seawater is moved as if on a conveyor through the surface and deep ocean, a trip that takes hundreds of years.

Deep Currents

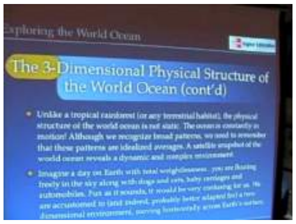
Thermohaline circulation drives deep ocean circulation. Thermo means heat and haline refers to salinity. Differences in temperature and in salinity change the density of seawater. So thermohaline circulation is the result of density differences in water masses because of their different temperature and salinity.

What is the temperature and salinity of very dense water? Lower temperature and higher salinity yield the densest water. When a volume of water is cooled, the molecules move less vigorously, so same number of molecules takes up less space and the water is denser. If salt is added to a volume of water, there are more molecules in the same volume, so the water is denser.

Downwelling

Changes in temperature and salinity of seawater take place at the surface. Water becomes dense near the poles. Cold polar air cools the water and lowers its temperature, increasing its salinity. Fresh water freezes out of seawater to become sea ice, which also increases the salinity of the remaining water. This very cold, very saline water is very dense and sinks. This sinking is called **downwelling**.

This video lecture discusses the vertical distribution of life in the oceans. Seawater density creates currents, which provide different habitats for different creatures: http://www.youtube.com/watch?v=LA1jxeXDsdA (6:12).



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Two things then happen. The dense water pushes deeper water out of its way and that water moves along the bottom of the ocean. This deep water mixes with less dense water as it flows. Surface currents move water into the space vacated at the surface where the dense water sank (**Figure** 6.18). Water also sinks into the deep ocean off of Antarctica.

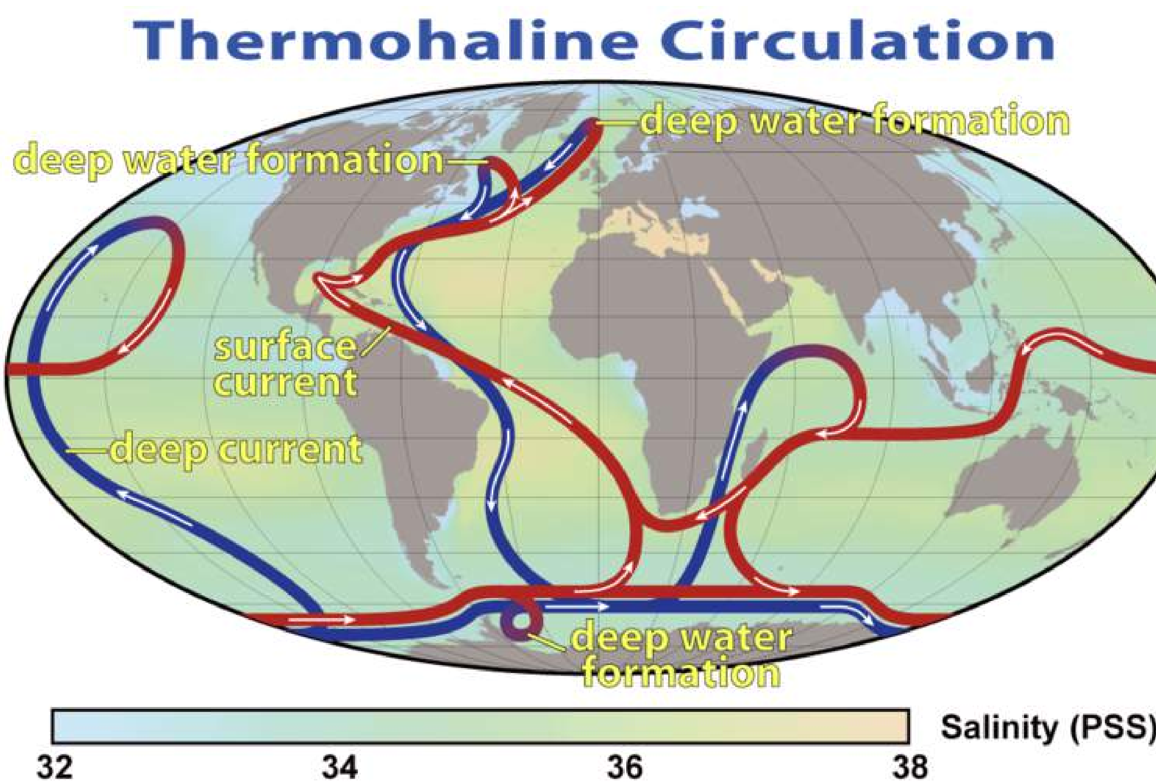

FIGURE 6.18

Cold water (blue lines) sinks in the North Atlantic, flows along the bottom of the ocean and upwells in the Pacific or Indian. The water then travels in surface currents (red lines) back to the North Atlantic. Deep water also forms off of Antarctica.

Upwelling

Since unlimited amounts of water cannot sink to the bottom of the ocean, water must rise from the deep ocean to the surface somewhere. This process is called **upwelling** (**Figure** 6.19).

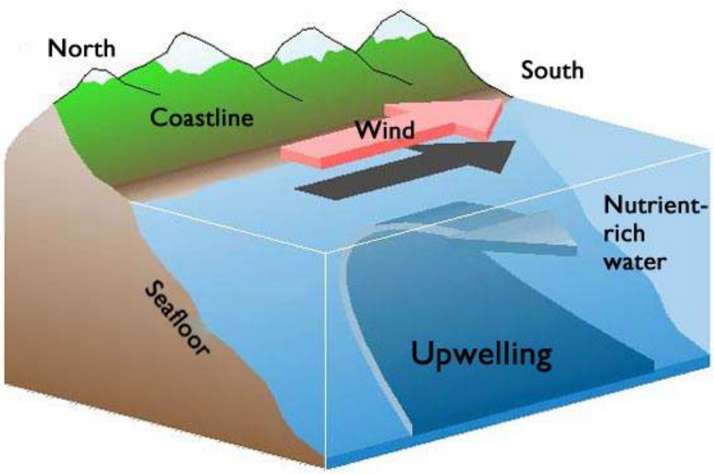

FIGURE 6.19
Upwelling forces denser water from below to take the place of less dense water at the surface that is pushed away by the wind.

Generally, upwelling occurs along the coast when wind blows water strongly away from the shore. This leaves a void that is filled by deep water that rises to the surface.

Upwelling is extremely important where it occurs. During its time on the bottom, the cold deep water has collected nutrients that have fallen down through the water column. Upwelling brings those nutrients to the surface. Those nutrients support the growth of plankton and form the base of a rich ecosystem. California, South America, South Africa, and the Arabian Sea all benefit from offshore upwelling.

An animation of upwelling is seen here: http://oceanservice.noaa.gov/education/kits/currents/03coastal4.html .

Upwelling also takes place along the Equator between the North and South Equatorial Currents. Winds blow the surface water north and south of the Equator, so deep water undergoes upwelling. The nutrients rise to the surface and support a great deal of life in the equatorial oceans.

Summary

- Cooling or evaporation of fresh water from the sea surface makes surface water dense and causes it to sink.
- Downwelling of cold, dense water drives thermohaline circulation.
- Upwelling takes place at some coastlines or along the Equator and brings cool, nutrient-rich water to the surface.

Making Connections

MEDIA
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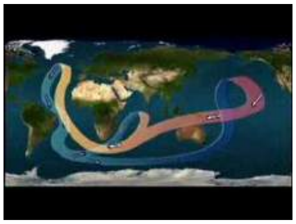
Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=FuOX23yXhZ8



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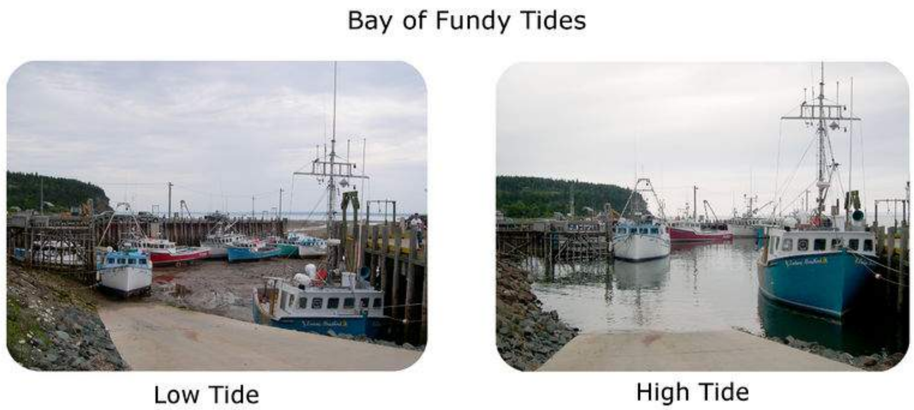
1. How does temperature effect the density of water?
2. How does salinity affect density?
3. What does the density difference create?
4. Where is the NADW?
5. Where is the AABW?
6. How long does take a water molecule to complete the circuit of the global conveyor belt?
7. What is an upwelling? What does it do?

Review

1. Why is upwelling important?
2. How does downwelling drive thermohaline circulation?
3. What would happen if water in the north Pacific no longer became cold and dense enough to sink?

6.8 Tides

- Define tides.
- Describe types of tides.
- Explain why tides occur.



How could a tide be so extreme?

These two photos show high tide (left) and low tide (right) at Bay of Fundy on the Gulf of Maine. The Bay of Fundy has the greatest tidal ranges on Earth at 38.4 feet. Why is this tidal range so extreme? Why aren't all tidal ranges so great? Tidal range depends on many factors, including the slope of the continental margin.

The Tides

Tides are the daily rise and fall of sea level at any given place. The pull of the Moon's gravity on Earth is the primary cause of tides and the pull of the Sun's gravity on Earth is the secondary cause (**Figure** 6.20). The Moon has a greater effect because, although it is much smaller than the Sun, it is much closer. The Moon's pull is about twice that of the Sun's.

To understand the tides it is easiest to start with the effect of the Moon on Earth. As the Moon revolves around our planet, its gravity pulls Earth toward it. The lithosphere is unable to move much, but the water is pulled by the gravity and a bulge is created. This bulge is the high tide beneath the Moon. On the other side of the Earth, a high tide is produced where the Moon's pull is weakest. These two water bulges on opposite sides of the Earth aligned with the Moon are the **high tides**. The places directly in between the high tides are **low tides**. As the Earth rotates beneath the Moon, a single spot will experience two high tides and two low tides approximately every day.

High tides occur about every 12 hours and 25 minutes. The reason is that the Moon takes 24 hours and 50 minutes to rotate once around the Earth, so the Moon is over the same location every 24 hours and 50 minutes. Since high tides occur twice a day, one arrives each 12 hours and 25 minutes. What is the time between a high tide and the next low tide?

The gravity of the Sun also pulls Earth's water towards it and causes its own tides. Because the Sun is so far away, its pull is smaller than the Moon's.

Some coastal areas do not follow this pattern at all. These coastal areas may have one high and one low tide per day or a different amount of time between two high tides. These differences are often because of local conditions, such as the shape of the coastline that the tide is entering.

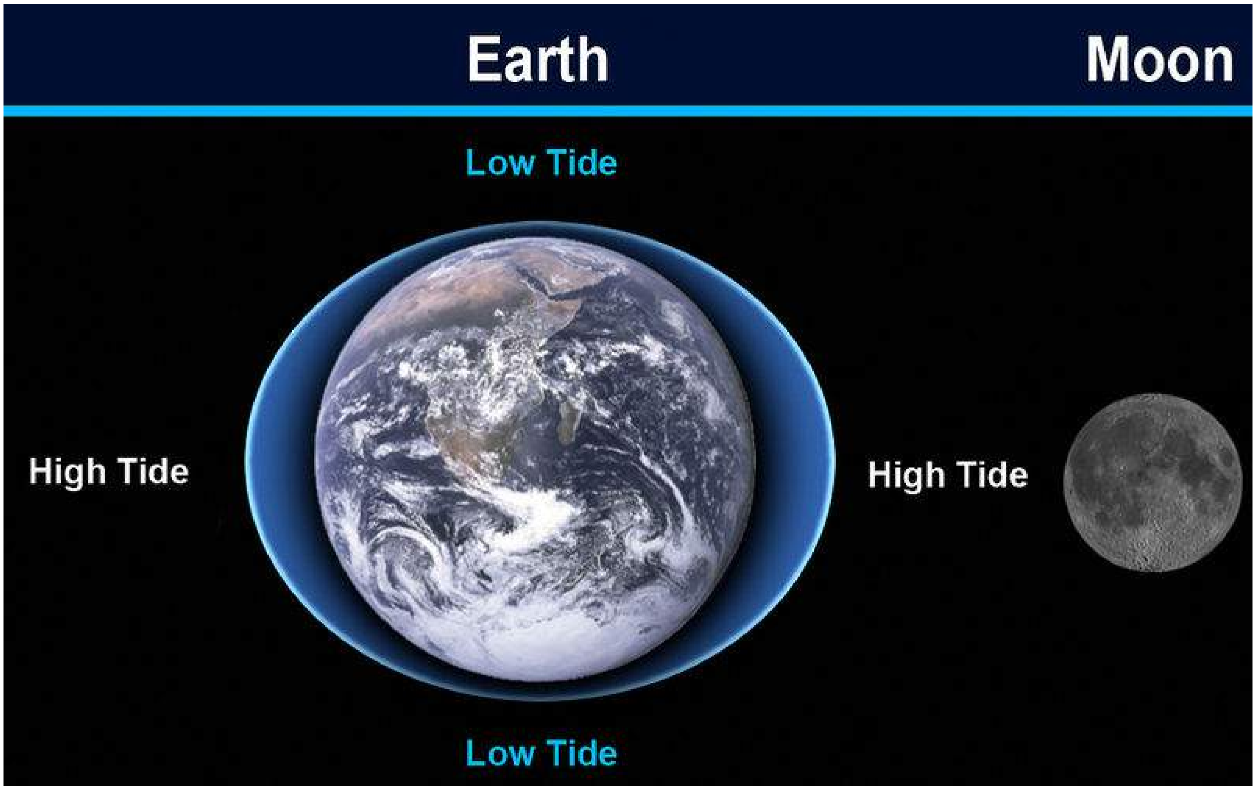


FIGURE 6.20
The gravitational attraction of the Moon to ocean water creates the high and low tides.

Tidal Range

The **tidal range** is the difference between the ocean level at high tide and the ocean level at low tide (**Figure** 6.21). The tidal range in a location depends on a number of factors, including the slope of the seafloor. Water appears to move a greater distance on a gentle slope than on a steep slope.

Monthly Tidal Patterns

If you look at the diagram of high and low tides on a circular Earth above, you'll see that tides are waves. So when the Sun and Moon are aligned, what do you expect the tides to look like?

Waves are additive, so when the gravitational pull of both bodies is in the same direction, the high tides are higher and the low tides lower than at other times through the month (**Figure** 6.22). These more extreme tides, with a greater tidal range, are called **spring tides**. Spring tides don't just occur in the spring; they occur whenever the Moon is in a new-moon or full-moon phase, about every 14 days.

Neap tides are tides that have the smallest tidal range, and they occur when the Earth, the Moon, and the Sun form a 90^o angle (**Figure** 6.23). They occur exactly halfway between the spring tides, when the Moon is at first or last quarter. How do the tides add up to create neap tides? The Moon's high tide occurs in the same place as the Sun's low tide and the Moon's low tide in the same place as the Sun's high tide. At neap tides, the tidal range is relatively small.

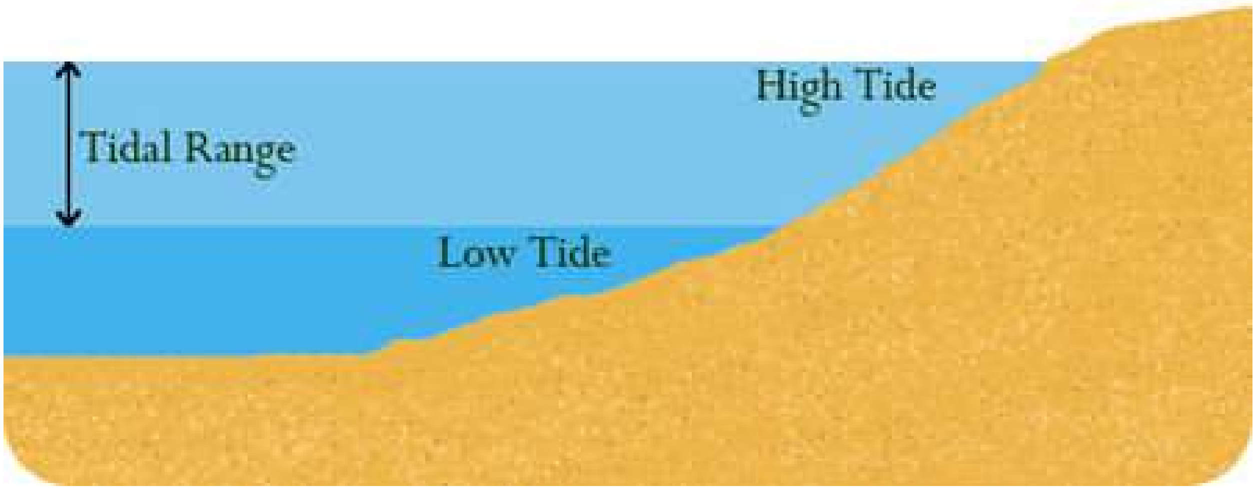


FIGURE 6.21
The tidal range is the difference between the ocean level at high tide and low tide.

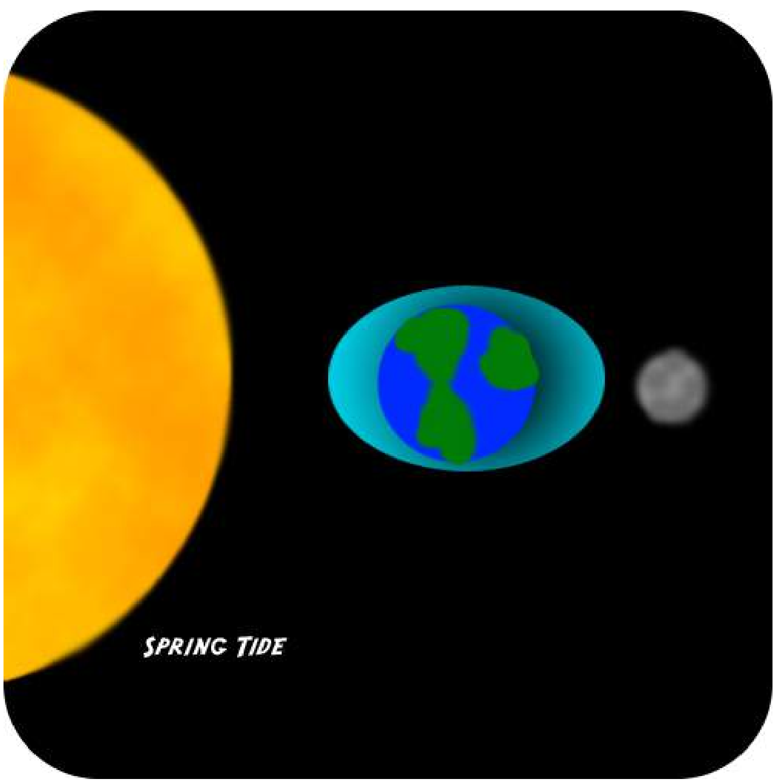


FIGURE 6.22
A spring tide occurs when the gravitational pull of both Moon and the Sun is in the same direction, making high tides higher and low tides lower and creating a large tidal range.

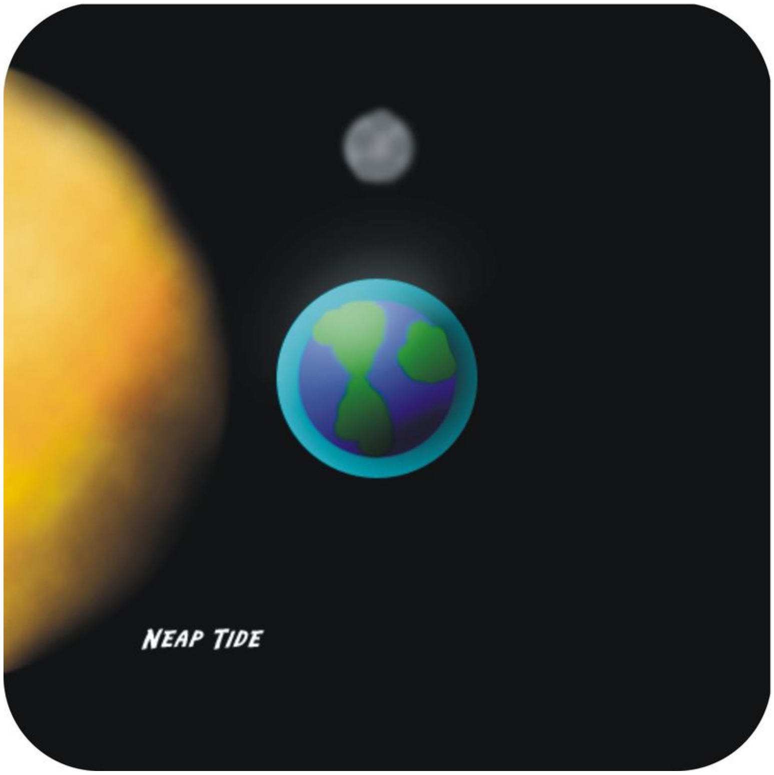


FIGURE 6.23
A neap tide occurs when the high tide of the Sun adds to the low tide of the Moon and vice versa, so the tidal range is relatively small.

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

A detailed animation of lunar tides is shown here: http://www.pbs.org/wgbh/nova/venice/tides.html .

Here is a link to see these tides in motion: http://oceanservice.noaa.gov/education/kits/tides/media/tide06a_450.gif .

A simple animation of spring and neap tides is found here: http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html .

Studying ocean tides' rhythmic movements helps scientists understand the ocean and the Sun/Moon/Earth system. This QUEST video explains how tides work, and visits the oldest continually operating tidal gauge in the Western Hemisphere.

Watch it at http://www.kqed.org/quest/television/science-on-the-spot-watching-the-tides .

MEDIA
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Summary

- The primary cause of tides is the gravitational attraction of the Moon, which causes two high and two low tides a day.
- When the Sun's and Moon's tides match, there are spring tides; when they are opposed, there are neap tides.
- The difference between the daily high and the daily low is the tidal range.

Practice

Use this resource to answer the questions that follow.

http://www.teachertube.com/viewVideo.php?video_id=655&title=The_Mystery_of_Earth_s_Tides

1. How often do tides occur?

2. What are tides?

3. What is a tidal bulge?

4. What causes tides?

5. How is the tidal bulge created?

Review

1. Using the terminology of waves, describe how the gravitational attraction of the Moon and Sun make a high tide and a low tide.

2. Describe the causes of spring and neap tides.

3. What are the possible reasons that the Bay of Fundy has such a large tidal range?

6.9 Seawater Chemistry

- Describe the composition of seawater.
- Explain the relationship between the composition of seawater and its properties.

What is salt?

Besides making food taste better, salt is important for the human diet. Before refrigeration, salt was essential for curing and preserving food. Even in antiquity people built access roads they called "salt roads" so that they could obtain this essential mineral. What is salt? It's what you get when you evaporate seawater!

Composition of Ocean Water

Remember that H_2O is a polar molecule, so it can dissolve many substances (**Figure** 6.24). Salts, sugars, acids, bases, and organic molecules can all dissolve in water.

Salinity

Where does the salt in seawater come from? As water moves through rock and soil on land it picks up ions. This is the flip side of weathering. Salts comprise about 3.5% of the mass of ocean water, but the salt content, or **salinity**, is different in different locations.

What would the salinity be like in an estuary? Where seawater mixes with fresh water, salinity is lower than average.

What would the salinity be like where there is lots of evaporation? Where there is lots of evaporation but little circulation of water, salinity can be much higher. The Dead Sea has 30% salinity —nearly nine times the average salinity of ocean water (**Figure** 6.25). Why do you think this water body is called the Dead Sea?

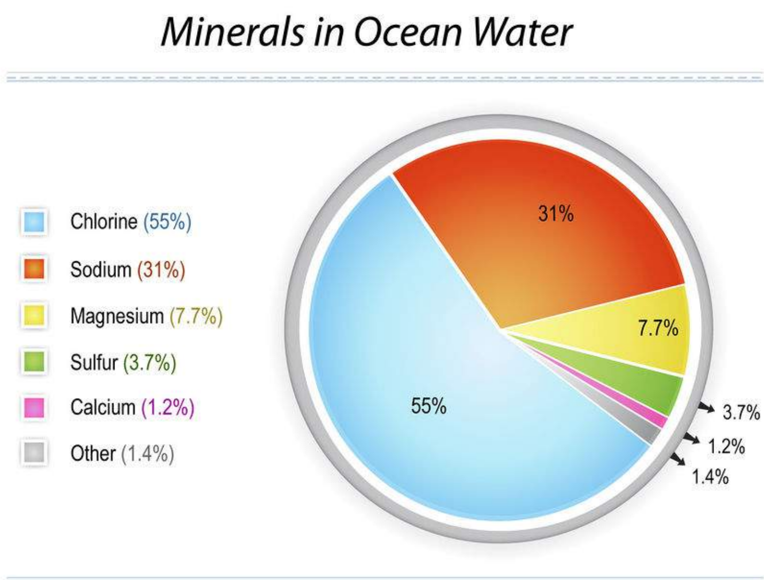
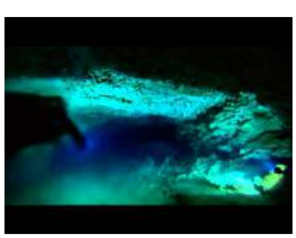


FIGURE 6.24
Ocean water is composed of many substances, many of them salts such as sodium, magnesium, and calcium chloride.

FIGURE 6.25
Because of the increased salinity, the water in the Dead Sea is very dense, it has such high salinity that people can easily float in it!

In some areas, dense saltwater and less dense freshwater mix, and they form an immiscible layer, just like oil and water. One such place is a "cenote", or underground cave, very common in certain parts of Central America. Check out the video below:

http://www.youtube.com/watch?v=dHn80f3lAUs



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Interactive ocean maps can show salinity, temperature, nutrients, and other characteristics: http://earthguide.ucsd.edu/earthguide/diagrams/levitus/index.html .

Density

With so many dissolved substances mixed in seawater, what is the **density** (mass per volume) of seawater relative to fresh water?

Water density increases as:

- salinity increases
- temperature decreases
- pressure increases

Differences in water density are responsible for deep ocean currents, as will be discussed in the "Deep Ocean Currents" concept.

Summary

- Water moving through rock and soil picks up ions that end up as salts in large water bodies.
- Ocean water contains salts, sugars, acids, bases, and organic molecules.
- Water density increases as salinity and pressure increase, or as temperature decreases.

Making Connections

MEDIA

Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

Ocean Chemistry

http://www.youtube.com/watch?v=KUadxcKtH-g

MEDIA

Click image to the left for more content.

1. What happens to water as it cools?
2. What plays a crucial role in ocean movement?
3. What does algae require?
4. What do diatoms require?
5. Why is calcium important to organisms in the oceans?
6. Why is phosphate required?
7. How does carbon enter the oceans?
8. What problems does increased ocean acidity cause?
9. What is a dead zone?
10. Where is nitrogen fixed in the ocean?
11. Where does the iron in oceans come from?
12. Why are there plans to seed areas of the ocean with iron?

Review

1. Streams aren't salty, so why is the ocean salty?
2. In a region of the ocean where evaporation is high, what happens to the density of the water?
3. What would need to happen for the all of the oceans to become more saline?

6.10 Coastal Pollution

- Explain the relationship between coastal pollution and marine dead zones.

Fertilizer makes things grow. How could it cause a dead zone?

Fertilizer from farms and yards carried from the Mississippi River into the Gulf of Mexico creates an enormous dead zone, where algae use up all the oxygen and nothing else can live. The largest, in 2002, was about 22,000 square kilometers (8,400 mi^2).

Ocean Pollution

Most ocean pollution comes as runoff from land and originates as agricultural, industrial, and municipal wastes (**Figure** 6.26). The remaining 20% of water pollution enters the ocean directly from oil spills and people dumping wastes directly into the water. Ships at sea empty their wastes directly into the ocean, for example.

Coastal pollution can make coastal water unsafe for humans and wildlife. After rainfall, there can be enough runoff pollution that beaches must be closed to prevent the spread of disease from pollutants. A surprising number of beaches are closed because of possible health hazards each year.

A large proportion of the fish we rely on for food live in the coastal wetlands or lay their eggs there. Coastal runoff from farm waste often carries water-borne organisms that cause lesions that kill fish. Humans who come in

FIGURE 6.26
In some areas of the world, ocean pollution is all too obvious.

contact with polluted waters and affected fish can also experience harmful symptoms. More than one-third of the shellfish-growing waters of the United States are adversely affected by coastal pollution.

A National Geographic video, "Why the Ocean Matters," has beautiful footage and a brief introduction to some of the problems facing the seas: http://video.nationalgeographic.com/video/environment/habitats-environment/habitats-oceans-env/why-ocean-matters/ .

Dead Zones

Fertilizers that run off of lawns and farm fields are extremely harmful to the environment. Nutrients, such as nitrates, in the fertilizer promote algae growth in the water they flow into. With the excess nutrients, lakes, rivers, and bays become clogged with algae and aquatic plants. Eventually these organisms die and decompose. Decomposition uses up all the dissolved oxygen in the water. Without oxygen, large numbers of plants, fish, and bottom-dwelling animals die.

Every year dead zones appear in lakes and nearshore waters. A dead zone is an area of hundreds of kilometers of ocean without fish or plant life.

The Mississippi is not the only river that carries the nutrients necessary to cause a dead zone. Rivers that drain regions where human population density is high and where crops are grown create dead zones all over the world (**Figure** 6.27).

Summary

- Most ocean pollution comes from land and much congregates in the coastal regions.
- Excess fertilizer travels in rivers to the sea and causes algae to bloom. These algae die and decomposition uses up the oxygen in an area, causing a dead zone.
- The dead zone in the Gulf of Mexico from Mississippi River runoff is getting larger each year.

Practice

Use these resources to answer the questions that follow

http://www.youtube.com/watch?v=xLv1vPEQyM0

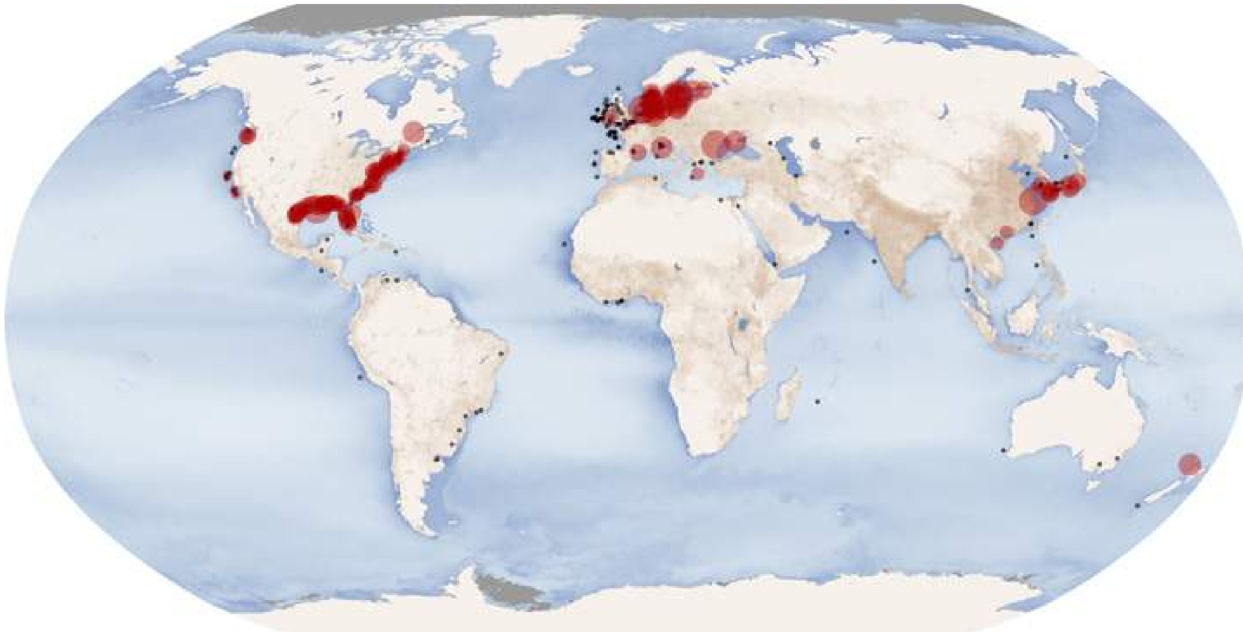


FIGURE 6.27

Dead zones off the coasts. Red dots show the location and size of the dead zone; black circles show the location but the size is unknown. Darker blue regions of the oceans indicate that organic particulates are high and may lead to a dead zone.

MEDIA

Click image to the left for more content.

1. Why does the US Coast Guard do vehicle patrols?
2. Why are storm drains under US Coast Guard jurisdiction?
3. What is the purpose of the pollution fines?

http://www.youtube.com/watch?v=MBpnuYul7B8

MEDIA

Click image to the left for more content.

4. Where are the best beaches?

5. Where are the dirtiest beaches?

6, What is the danger of swimming in contaminated water?

7. What is the danger of digging in the sand?

Review

1. What are the consequences of coastal pollution?
2. What are the sources of coastal pollution?
3. What sequence of events causes a dead zone?

6.11 Ocean Garbage Patch

- Explain how trash ends up as ocean debris.
- Trace the path of trash to the ocean garbage patch.

How could these balloons kill a sea turtle?

Balloons flying off into the sky symbolize freedom and happiness. Eventually those balloons pop and the plastic falls to the surface. Much of this plastic will end up in the sea where it may be accidentally ingested by a marine organism —with dire results.

Marine Trash

Trash from land may end up as trash in the ocean, sometimes extremely far from land. Some of it will eventually wash ashore, possibly far from where it originated (**Figure** 6.28).

Sources of Trash

Although people had once thought that the trash found everywhere at sea was from ships, it turns out that 80% is from land. Some of that is from runoff, some is blown from nearshore landfills, and some is dumped directly into the sea.

The 20% that comes from ships at sea includes trash thrown overboard by large cruise ships and many other vessels. It also includes lines and nets from fishing vessels. Ghost nets, nets abandoned by fishermen intentionally or not, float the seas and entangle animals so that they cannot escape. Containers sometimes go overboard in storms. Some noteworthy events, like a container of rubber ducks that entered the sea in 1992, are used to better understand ocean currents. The ducks went everywhere!

FIGURE 6.28
Trash has washed up on this beach.

Makeup of Trash

About 80% of the trash that ends up in the oceans is plastic. This is because a large amount of the trash produced since World War II is plastic. Also many types of plastic do not biodegrade, so they simply accumulate. While many types of plastic photodegrade —that is, they break up in sunlight —this process only works when the plastics are dry. Plastic trash in the water does break down into smaller pieces, eventually becoming molecule-sized polymers. Other trash in the oceans includes chemical sludge and materials that do biodegrade, like wood.

Toxic chemicals

Some plastics contain toxic chemicals, such as bisphenol A. Plastics can also absorb organic pollutants that may be floating in the water, such as the pesticide DDT (which is banned in the U.S. but not in other nations) and some endocrine disruptors.

Effect on Organisms

Marine birds, such as albatross, or animals like sea turtles, live most of their lives at sea and just come ashore to mate. These organisms can't break down the plastic and they may eventually die (**Figure** 6.29). Boats may be affected. Plastic waste is estimated to kill 100,000 sea turtles and marine mammals annually, but exact numbers are unknown.

Plastic shopping bags are extremely abundant in the oceans. If an organism accidentally ingests one, it may clog digestion and cause starvation by stopping food from moving through or making the animal not feel hungry.

The Great Pacific Garbage Patch

Trash from the lands all around the North Pacific is caught up in currents. The currents bring the trash into the center of the North Pacific Gyre. Scientists estimate that it takes about six years for trash to move from west coast of North America to the center of the gyre. The concentration of trash increases toward the center of the gyre.

While recognizable pieces of garbage are visible, much of the trash is tiny plastic polymers that are invisible but can be detected in water samples. The particles are at or just below the surface within the gyre. Plastic confetti-like pieces are visible beneath the surface at the gyre's center.

FIGURE 6.29
This albatross likely died from the plastic it had ingested.

FIGURE 6.30
Plastic bags in the ocean can be mistaken for food by an unsuspecting marine predator.

The size of the garbage patch is unknown, since it can't be seen from above. Some people estimate that it's twice the size of continental U.S, with a mass of 100 million tons.

Effect on Organisms

In some areas, plastics have seven times the concentration of zooplankton. This means that filter feeders are ingesting a lot of plastics. This may kill the organisms or the plastics may remain in their bodies. They are then eaten by larger organisms that store the plastics and may eventually die. Fish may eat organisms that have eaten plastic and then be eaten by people. This also exposes humans to toxic chemicals that the fish may have ingested with the plastic.

There are similar patches of trash in the gyres of the North Atlantic and Indian oceans. The Southern Hemisphere has less trash buildup because less of the region is continent.

Summary

- Trash from land (80%) or human activities at sea (20%) ends up in the oceans; about 80% of this trash is plastic.
- Plastic trash does not usually biodegrade in the ocean but just forms tiny polymers that resemble plankton.
- Plastic pieces of trash and plastic molecules can kill marine organisms by becoming lodged in their digestive systems or by trapping them so they can't swim.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=8a4S23uXIcM

MEDIA

Click image to the left for more content.

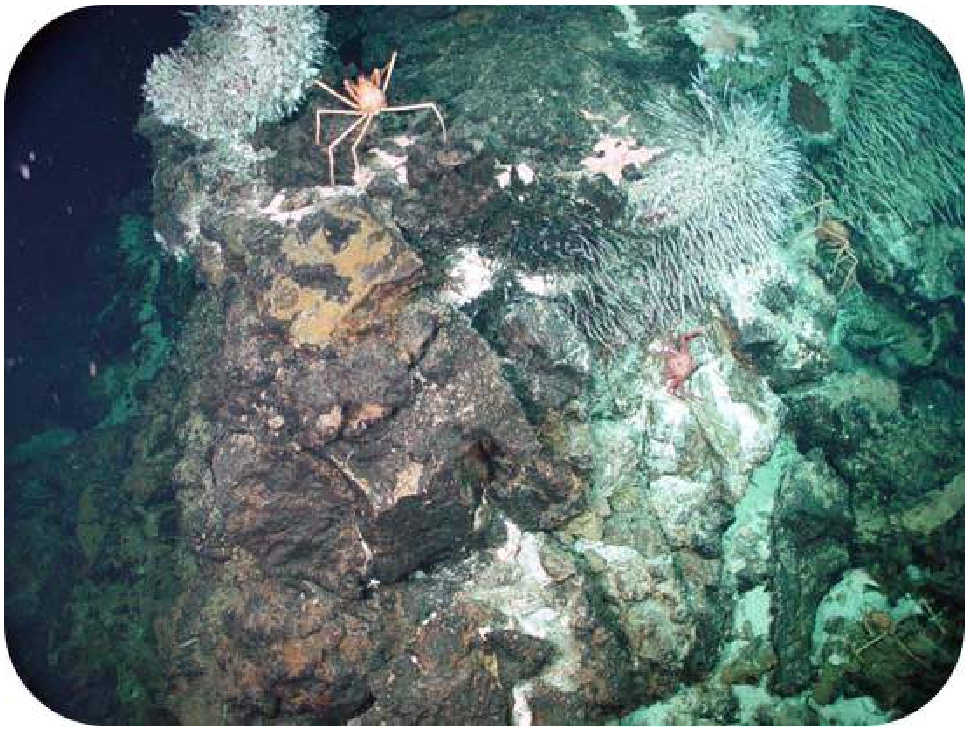
1. What created the garbage patch?
2. How much stuff does it contain?
3. What makes up 80% of the patch?
4. What is the problem with plastic?
5. Where does the garbage come from?
6. What is the solution to stop adding to the patch?

Review

1. How can plastic kill marine organisms?
2. Since plastic doesn't biodegrade in the oceans, what does the future hold? What can be done to make the future better?
3. Some people say that the Great Pacific Garbage Patch is a hoax. What can scientists do to show people that it is real?

6.12 Ocean Ecosystems

- Describe the various types of ocean ecosystems.



Which ecosystem doesn't depend on photosynthesis?

When scientists first dove in Alvin and witnessed hydrothermal vents, they were not surprised by the eruptions of hot water. But they never anticipated finding life there. Without sunlight, they knew that photosynthesis could not be the basis of this community. Eventually they discovered a different way of producing food, chemosynthesis. Many more hydrothermal vents were discovered and many more types of vent organisms.

The Intertidal

Conditions in the intertidal zone change rapidly as water covers and uncovers the region and waves pound on the rocks. A great abundance of life is found in the intertidal zone (**Figure** 6.31). High energy waves hit the organisms that live in this zone, so they must be adapted to pounding waves and exposure to air during low tides. Hard shells protect from waves and also protect against drying out when the animal is above water. Strong attachments keep the animals anchored to the rock.

In a tide pool, as in the photo, what organisms are found where and what specific adaptations do they have to that zone? The mussels on the top left have hard shells for protection and to prevent drying because they are often not covered by water. The sea anemones in the lower right are more often submerged and have strong attachments but can close during low tides.

Many young organisms get their start in estuaries and so they must be adapted to rapid shifts in salinity.

FIGURE 6.31
Organisms in a tide pool include sea stars and sea urchins.

Reefs

Corals and other animals deposit calcium carbonate to create rock **reefs** near the shore. Coral reefs are the "rainforests of the oceans," with a tremendous amount of species diversity (**Figure** 6.32).

FIGURE 6.32
Coral reefs are among the most densely inhabited and diverse areas on the globe.

Reefs can form interesting shapes in the oceans. Remember that hot spots create volcanoes on the seafloor. If these volcanoes rise above sea level to become islands, and if they occur in tropical waters, coral reefs will form on them. Since the volcanoes are cones, the reef forms in a circle around the volcano. As the volcano comes off the hot spot, the crust cools. The volcano subsides and then begins to erode away (**Figure** 6.33).

Eventually, all that is left is a reef island called an atoll. A lagoon is found inside the reef.

FIGURE 6.33
In this image of Maupiti Island in the South Pacific, the remnants of the volcano are surrounded by the circular reef.

Oceanic Zone

The open ocean is a vast area. Food either washes down from the land or is created by photosynthesizing plankton. Zooplankton and larger animals feed on the phytoplankton and on each other. Larger animals such as whales and giant groupers may live their entire lives in the open water.

How do fish survive in the deepest ocean? The few species that live in the greatest depths are very specialized (**Figure** 6.34). Since it's rare to find a meal, the fish use very little energy; they move very little, breathe slowly, have minimal bone structure and a slow metabolism. These fish are very small. To maximize the chance of getting a meal, some species may have jaws that unhinge to accept a larger fish or backward-folding teeth to keep prey from escaping.

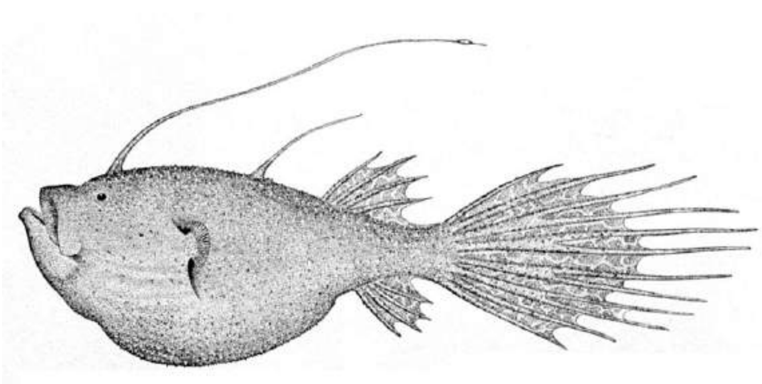


FIGURE 6.34
An 1896 drawing of a deep sea angler fish with a bioluminescent "lure" to attract prey.

Many ocean-related videos are found in National Geographic Videos, Environment Video, Habitat, Ocean section: http://video.nationalgeographic.com/video/player/environment/ . Just a few are listed below.

- How we can know what lives in the ocean is in "Deep-Sea Robo Help."
- Some of the results of the Census of Marine Life have been released and are discussed in "Record-Breaking Sea-Creature Surveys Released."
- Bioluminescence is common in the oceans and seen in "Why Deep Sea Creatures Glow."

Hydrothermal Vents

Hydrothermal vents are among the most unusual ecosystems on Earth since they are dependent on chemosynthetic organisms at the base of the food web. At mid-ocean ridges at **hydrothermal vents**, bacteria that use **chemosynthesis** for food energy are the base of a unique ecosystem (**Figure** 6.35). This ecosystem is entirely separate from the photosynthesis at the surface. Shrimp, clams, fish, and giant tube worms have been found in these extreme places.

FIGURE 6.35
Giant tube worms found at hydrothermal vents get food from the chemosynthetic bacteria that live within them. The bacteria provide food; the worms provide shelter.

A video explaining hydrothermal vents with good footage is seen here: http://www.youtube.com/watch?v=rFHtVRKoaUM .

Summary

- In the ocean, phytoplankton photosynthesize as the main food source. They are eaten by zooplankton and other larger animals.
- Organisms that live in the deepest ocean have amazing adaptations to the exceptionally harsh conditions, such as unhinging jaws, backward-folding teeth, or a bioluminescent lure.
- A hydrothermal vent ecosystem has chemosynthesis as its food source. The ecosystem is independent of photosynthesis at the surface.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use these resources to answer the questions that follow.

http://www.untamedscience.com/biology/biomes/intertidal-zone-aquatic-biome/

MEDIA
Click image to the left for more content.

1. What is the intertidal zone?
2. What do organisms in an intertidal zone have to deal with each day?
3. What is zonation?
4. How have some of the organisms in the intertidal zone adapted to life there?

http://www.untamedscience.com/biology/biomes/deep-sea-biome

MEDIA
Click image to the left for more content.

5. Why is the deep sea not well explored?
6. What organisms live in the epipelagic zone?
7. What organisms live in the mesopelagic zone?
8. What color are most of the animals in this zone?
9. What is bioluminescence?
10. What is found in the deep scattering layer?

Review

1. Why is there so much biodiversity in the intertidal zone?
2. Why is survival in the deep ocean difficult? What adaptations to organisms have to do this?
3. What is bioluminescence and how does it help organisms survive in the ocean?

6.13 Marine Food Chains

- Understand where the food energy comes from for marine food chains.

What's the most unusual life form you could see on Earth?

Some people might disagree. But the most unusual life on Earth could be the strange organisms that live at hydrothermal vents at mid-ocean ridges. These organisms break down chemicals to make food energy. They engage in chemosynthesis. Would you like to see an ecosystem with chemosynthesis at its base?

Marine Food Chains

Pictured below is a marine food chain (**Figure** 6.36). Phytoplankton form the base of the food chain. Phytoplankton are the most important primary producers in the ocean. They use sunlight and nutrients to make food by **photosynthesis**. Small zooplankton consume phytoplankton. Larger organisms eat the small zooplankton. Larger predators eat these consumers. In an unusual relationship, some enormous whales depend on plankton for their food. They filter tremendous amounts of these tiny creatures out of the water.

The bacteria that make food from chemicals are also primary producers. These organisms do not do photosynthesis since there is no light at the vents. They do something called **chemosynthesis**. They break down chemicals to make food.

When marine organisms die, decomposers break them down. This returns their nutrients to the water. The nutrients can be used again to make food. Decomposers in the oceans include bacteria and worms. Many live on the ocean floor. Do you know why?

Vocabulary

- **chemosynthesis**: Process of breaking down chemicals to make food energy.
- **photosynthesis**: Process of using inorganic matter and sunlight to make food energy.

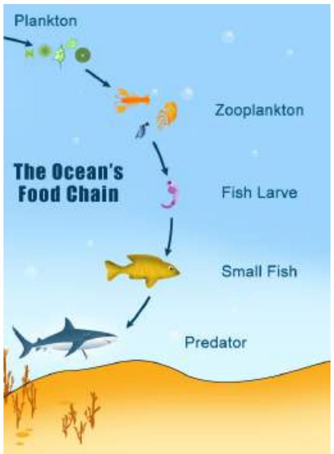


FIGURE 6.36
Many marine food chains look like this example.

Summary

- Photosynthesis is the base of nearly all food chains on Earth. This is true of marine food chains, too.
- In chemosynthesis, organisms break down chemicals to make food energy.
- As on land, marine decomposers break down dead organisms. They release nutrients.

Practice

Use the resource below to answer the questions that follow.

- **Primary Producers** at http://www.youtube.com/watch?v=TyM7MlRrSSU (3:17)

MEDIA
Click image to the left for more content.

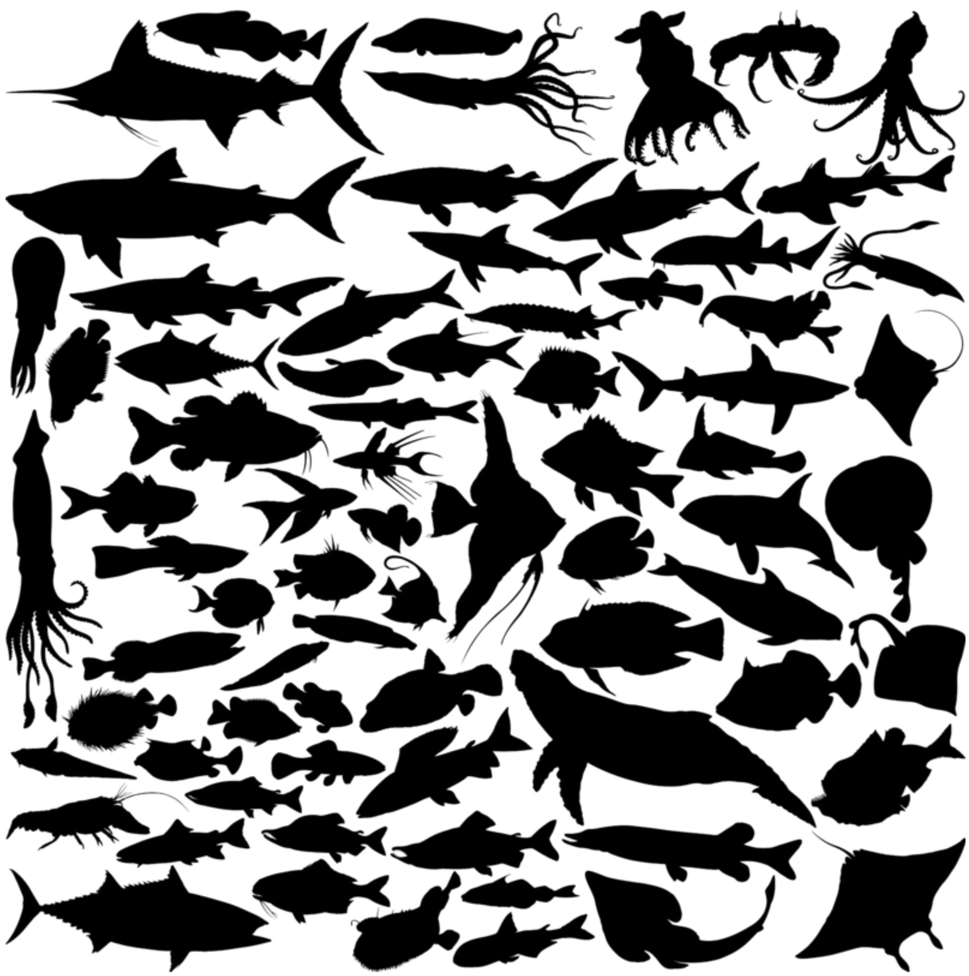
1. Why are fish valuable?
2. What are primary producers?
3. What is chemosynthesis?
4. What is photosynthesis?
5. What are the primary producers of the ocean? Which gas do they use and which do they release into the atmosphere?
6. Why are the primary producers of the ocean important?

Review

1. Compare and contrast the two types of primary production discussed here.
2. What is a typical marine food chain like?
3. What is the role of decomposers in a marine food chain?

6.14 Types of Marine Organisms

- Describe types of marine organisms.



How does the ocean seem all the same, yet have so much biodiversity?

Although it may seem like the ocean is all the same, there are many different habitats based on temperature, salinity, pressure, light, currents, and other factors. Organisms have adapted to these conditions in many interesting and effective ways. Covering 70% of Earth's surface, the oceans are home to a large portion of all life on Earth.

Types of Ocean Organisms

The smallest and largest animals on Earth live in the oceans. Why do you think the oceans can support large animals?

Marine animals breathe air or extract oxygen from the water. Some float on the surface and others dive into the ocean's depths. There are animals that eat other animals, and plants generate food from sunlight. A few bizarre creatures break down chemicals to make food! The following section divides ocean life into seven basic groups.

Plankton

Plankton are organisms that cannot swim but that float along with the current. The word "plankton" comes from the Greek for wanderer. Most plankton are microscopic, but some are visible to the naked eye (**Figure** 6.37).

Phytoplankton are tiny plants that make food by photosynthesis. Because they need sunlight, phytoplankton live in the photic zone. Phytoplankton are responsible for about half of the total **primary productivity** (food energy) on Earth. Like other plants, phytoplankton release oxygen as a waste product.

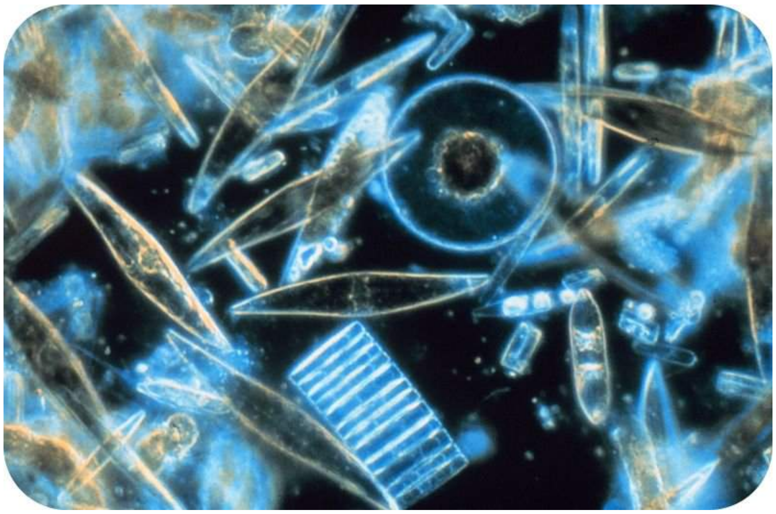


FIGURE 6.37
Microscopic diatoms are a type of phytoplankton.

A video of a research vessel sampling plankton is seen here: http://www.youtube.com/watch?v=mQG4zAoh6xc .

Zooplankton, or animal plankton, eat phytoplankton as their source of food (**Figure** 6.38). Some zooplankton live as plankton all their lives and others are juvenile forms of animals that will attach to the bottom as adults. Some small invertebrates live as zooplankton.

FIGURE 6.38
Copepods are abundant and so are an important food source for larger animals.

Plants and Algae

The few true plants found in the oceans include salt marsh grasses and mangrove trees. Although they are not true plants, large algae, which are called seaweed, also use photosynthesis to make food. Plants and seaweeds are found in the neritic zone, where the light they need penetrates so that they can photosynthesize (**Figure** 6.39).

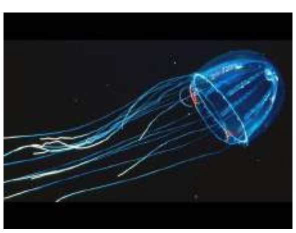
FIGURE 6.39
Kelp grows in forests in the neritic zone. Otters and other organisms depend on the kelp-forest ecosystem.

Marine Invertebrates

The variety and number of **invertebrates**, animals without a backbone, is truly remarkable (**Figure** 6.40). Marine invertebrates include sea slugs, sea anemones, starfish, octopuses, clams, sponges, sea worms, crabs, and lobsters. Most of these animals are found close to the shore, but they can be found throughout the ocean.

Jellies are otherworldly creatures that glow in the dark, without brains or bones, some more than 100 feet long. Along with many other ocean areas, they live just off California's coast.

Learn more about jellies by watching http://science.kqed.org/quest/video/amazing-jellies/ .



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Fish

Fish are **vertebrates**; they have a backbone. What are some of the features fish have that allows them to live in the oceans? All fish have most or all of these traits:

- Fins with which to move and steer.
- Scales for protection.
- Gills for extracting oxygen from the water.
- A swim bladder that lets them rise and sink to different depths.
- Ectothermy (cold-bloodedness), so that their bodies are the same temperature as the surrounding water.

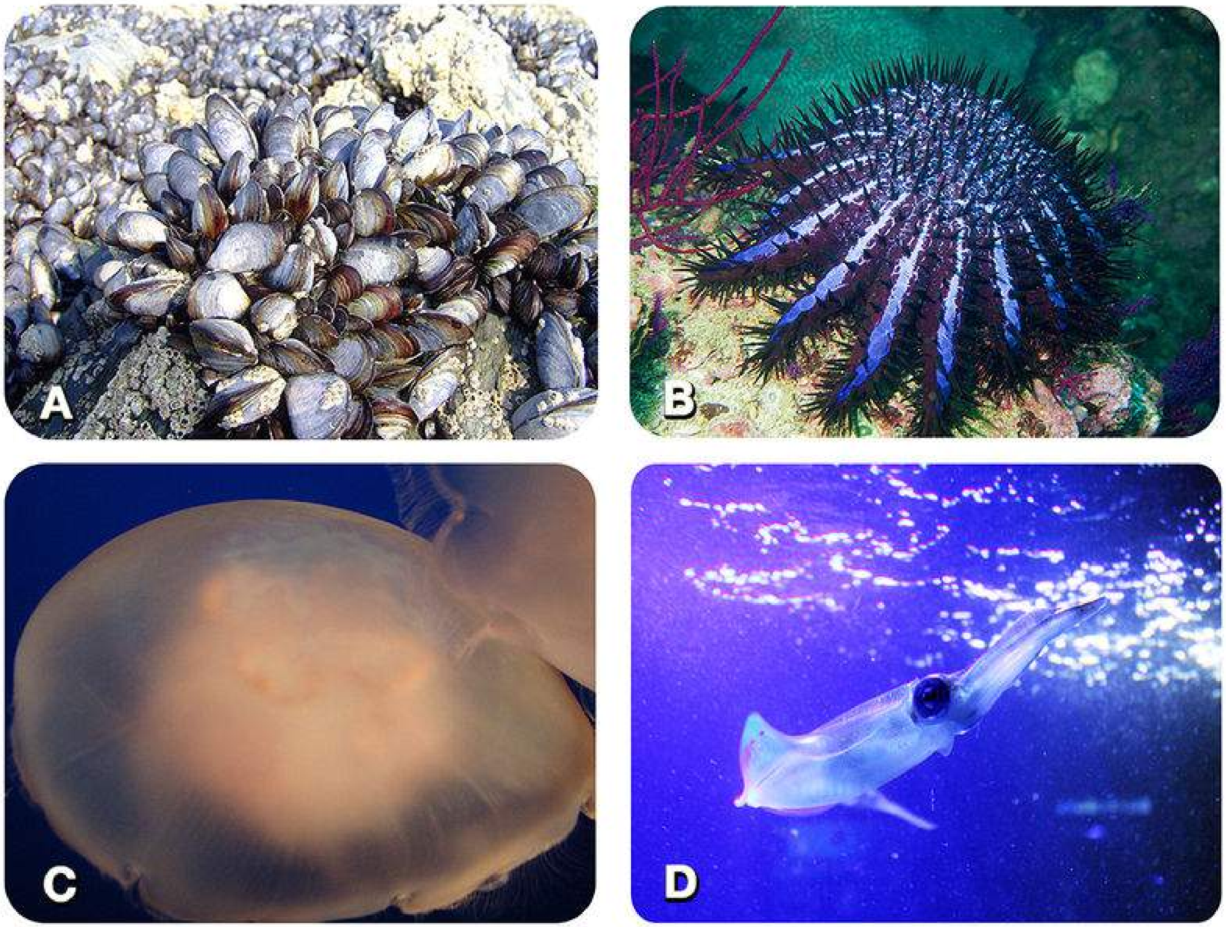

FIGURE 6.40

(a) Mussels; (b) Crown of thorns sea star; (c) Moon jelly; (d) A squid.

- Bioluminescence, or light created from a chemical reaction that can attract prey or mates in the dark ocean.

Included among the fish are sardines, salmon, and eels, as well as the sharks and rays (which lack swim bladders) (**Figure** 6.41).

Reptiles

Only a few types of reptiles live in the oceans and they live in warm water. Why are reptiles so restricted in their ability to live in the sea? Sea turtles, sea snakes, saltwater crocodiles, and marine iguana that are found only at the Galapagos Islands sum up the marine reptile groups (**Figure** 6.42). Sea snakes bear live young in the ocean, but turtles, crocodiles, and marine iguanas all lay their eggs on land.

FIGURE 6.41
The Great White Shark is a fish that preys on other fish and marine mammals.

FIGURE 6.42
Sea turtles are found all over the oceans, but their numbers are diminishing.

Seabirds

Many types of birds are adapted to living in the sea or on the shore. With their long legs for wading and long bills for digging in sand for food, shorebirds are well adapted for the intertidal zone. Many seabirds live on land but go to sea to fish, such as gulls, pelicans, and frigate birds. Some birds, like albatross, spend months at sea and only come on shore to raise chicks (**Figure** 6.43).

Marine Mammals

What are the common traits of mammals? Mammals are endothermic (warm-blooded) vertebrates that give birth to live young, feed them with milk, and have hair, ears, and a jaw bone with teeth.

What traits might mammals have to be adapted to life in the ocean?

FIGURE 6.43
(a) Shorebirds; (b) Seabirds; (c) Albatross.

- For swimming: streamlined bodies, slippery skin or hair, fins.
- For warmth: fur, fat, high metabolic rate, small surface area to volume, specialized blood system.
- For salinity: kidneys that excrete salt, impervious skin.

The five types of marine mammals are pictured here: (**Figure** 6.44).

FIGURE 6.44
(a) Cetaceans: whales, dolphins, and porpoises. (b) Sirenians: manatee and the dugong. (c) Mustelids: Sea otters (terrestrial members are skunks, badgers and weasels). (d) Pinnipeds: Seals, sea lions, and walruses. (e) Polar bear.

Summary

- Plankton are tiny organisms that are swept along on currents. Phytoplankton are tiny photosynthesizers and zooplankton are tiny animals.
- Fish have gills for breathing, swim bladders for rising and sinking, and other adaptations for life in the oceans.
- Shorebirds live at the interface of land and sea; some birds live on land but fish at sea, and some birds spend most of their time at sea and only come to shore to nest.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/news/animals-news/coml-complete-census-vin/

1. When did the census begin?

2. How many expeditions occurred during this census?

3. What was the purpose of this census?

4. What did the researchers find in Australia?

5. What did they discover about the tuna off of Northern Europe?

6. What did this census create?

Additional videos and information can be found at: http://www.coml.org/video-gallery .

Review

1. How are phytoplankton different from plants?

2. Describe how fish are adapted to life in the oceans.

3. Describe how marine mammals are adapted to life in the oceans. How are these adaptations different from those of fish?

6.15 Importance of the Oceans

- Describe the important roles of oceans as related to climate, the water cycle, and biodiversity.

Just what is down there?

Mostly the oceans are cold, dark and have extremely high pressure. Except at the very top, they are completely inhospitable to humans. Even this humpback whale can only dive to about 700 feet, so there's a lot about the ocean it doesn't know. Earth would not be the same planet without its oceans.

Oceans Moderate Climate

The oceans, along with the atmosphere, keep temperatures fairly constant worldwide. While some places on Earth get as cold as -70^{o}C and others as hot as 55^{o}C, the range is only 125^{o}C. On Mercury temperatures go from -180^{o}C to 430^{o}C, a range of 610^{o}C.

The oceans, along with the atmosphere, distribute heat around the planet. The oceans absorb heat near the Equator and then move that solar energy to more polar regions. The oceans also moderate climate within a region. At the same latitude, the temperature range is smaller in lands nearer the oceans than away from the oceans. Summer temperatures are not as hot, and winter temperatures are not as cold, because water takes a long time to heat up or cool down.

Water Cycle

The oceans are an essential part of Earth's water cycle. Since they cover so much of the planet, most evaporation comes from oceans and most precipitation falls on oceans.

Biologically Rich

The oceans are home to an enormous amount of life. That is, they have tremendous biodiversity (**Figure** 6.45). Tiny ocean plants create the base of a food web that supports all sorts of life forms. Marine life makes up the majority of all biomass on Earth. (**Biomass** is the total mass of living organisms in a given area.) These organisms supply us with food and even the oxygen created by marine plants.

FIGURE 6.45
Polar bears are well adapted to frigid Arctic waters.

Summary

- Oceans moderate Earth's temperature by not changing temperature rapidly and by distributing heat around the planet.
- Oceans are an enormous reservoir for water in the water cycle.
- Oceans have tremendous biodiversity and the majority of all biomass on Earth.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/environment/habitats-environment/habitats-oceans-env/why-ocean-matters/

1. What are found in the oceans?

2. How much oxygen does the ocean produce?
3. How much of the water is covered by water?
4. How much of the ocean is protected?
5. What percentage of large predators are gone?
6. What percentage of coral reefs have disappeared?

Review

1. What organisms form the base of the ocean food web?
2. How do the oceans moderate Earth's temperature?
3. What role do oceans play in the water cycle?

6.16 References

1. Courtesy of US Geological Survey. These cliffs are being eroded by waves. Public Domain
2. (A) Ben Salter; (B) David Sim (Flickr:victoriapeckham); (C) Herry Lawford. Pictures showing a wave-cut platform, arch, and sea stacks formed by wave erosion. CC BY 2.0
3. Mark A. Wilson (User:Wilson44691/Wikimedia Commons). Quartz, rock fragments, and shell make up the sand along a beach. Public Domain
4. User:Surachit/Wikimedia Commons and User:Feydey/Wikimedia Commons. Features formed by wave-deposited sand. Public Domain
5. Courtesy of NASA. Picture of a barrier island. Public Domain
6. User:Oikos-team/Wikipedia. Groins, breakwaters, and seawalls are used to protect coastlines. Public Domain
7. Flickr:MarinoCarlos. A breakwater protecting a beach. CC BY 2.0
8. Rev Stan. A groin slows sand on the up-current side. CC BY 2.0
9. Peter Stevens (Flickr:nordique). A seawall protecting a shore. CC BY 2.0
10. Courtesy of US Navy. An echo sounder creates a 3D map of the seafloor. Public Domain
11. Courtesy of Michael Van Woert and the National Oceanic and Atmospheric Administration. A Niskin bottle is used to sample seawater. Public Domain
12. Courtesy of National Oceanic and Atmospheric Administration. The Alvin submersible. Public Domain
13. Jodi So. Diagram of the vertical and horizontal ocean zones. CC BY-NC 3.0
14. User:Vargklo/Wikipedia. Diagram of how an ocean wave travels. Public Domain
15. Courtesy of Rick Lumpkin, NOAA/AOML. Map of the major surface ocean currents. Public Domain
16. CK-12 Foundation, using map courtesy of User:Wereon/Wikimedia Commons and US Geological Survey. Map of the ocean gyres. CC BY-NC 3.0 (map available in the public domain)
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25. Adam Baker. Man floating on the Dead Sea. CC BY 2.0
26. Stephen Codrington. Garbage floating in polluted ocean. CC BY 2.5
27. Courtesy of Robert Simmon and Jesse Allen, NASA's Earth Observatory. Map of dead zones around the world. Public Domain
28. Flickr:epSos .de. Trash washing up on the beach. CC BY 2.0
29. Courtesy of Duncan Wright/US Fish and Wildlife Services. This albatross likely died from the plastic it had ingested. Public Domain
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31. Flickr:mountainamoeba. Organisms in a tide pool include a sea star and a sea urchin. CC BY 2.0
32. NOAA's National Ocean Service. Coral reefs are among the most densely inhabited and diverse areas on the globe. CC BY 2.0
33. Courtesy of Robert Simmon and NASA's Earth Observatory. The remnants of a volcano are surrounded by the circular reef. Public Domain

34. G Brown Goode and Tarleton H Bean. A drawing of a deep sea angler fish. Public Domain
35. Courtesy of the National Science Foundation. Tube worms, which live at hydrothermal vents. Public Domain
36. Zappy's. Example of a marine food chain. CC BY-NC 3.0
37. Courtesy of Gordon T Taylor/US National Oceanic and Atmospheric Administration. Microscopic diatoms are a type of phytoplankton. Public Domain
38. Courtesy of NOAA. Picture of a copepod, an example food source for larger animals. Public Domain
39. User:Daderot/Wikimedia Commons. Picture of a kelp forest, which grows in the neritic zone. Public Domain
40. Mussels: Rebecca Wood; Sea star: Joi Ito; Moon jelly: Lyn Gateley; Squid: fto mizno. Picture of mussels, a sea star, moon jelly, and squid. CC BY 2.0
41. Terry Goss. Picture of a Great White Shark. CC BY 2.5
42. NOAA's National Ocean Services. Picture of a sea turtle. CC BY 2.0
43. (a) Michele Lamberti; (b) and (c) Courtesy of Duncan Wright, US Fish and Wildlife Service. Picture of shorebirds, seabirds, and an albatross. (a) CC BY 2.0; (b) and (c) Public Domain
44. (a) Ste Elmore; (b) NOAA's National Ocean Service; (c) Joe Robertson; (d) David Corby; (e) Ansgar Walk. Picture of the five types of marine mammals: cetaceans, sirenians, mustelids, pinnipeds, and polar bears. (a) CC BY 2.0; (b) CC BY 2.0; (c) CC BY 2.0; (d) CC BY 2.5; (e) CC BY 2.5
45. Erica Peterson. Polar bear swimming in the Arctic Ocean. CC BY 2.0

CHAPTER 7 The Atmosphere

Chapter Outline

7.1 Composition of the Atmosphere

- Describe the composition of the atmosphere.

Did life evolve to match the atmosphere or is the fit just coincidence?

Life as we know it would not survive if there were no ozone layer to protect it from high energy ultraviolet radiation. Most life needs oxygen to survive. Nitrogen is also needed, albeit in a different form from that found in the atmosphere. Greenhouse gases keep the temperature moderate so that organisms can live around the planet. Life evolved to match the conditions that were available and to some extent changed the atmosphere to suit its needs.

Composition of Air

Several properties of the atmosphere change with altitude, but the composition of the natural gases does not. The proportions of gases in the atmosphere are everywhere the same, with one exception. At about 20 km to 40 km above the surface, there is a greater concentration of ozone molecules than in other portions of the atmosphere. This is called the **ozone layer**.

Nitrogen and Oxygen

Nitrogen and oxygen together make up 99% of the planet's atmosphere. Nitrogen makes up the bulk of the atmosphere, but is not involved in geological or biological processes in its gaseous form. Nitrogen fixing is described in the chapter Life on Earth. Oxygen is extremely important because it is needed by animals for respiration. The rest of the gases are minor components but sometimes are very important (**Figure** 7.1).

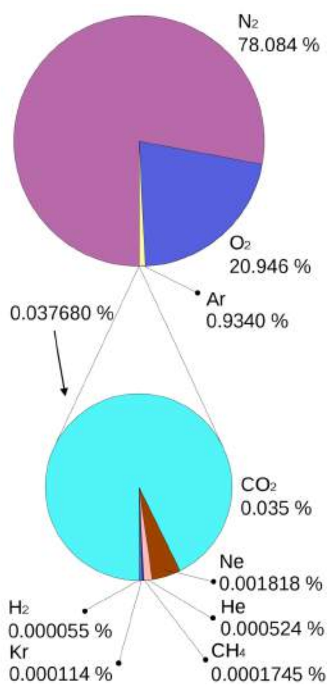


FIGURE 7.1

Nitrogen and oxygen make up 99% of the atmosphere; carbon dioxide is a very important minor component.

Water Vapor

Humidity is the amount of water vapor in the air. Humidity varies from place to place and season to season. This fact is obvious if you compare a summer day in Atlanta, Georgia, where humidity is high, with a winter day in Phoenix, Arizona, where humidity is low. When the air is very humid, it feels heavy or sticky. Dry air usually feels more comfortable. When humidity is high, water vapor makes up only about 4% of the atmosphere.

Where around the globe is mean atmospheric water vapor higher and where is it lower (**Figure** 7.2)? Why? Higher humidity is found around the equatorial regions because air temperatures are higher and warm air can hold more moisture than cooler air. Of course, humidity is lower near the polar regions because air temperature is lower.

Greenhouse Gases

Remember that greenhouse gases trap heat in the atmosphere. Important natural greenhouse gases include carbon dioxide, methane, water vapor, and ozone. CFCs and some other man-made compounds are also greenhouse gases.

Particulates

Some of what is in the atmosphere is not gas. Particles of dust, soil, fecal matter, metals, salt, smoke, ash, and other solids make up a small percentage of the atmosphere and are called **particulates**. Particles provide starting points

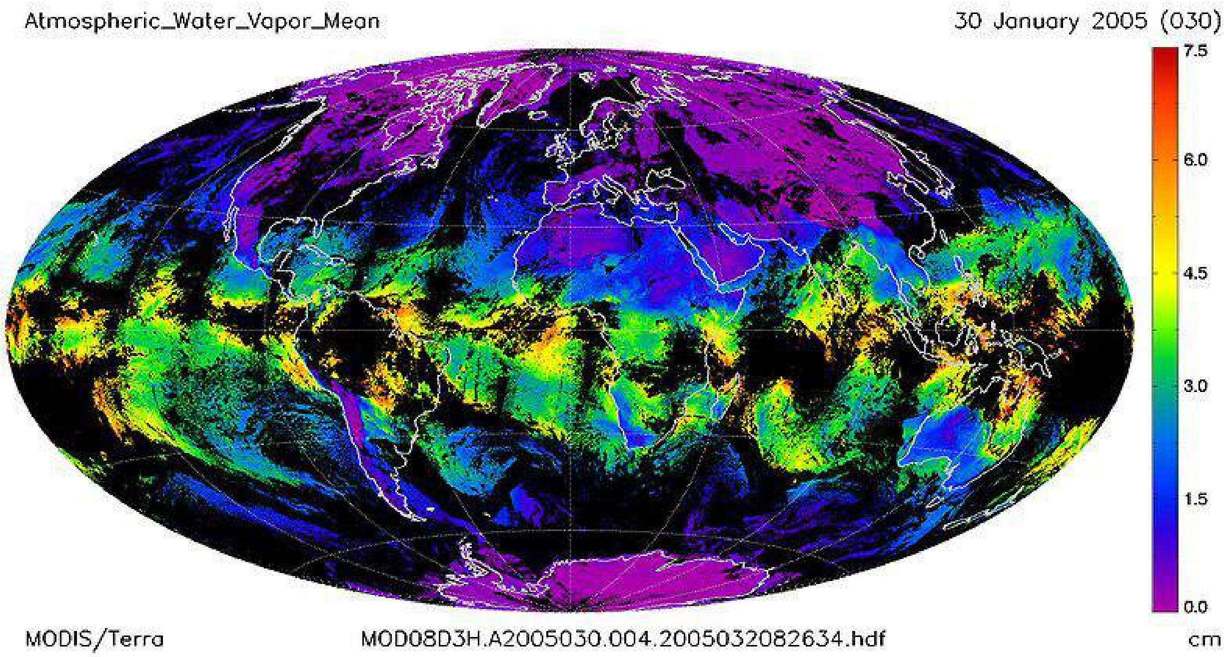


FIGURE 7.2
Mean winter atmospheric water vapor in the Northern Hemisphere when temperature and humidity are lower than they would be in summer.

(or nuclei) for water vapor to condense on and form raindrops. Some particles are pollutants.

Summary

- The major atmospheric gases are nitrogen and oxygen. The atmosphere also contains minor amounts of other gases, including carbon dioxide.
- Greenhouse gases trap heat in the atmosphere and include carbon dioxide, methane, water vapor, and ozone.
- Not everything in the atmosphere is gas; particulates are particles that are important as the nucleus of raindrops and snowflakes.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Ozone**

1. What is ozone?

2. Where is ozone found?

3. What does ozone do?

4. What does ozone consist of?

5. What does ozone absorb?

Review

1. What are the two major atmospheric gases and what roles do they play?
2. What are the important greenhouse gases?
3. What is humidity?

7.2 Pressure and Density of the Atmosphere

- Define air density and air pressure and explain how they change with increasing altitude.

Have your ears ever popped?

If your ears have ever "popped," you have experienced a change in air pressure. Ears "pop" because the air pressure is different on the inside and the outside.

Pressure and Density

The atmosphere has different properties at different elevations above sea level, or **altitudes**.

Density

The air density (the number of molecules in a given volume) decreases with increasing altitude. This is why people who climb tall mountains, such as Mt. Everest, have to set up camp at different elevations to let their bodies get used to the decreased air density (**Figure** 7.3).

Why does air density decrease with altitude? Gravity pulls the gas molecules towards Earth's center. The pull of gravity is stronger closer to the center, at sea level. Air is denser at sea level, where the gravitational pull is greater.

Pressure

Gases at sea level are also compressed by the weight of the atmosphere above them. The force of the air weighing down over a unit of area is known as its atmospheric pressure, or **air pressure**. Why are we not crushed? The molecules inside our bodies are pushing outward to compensate. Air pressure is felt from all directions, not just from above.

FIGURE 7.3
This bottle was closed at an altitude of 3,000 meters where air pressure is lower. When it was brought down to sea level, the higher air pressure caused the bottle to collapse.

At higher altitudes the atmospheric pressure is lower and the air is less dense than at lower altitudes. That's what makes your ears pop when you change altitude. Gas molecules are found inside and outside your ears. When you change altitude quickly, like when an airplane is descending, your inner ear keeps the density of molecules at the original altitude. Eventually the air molecules inside your ear suddenly move through a small tube in your ear to equalize the pressure. This sudden rush of air is felt as a popping sensation.

Summary

- Air density and pressure decrease with increasing altitude.
- Ears pop as air pressure inside and outside the ear equalizes.
- Gravity pulls more air molecules toward the center of the planet.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=7_yf-iRf8Vc

MEDIA
Click image to the left for more content.

1. What is pressure?
2. What does air have?
3. Where does the atmosphere end?
4. What is air pressure?
5. What is the air pressure in Key West, Florida?
6. Explain the relationship between air pressure and altitude.

Review

1. Why does air density decrease with altitude?
2. Temperature also decreases with altitude. How does that relate to the change in air density?
3. Why are we not crushed by the weight of the atmosphere on our shoulders?

7.3 Heat Transfer in the Atmosphere

- Explain how conduction and convection work in the atmosphere.

What could cause such a spectacular, swirling funnel of air?

For many people, this sight is unfamiliar. It is a tornado. Tornadoes happen when heat is rapidly transferred between layers in the atmosphere.

Heat Transfer in the Atmosphere

Heat moves in the atmosphere the same way it moves through the solid Earth or another medium. What follows is a review of the way heat flows, but applied to the atmosphere.

Radiation is the transfer of energy between two objects by electromagnetic waves. Heat radiates from the ground into the lower atmosphere.

In **conduction**, heat moves from areas of more heat to areas of less heat by direct contact. Warmer molecules vibrate rapidly and collide with other nearby molecules, transferring their energy. In the atmosphere, conduction is more effective at lower altitudes, where air density is higher. This transfers heat upward to where the molecules are spread further apart or transfers heat laterally from a warmer to a cooler spot, where the molecules are moving less vigorously.

Heat transfer by movement of heated materials is called **convection**. Heat that radiates from the ground initiates convection cells in the atmosphere (**Figure** 7.4).

What Drives Atmospheric Circulation?

Different parts of the Earth receive different amounts of solar radiation. Which part of the planet receives the most solar radiation? The Sun's rays strike the surface most directly at the Equator.

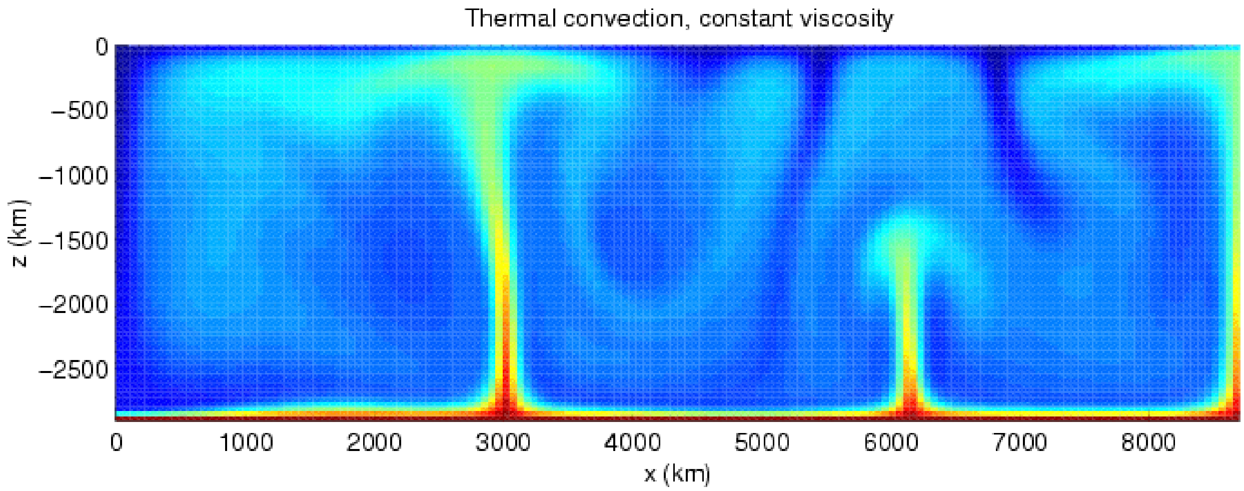


FIGURE 7.4
Thermal convection where the heat source is at the bottom and there is a ceiling at the top.

The difference in solar energy received at different latitudes drives atmospheric circulation.

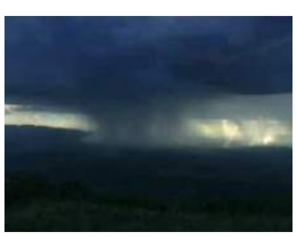
Summary

- In conduction, substances must be in direct contact as heat moves from areas of more heat to areas of less heat.
- In convection, materials move depending on their heat relative to nearby materials.
- The Equator receives more solar energy than other latitudes.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=ajQ3hm5JidU



MEDIA
Click image to the left for more content.

1. What powers our weather?
2. What does heat cause?
3. How does the tilt of the Earth affect heating?
4. What causes wind?

5. What occurs in the water?

Review

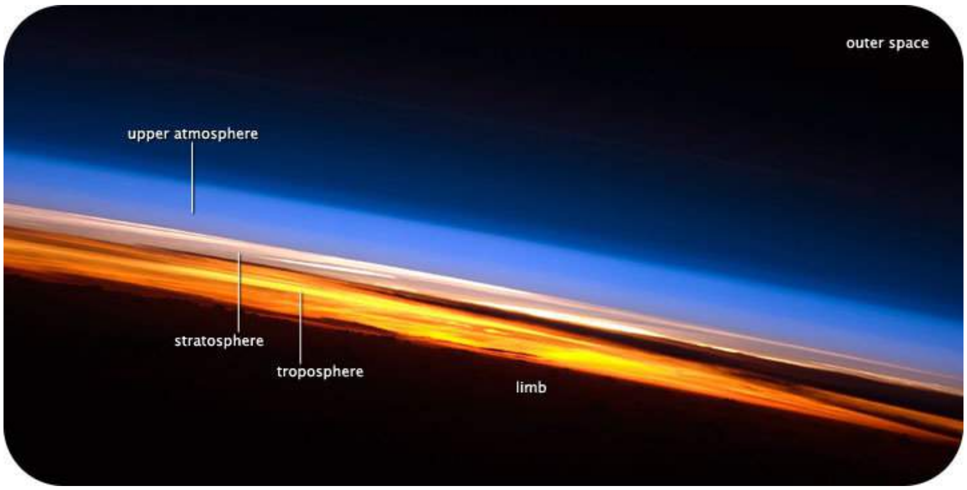
1. What is moving in conduction? What is moving in convection?

2. The poles experience 24 hours of daylight in their summer. Why do poles receive less solar radiation than the Equator?

3. What drives atmospheric circulation?

7.4 Temperature of the Atmosphere

- Define temperature gradient.
- Explain the relationship between air temperature and the layers of Earth's atmosphere.
- Describe the relationship between air temperature and density.



Did you know that you can see the layers of the atmosphere?

The layers of the atmosphere appear as different colors in this image from the International Space Station.

Air Temperature

The atmosphere is layered, corresponding with how the atmosphere's temperature changes with altitude. By understanding the way temperature changes with altitude, we can learn a lot about how the atmosphere works.

Warm Air Rises

Why does warm air rise (**Figure** 7.5)? Gas molecules are able to move freely, and if they are uncontained, as they are in the atmosphere, they can take up more or less space.

- When gas molecules are cool, they are sluggish and do not take up as much space. With the same number of molecules in less space, both air density and air pressure are higher.
- When gas molecules are warm, they move vigorously and take up more space. Air density and air pressure are lower.

Warmer, lighter air is more buoyant than the cooler air above it, so it rises. The cooler air then sinks down, because it is denser than the air beneath it. This is convection, which was described in the chapter Plate Tectonics.

Temperature Gradient

The property that changes most strikingly with altitude is air temperature. Unlike the change in pressure and density, which decrease with altitude, changes in air temperature are not regular. A change in temperature with distance is called a **temperature gradient**.

FIGURE 7.5
Papers held up by rising air currents above a radiator demonstrate the important principle that warm air rises.

Layers

The atmosphere is divided into layers based on how the temperature in that layer changes with altitude, the layer's temperature gradient (**Figure** 7.6). The temperature gradient of each layer is different. In some layers, temperature increases with altitude and in others it decreases. The temperature gradient in each layer is determined by the heat source of the layer (See opening image).

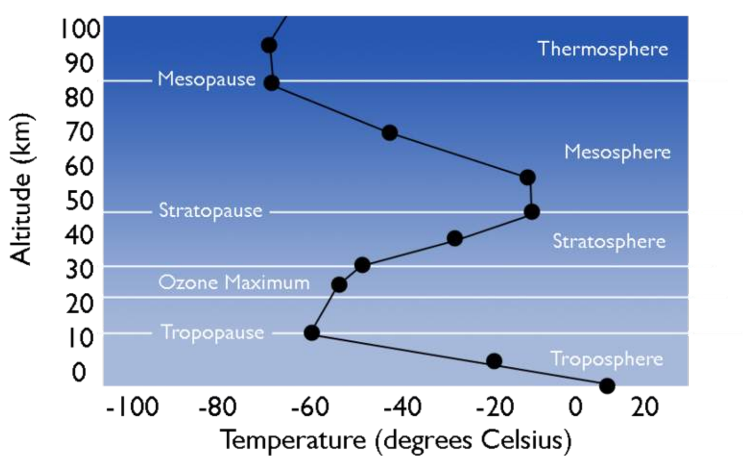
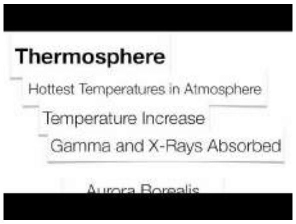


FIGURE 7.6
The four main layers of the atmosphere have different temperature gradients, creating the thermal structure of the atmosphere.

Most of the important processes of the atmosphere take place in the lowest two layers: the troposphere and the stratosphere.

This video is very thorough in its discussion of the layers of the atmosphere. Remember that the chemical composition of each layer is nearly the same except for the ozone layer that is found in the stratosphere **(8a)**: http://www.y outube.com/watch?v=S-YAKZoy1A0 (6:44).



MEDIA
Click image to the left for more content.

Summary

- Warm air rises, cool air sinks. Warm air has lower density.
- Different layers of the atmosphere have different temperature gradients.
- Temperature gradient is the change in temperature with distance.

Practice

Use this resource to answer the questions that follow

http://uccpbank.k12hsn.org/courses/APEnvironmentalScience/course%20files/multimedia/lesson19/animations/2d_-Earths_Atmosphere.html

1. Explain the extent of the troposphere.
2. What is the tropopause?
3. What is the temperature range of the troposphere?
4. What drives the Earth's weather?
5. Explain the structure of the stratosphere.
6. What is the temperature range of the stratosphere?
7. What does the stratosphere contain?
8. Explain the structure of the mesosphere.
9. What is the temperature range of the mesosphere?
10. Where is the thermosphere?
11. What does the thermosphere contain?
12. What is the temperature of the thermosphere?

Review

1. What causes convection in the atmosphere?
2. Why do the different layers of the atmosphere have different temperature gradients?
3. How does temperature change with distance in the atmosphere?

7.5 Troposphere

- Describe the characteristics and importance of the troposphere.
- Explain temperature inversion and its role in the troposphere.

Why is the troposphere important?

All of the wind, rain, and snow on Earth, as well as all of the air you breathe, is in the troposphere. The troposphere is the lowest and most important layer of the atmosphere. In this photo, a cumulonimbus cloud close to the surface over western Africa extends upward through the troposphere but does not pass into the stratosphere.

Temperature Gradient

The temperature of the **troposphere** is highest near the surface of the Earth and decreases with altitude. On average, the temperature gradient of the troposphere is 6.5^oC per 1,000 m (3.6^oF per 1,000 ft) of altitude.

Earth's surface is the source of heat for the troposphere. Rock, soil, and water on Earth absorb the Sun's light and radiate it back into the atmosphere as heat, so there is more heat near the surface. The temperature is also higher near the surface because gravity pulls in more gases. The greater density of gases causes the temperature to rise.

Notice that in the troposphere warmer air is beneath cooler air. This condition is unstable since warm air is less dense than cool air. The warm air near the surface rises and cool air higher in the troposphere sinks, so air in the troposphere does a lot of mixing. This mixing causes the temperature gradient to vary with time and place. The rising and sinking of air in the troposphere means that all of the planet's weather takes place in the troposphere.

Temperature Inversion

Sometimes there is a temperature **inversion**, in which air temperature in the troposphere increases with altitude and warm air sits over cold air. Inversions are very stable and may last for several days or even weeks. Inversions form:

- Over land at night or in winter when the ground is cold. The cold ground cools the air that sits above it, making this low layer of air denser than the air above it.
- Near the coast, where cold seawater cools the air above it. When that denser air moves inland, it slides beneath the warmer air over the land.

Since temperature inversions are stable, they often trap pollutants and produce unhealthy air conditions in cities (**Figure** 7.7).

FIGURE 7.7
Smoke makes a temperature inversion visible. The smoke is trapped in cold dense air that lies beneath a cap of warmer air.

At the top of the troposphere is a thin layer in which the temperature does not change with height. This means that the cooler, denser air of the troposphere is trapped beneath the warmer, less dense air of the stratosphere. Air from the troposphere and stratosphere rarely mix.

Summary

- In the troposphere warm air ordinarily sits below cooler air.
- With a temperature inversion, cold air sits below warm air and can't move.
- An inversion starts over land at night or in the winter, or near the coast.

Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/100-greatest-discoveries-shorts-atmospheric-layers.html

MEDIA
Click image to the left for more content.

1. Who was Leon Teisserenc de Bort?
2. What instruments did de Bort use?

3. What is the extent of the first layer?
4. What does troposphere mean?
5. What occurs in the troposphere?
6. What was the legacy if de Bort's studies?

Review

1. How does an inversion form at a coastal area?
2. What is the source of heat in the troposphere?
3. Describe the temperature gradient found in the troposphere.

7.6 Stratosphere

- Describe the stratosphere and the ozone layer within it.
- Explain the ozone layer's importance to life on Earth.

The pilot says, "We are now at our cruising altitude of 30,000 feet." Why do planes fly so high?

That altitude gets them out of the troposphere and into the stratosphere. Although the arc that they must travel is greater the further from the surface they get, fuel costs are lower because there is less friction due to the lower air density. Also, there is little air turbulence, which makes the passengers happier.

Stratosphere

There is little mixing between the **stratosphere**, the layer above the troposphere, and the troposphere below it. The two layers are quite separate. Sometimes ash and gas from a large volcanic eruption may burst into the stratosphere. Once in the stratosphere, it remains suspended there for many years because there is so little mixing between the two layers.

Temperature Gradient

In the stratosphere, temperature increases with altitude. What is the heat source for the stratosphere? The direct heat source for the stratosphere is the Sun. Air in the stratosphere is stable because warmer, less dense air sits over cooler, denser air. As a result, there is little mixing of air within the layer.

The Ozone Layer

The **ozone layer** is found within the stratosphere between 15 to 30 km (9 to 19 miles) altitude. The ozone layer has a low concentration of ozone; it's just higher than the concentration elsewhere. The thickness of the ozone layer varies by the season and also by latitude.

Ozone is created in the stratosphere by solar energy. Ultraviolet radiation splits an oxygen molecule into two oxygen atoms. One oxygen atom combines with another oxygen molecule to create an ozone molecule, O_3. The ozone is unstable and is later split into an oxygen molecule and an oxygen atom. This is a natural cycle that leaves some ozone in the stratosphere.

The ozone layer is extremely important because ozone gas in the stratosphere absorbs most of the Sun's harmful ultraviolet (UV) radiation. Because of this, the ozone layer protects life on Earth. High-energy UV light penetrates cells and damages DNA, leading to cell death (which we know as a bad sunburn). Organisms on Earth are not adapted to heavy UV exposure, which kills or damages them. Without the ozone layer to reflect UVC and UVB radiation, most complex life on Earth would not survive long.

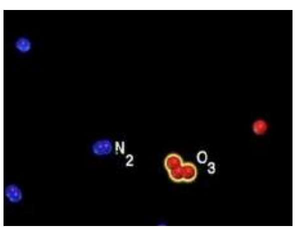
Summary

- There is little mixing between the troposphere, where all the turbulence is, and the stratosphere.
- Ozone gas protects life on Earth from harmful UV light, which damages cells.
- The ozone layer, in the stratosphere, has a higher concentration of ozone than other spots in the atmosphere.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=LNEm_2vOMqo



MEDIA
Click image to the left for more content.

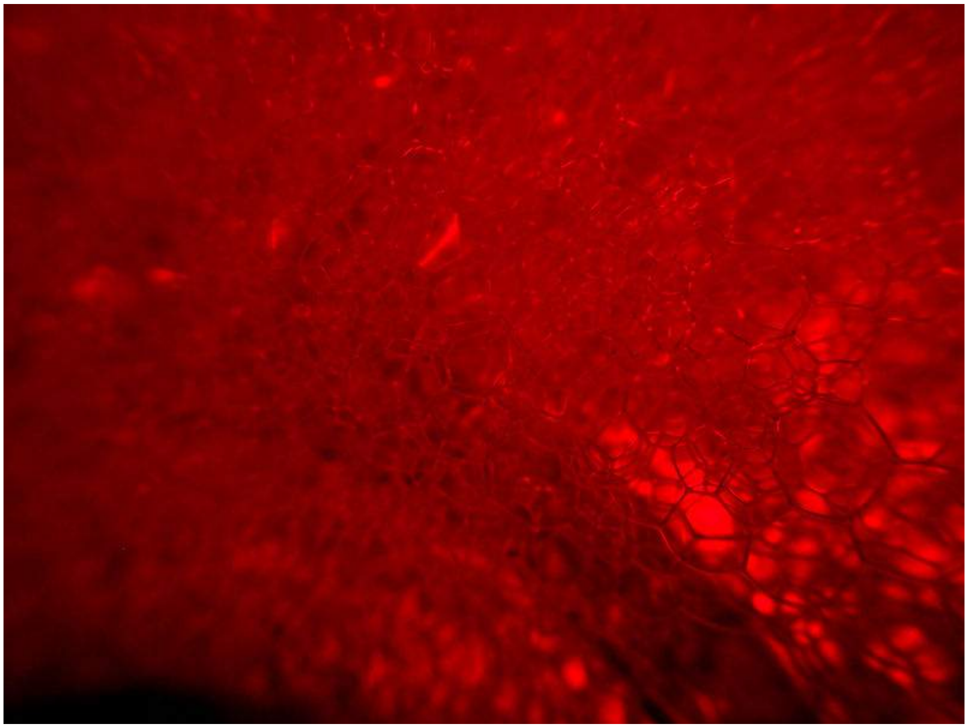
1. Where is the stratosphere located?
2. How is ozone created?
3. How is stable ozone created?
4. What does ozone become after it is broken apart?
5. Why is ozone important?

Review

1. Why doesn't air mix between the troposphere and stratosphere?
2. Why does one part of the stratosphere earn the name ozone layer?
3. What is the natural cycle that creates and destroys ozone molecules?

7.7 Mesosphere

- Describe the mesosphere.



What can make your blood boil?

Believe it or not, if you were in the mesosphere without a space suit, your blood would boil! This is because the pressure is so low that liquids would boil at normal body temperature.

Mesosphere

Above the stratosphere is the **mesosphere**. Temperatures in the mesosphere decrease with altitude. Because there are few gas molecules in the mesosphere to absorb the Sun's radiation, the heat source is the stratosphere below. The mesosphere is extremely cold, especially at its top, about -90^{o}C (-130^{o}F).

Air Density

The air in the mesosphere has extremely low density: 99.9% of the mass of the atmosphere is below the mesosphere. As a result, air pressure is very low (**Figure** 7.8). A person traveling through the mesosphere would experience severe burns from ultraviolet light since the ozone layer, which provides UV protection, is in the stratosphere below. There would be almost no oxygen for breathing. And, of course, your blood would boil at normal body temperature.

Summary

- The mesosphere has a very low density of gas molecules.

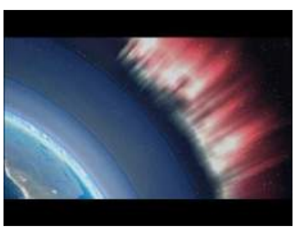
FIGURE 7.8
Although the mesosphere has extremely low pressure, it occasionally has clouds. The clouds in the photo are mesopheric clouds called **noctilucent clouds**.

- Temperature decreases in the mesosphere with altitude because the heat source is the stratosphere.
- The mesosphere is no place for human life!

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=mUZ4faPCiDY



MEDIA
Click image to the left for more content.

1. Where is the mesophere found?
2. What does it protect us from?
3. What are noctilucent clouds?
4. When can noctilucent clouds be seen?
5. Why can they only be seen at that time?

Review

1. Why would a person get severe burns in the mesosphere?
2. Why would a person's blood boil in the mesosphere?
3. How can meteors burn in the mesosphere when the air density is so low?

7.8 Thermosphere and Beyond

- Describe the characteristics of the far outer atmosphere.
- Explain how aurora form.

How can people live in the thermosphere?

The inhabitants of the International Space Station and other space stations live in the thermosphere. Of course, they couldn't survive in the thermosphere environment without being inside the station or inside a space suit, but right now people are living that far from Earth's surface.

Thermosphere

The density of molecules is so low in the **thermosphere** that one gas molecule can go about 1 km before it collides with another molecule. Since so little energy is transferred, the air feels very cold (See opening image).

Ionosphere

Within the thermosphere is the **ionosphere**. The ionosphere gets its name from the solar radiation that ionizes gas molecules to create a positively charged ion and one or more negatively charged electrons. The freed electrons travel within the ionosphere as electric currents. Because of the free ions, the ionosphere has many interesting characteristics.

At night, radio waves bounce off the ionosphere and back to Earth. This is why you can often pick up an AM radio station far from its source at night.

Magnetosphere

The Van Allen radiation belts are two doughnut-shaped zones of highly charged particles that are located beyond the atmosphere in the **magnetosphere**. The particles originate in solar flares and fly to Earth on the solar wind. Once trapped by Earth's magnetic field, they follow along the field's magnetic lines of force. These lines extend from above the Equator to the North Pole and also to the South Pole, then return to the Equator.

Aurora

When massive solar storms cause the Van Allen belts to become overloaded with particles, the result is the most spectacular feature of the ionosphere —the nighttime **aurora** (**Figure** 7.9). The particles spiral along magnetic field lines toward the poles. The charged particles energize oxygen and nitrogen gas molecules, causing them to light up. Each gas emits a particular color of light.

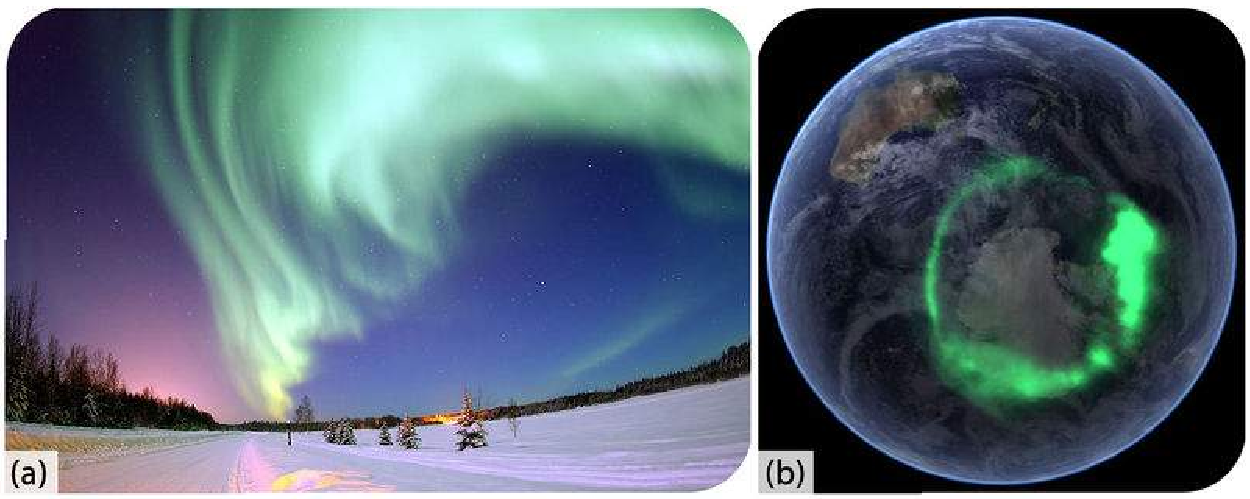


FIGURE 7.9

(a) Spectacular light displays are visible as the aurora borealis or northern lights in the Northern Hemisphere. (b) The aurora australis or southern lights encircles Antarctica.

What would Earth's magnetic field look like if it were painted in colors? It would look like the aurora! This QUEST video looks at the aurora, which provides clues about the solar wind, Earth's magnetic field and Earth's atmosphere.

Watch it at http://science.kqed.org/quest/video/illuminating-the-northern-lights/ .

MEDIA

Click image to the left for more content.

Exosphere

There is no real outer limit to the **exosphere**, the outermost layer of the atmosphere; the gas molecules finally become so scarce that at some point there are no more. Beyond the atmosphere is the solar wind. The **solar wind** is made of high-speed particles, mostly protons and electrons, traveling rapidly outward from the Sun.

Summary

- The solar wind is made of high speed particles from the Sun that travel through the solar system.
- The particles that create the aurora travel along Earth's magnetic field lines.
- Solar radiation ionizes gas molecules that travel as electric currents.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=lT3J6a9p_o8

MEDIA
Click image to the left for more content.

1. Where does the aurora borealis begin?
2. What occurs in the Sun to release energy?
3. What is plasma? What does it do?
4. What is a solar storm?
5. How long does it take a solar storm to reach Earth?
6. What protects us from solar storms?
7. What causes the night time aurora?

Review

1. How did the ionosphere get its name?
2. Why and when can you pick up AM radio stations far from their sources?
3. What causes the aurora and where in the atmosphere does it take place?

7.9 Circulation in the Atmosphere

- Explain why atmospheric circulation occurs.

Why do we say Earth's temperature is moderate?

It may not look like it, but various processes work to moderate Earth's temperature across the latitudes. Atmospheric circulation brings warm equatorial air poleward and frigid polar air toward the Equator. If the planet had an atmosphere that was stagnant, the difference in temperature between the two regions would be much greater.

Air Pressure Zones

Within the troposphere are convection cells (**Figure** 7.10). Air heated at the ground rises, creating a **low pressure zone**. Air from the surrounding area is sucked into the space left by the rising air. Air flows horizontally at top of the troposphere; horizontal flow is called **advection**. The air cools until it descends. When the air reaches the ground, it creates a **high pressure zone**. Air flowing from areas of high pressure to low pressure creates winds. The greater the pressure difference between the pressure zones, the faster the wind blows.

Warm air can hold more moisture than cool air. When warm air rises and cools in a low pressure zone, it may not be able to hold all the water it contains as vapor. Some water vapor may condense to form clouds or precipitation. When cool air descends, it warms. Since it can then hold more moisture, the descending air will evaporate water on the ground.

Wind

Air moving between large high and low pressure systems at the bases of the three major convection cells creates the global wind belts. These planet-wide air circulation systems profoundly affect regional climate. Smaller pressure

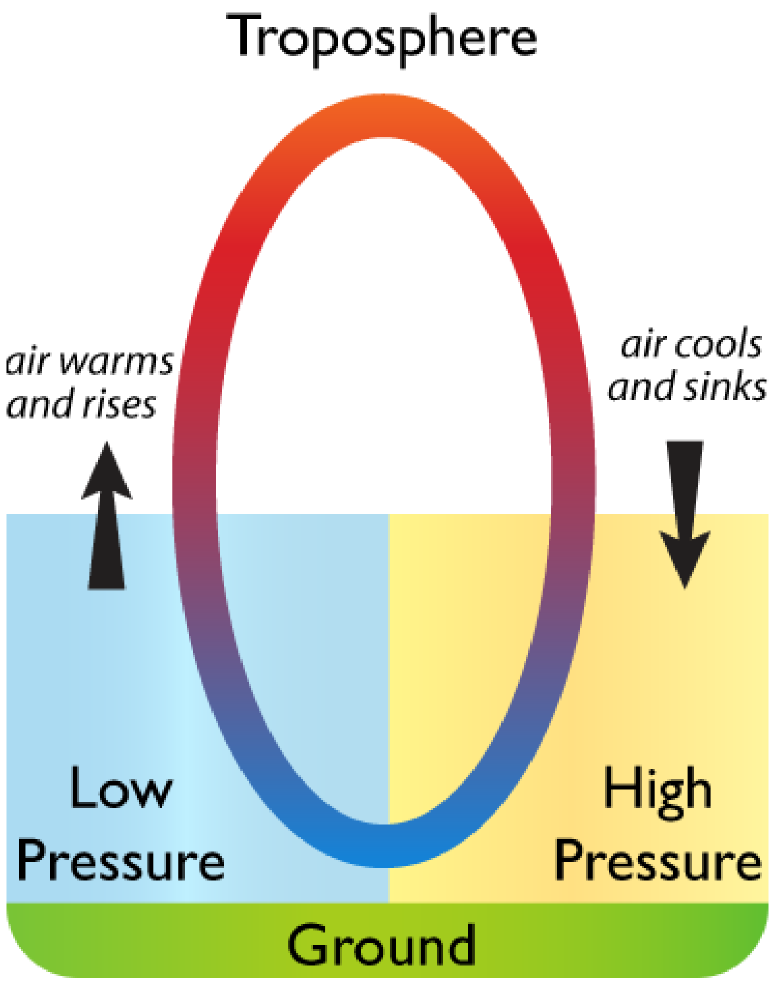


FIGURE 7.10
Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

systems create localized winds that affect the weather and climate of a local area.

An online guide to air pressure and winds from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fw/home.rxml .

Atmospheric Circulation

Two Convection Cells

Because more solar energy hits the Equator, the air warms and forms a low pressure zone. At the top of the troposphere, half moves toward the North Pole and half toward the South Pole. As it moves along the top of the troposphere it cools. The cool air is dense, and when it reaches a high pressure zone it sinks to the ground. The air is sucked back toward the low pressure at the Equator. This describes the convection cells north and south of the Equator.

Plus Coriolis Effect

If the Earth did not rotate, there would be one convection cell in the northern hemisphere and one in the southern with the rising air at the Equator and the sinking air at each pole. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the Coriolis effect must be taken into account.

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the Coriolis effect (**Figure** 7.11). Air rises at the Equator, but as it moves toward the pole at the top of the troposphere, it deflects to the right. (Remember that it just appears to deflect to the right because the ground beneath it moves.) At about 30°N latitude, the air from the Equator meets air flowing toward the Equator from the higher latitudes. This air is cool because it has come from higher latitudes. Both batches of air descend, creating a high pressure zone. Once on the ground, the air returns to the Equator. This convection cell is called the Hadley Cell and is found between 0° and 30°N.

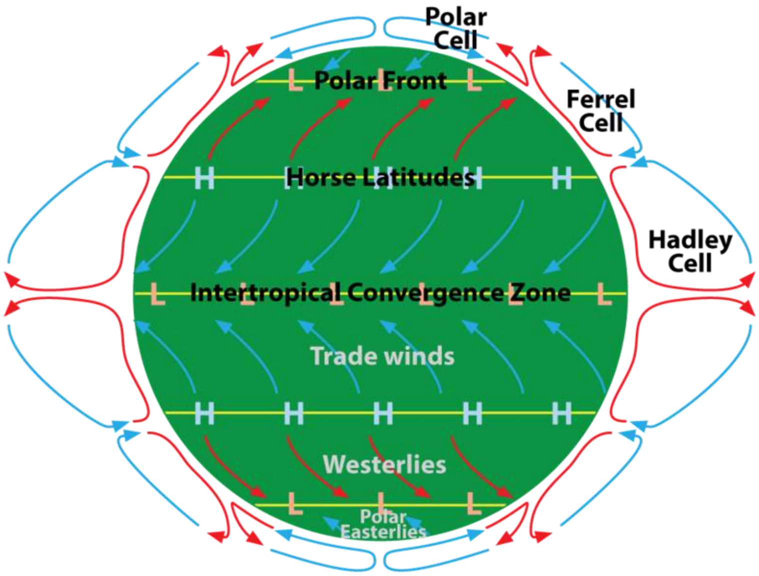


FIGURE 7.11
The atmospheric circulation cells, showing direction of winds at Earth's surface.

Equals Three Convection Cells

There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30°N and 50° to 60°N. This cell shares its southern, descending side with the Hadley cell to its south. Its northern rising limb is shared with the Polar cell located between 50°N to 60°N and the North Pole, where cold air descends.

Plus Three in the Southern Hemisphere

There are three mirror image circulation cells in the Southern Hemisphere. In that hemisphere, the Coriolis effect makes objects appear to deflect to the left. The total number of atmospheric circulation cells around the globe is six.

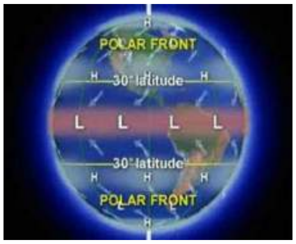
Summary

- The atmosphere has six major convection cells, three in the northern hemisphere and three in the southern.
- Coriolis effect results in there being three convection cells per hemisphere rather than one.
- Winds blow at the base of the atmospheric convection cells.

Practice

Use this resource to answer the questions that follow.

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



MEDIA

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1. Where is insolation strongest?
2. What type of pressure occurs at the Equator?
3. What type of pressure occurs at the poles?
4. What are Hadley cells?
5. Where does convection occur?
6. How do surface winds move?
7. What is the polar front?
8. How does air move at high altitudes?

Review

1. Diagram and label the parts of a convection cell in the troposphere.
2. How many major atmospheric convection cells would there be without Coriolis effect? Where would they be?
3. How does Coriolis effect change atmospheric convection?

7.10 Heat Budget of Planet Earth

- Explain Earth's heat budget and its relationship to solar radiation.

How does heat on Earth resemble a household budget?

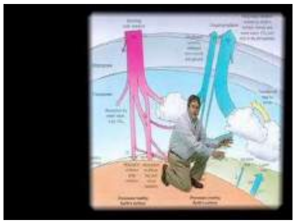
The heat left on Earth is heat in minus heat out. If more energy comes into the system than goes out of the system, the planet warms. If less energy goes into the system than goes out of the system, the planet cools. Replace the word "money" for "heat" and "on Earth" to "in your bank account" and you describe a household budget. Of course, Earth's heat budget is a lot more complex than a simple household budget.

Heat at Earth's Surface

About half of the solar radiation that strikes the top of the atmosphere is filtered out before it reaches the ground. This energy can be absorbed by atmospheric gases, reflected by clouds, or scattered. Scattering occurs when a light wave strikes a particle and bounces off in some other direction.

About 3% of the energy that strikes the ground is reflected back into the atmosphere. The rest is absorbed by rocks, soil, and water and then radiated back into the air as heat. These infrared wavelengths can only be seen by infrared sensors.

The basics of Earth's annual heat budget are described in this video: http://www.youtube.com/watch?v=mjj2i3hNQF0 (5:40).



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The Heat Budget

Because solar energy continually enters Earth's atmosphere and ground surface, is the planet getting hotter? The answer is no (although the next section contains an exception), because energy from Earth escapes into space through the top of the atmosphere. If the amount that exits is equal to the amount that comes in, then average global temperature stays the same. This means that the planet's heat budget is in balance. What happens if more energy comes in than goes out? If more energy goes out than comes in?

To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy is different at different latitudes. Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why? See the **Table** 7.1.

TABLE 7.1: The Amount of Incoming Solar Energy

	Day Length	Sun Angle	Solar Radiation	Albedo
Equatorial Region	Nearly the same all year	High	High	Low
Polar Regions	Night 6 months	Low	Low	High

Note: Colder temperatures mean more ice and snow cover the ground, making albedo relatively high.

This animation shows the average surface temperature across the planet as it changes through the year: Monthly Mean Temperatures at http://upload.wikimedia.org/wikipedia/commons/b/b3/MonthlyMeanT.gif .

The difference in solar energy received at different latitudes drives atmospheric circulation.

Summary

- Incoming solar radiation is absorbed by atmospheric gases, reflected by clouds, or scattered.
- Much of the radiation that strikes the ground is radiated back into the atmosphere as heat.
- More solar radiation strikes the Equator than the poles.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=JFfD6jn_OvA

MEDIA
Click image to the left for more content.

1. What does CERES measure?
2. What does the acronym CERES stand for?
3. What is the ideal radiation budget?
4. How much of the Sun's radiation is reflected?
5. How much energy does the ocean absorb?
6. What are scientists finding with CERES?
7. Why is the Earth warming?
8. What is a carbon footprint?

Review

1. If the Sun suddenly started to emit more energy, what would happen to Earth's heat budget and the planet's temperature?
2. If more greenhouse gases were added to the atmosphere, what would happen to Earth's heat budget and the planet's temperature?
3. What happens to sunlight that strikes the ground?

7.11 Solar Energy and Latitude

- Describe the different amounts of solar energy that strike at different latitudes.

This is Antarctica. What season is this?

The Sun is always up, even in the middle of the night. That's the photo on the left. In the day, the Sun never gets too high in the sky. That's the photo on the right. So, this is summer. In the winter, it's just dark in Antarctica.

Energy and Latitude

Different parts of Earth's surface receive different amounts of sunlight (**Figure** 7.12). 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.

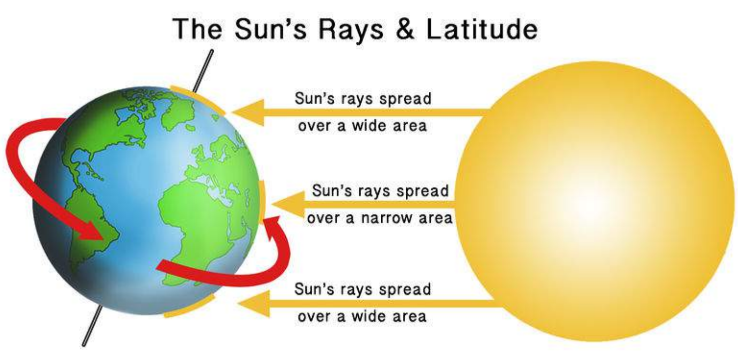

FIGURE 7.12
The lowest latitudes get the most energy from the Sun. The highest latitudes get the least.

The difference in solar energy received at different latitudes drives **atmospheric circulation**. Places that get more solar energy have more heat. Places that get less solar energy have less heat. Warm air rise, and cool air sinks. These principles mean that air moves around the planet. The heat moves around the globe in certain ways. This determines the way the atmosphere moves.

Vocabulary

- **atmospheric circulation**: The major movements of air in the atmosphere.

Summary

- A lot of the solar energy that reaches Earth hits the Equator.
- Much less solar energy gets to the poles.
- The difference in the amount of solar energy drives atmospheric circulation.

Practice

Use the resource below to answer the questions that follow.

- **The Effect of Latitude on Solar Heating** at http://www.kidsgeo.com/geography-for-kids/0074-latitude-effects-temperature.php

1. What is latitude?
2. What does latitude mean to the heating of the Earth?
3. Why do high latitudes receive less sunlight?
4. What is the angle of incidence?

Review

1. The North Pole receives sunlight 24 hours a day in the summer. Why does it receive less solar radiation than the Equator?
2. What part of Earth receives the most solar radiation in a year? Why?
3. What makes the atmosphere move the way it does?

7.12 Air Masses

- Explain how air masses form, move, and influence weather.

Why do these air balloons rise?

Warm air rises and cool air sinks. In a hot air balloon, a heater heats the air inside the balloon. When the weight of the warm air plus the balloon is less than the weight of the cooler air outside the balloon, the balloon will rise. Air masses work on the same principles, rising and falling when they confront an obstacle, such as another air mass.

What is an Air Mass?

An **air mass** is a batch of air that has nearly the same temperature and humidity (**Figure** 7.13). An air mass acquires these characteristics above an area of land or water known as its source region. When the air mass sits over a region for several days or longer, it picks up the distinct temperature and humidity characteristics of that region.

Air Mass Formation

Air masses form over a large area; they can be 1,600 km (1,000 miles) across and several kilometers thick. Air masses form primarily in high pressure zones, most commonly in polar and tropical regions. Temperate zones are ordinarily too unstable for air masses to form. Instead, air masses move across temperate zones, so the middle latitudes are prone to having interesting weather.

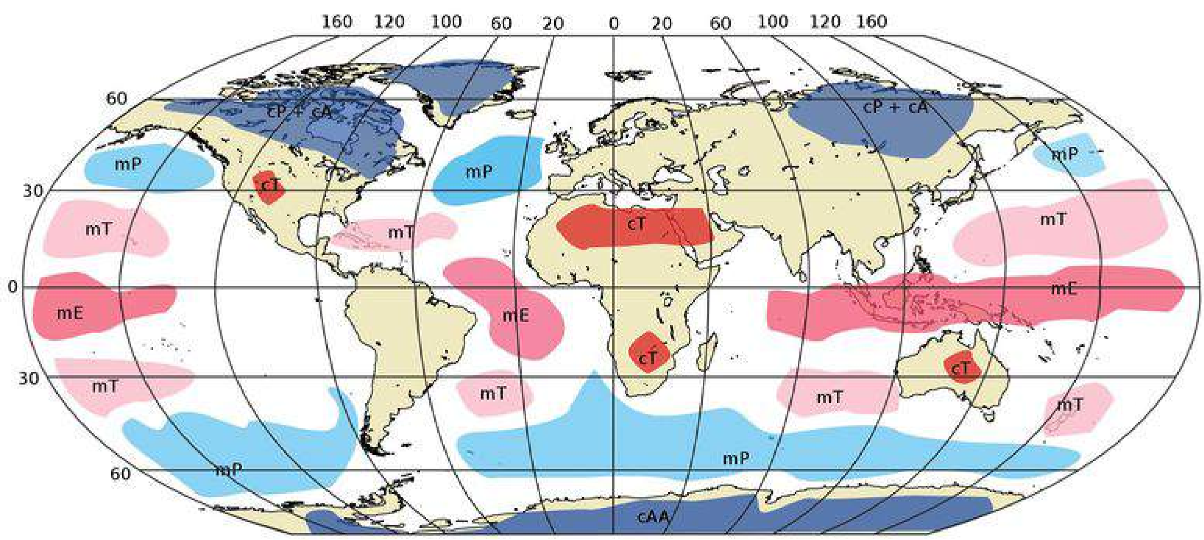

FIGURE 7.13

The source regions of air masses found around the world. Symbols: (1) origin over a continent (c) or an ocean (m, for maritime); (2) arctic (A), polar (P,) tropical (T), and equatorial (E); (3) properties relative to the ground it moves over: k, for colder, w for warmer.

What does an air mass with the symbol cPk mean? The symbol cPk is an air mass with a continental polar source region that is colder than the region it is now moving over.

Air Mass Movement

Air masses are slowly pushed along by high-level winds. When an air mass moves over a new region, it shares its temperature and humidity with that region. So the temperature and humidity of a particular location depends partly on the characteristics of the air mass that sits over it.

Storms

Storms arise if the air mass and the region it moves over have different characteristics. For example, when a colder air mass moves over warmer ground, the bottom layer of air is heated. That air rises, forming clouds, rain, and sometimes thunderstorms. How would a moving air mass form an inversion? When a warmer air mass travels over colder ground, the bottom layer of air cools and, because of its high density, is trapped near the ground.

Moderate Temperature

In general, cold air masses tend to flow toward the Equator and warm air masses tend to flow toward the poles. This brings heat to cold areas and cools down areas that are warm. It is one of the many processes that act to balance out the planet's temperatures.

Figures and animations explain weather basics at this USA Today site: http://www.usatoday.com/weather/wstorm0.htm .

An online guide from the University of Illinois about air masses and fronts is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/af/home.rxml .

Summary

- An air mass has roughly the same temperature and humidity.
- Air masses form over regions where the air is stable for a long enough time that the air can take on the characteristics of the region.
- Air masses move when they are pushed by high level winds.

Practice

Use this resource to answer the questions that follow.

http://video.about.com/weather/Types-of-Air-Masses.htm

1. What is air mass?
2. What determines the types of air masses?
3. What is continental air?
4. What is maritine air?
5. What is tropical air?
6. What is polar air?
7. List the four types of air masses and give the abbreviation for each.
8. What characterizes arctic air?
9. What characterizes equatorial air?

Review

1. How do the movements of air masses moderate temperature?
2. Why do air masses form mostly in high pressure areas?
3. What is the relationship between air masses and storms?

7.13 Local Winds

- Describe the different types of local winds and explain how they are created.
- Explain how types of local winds influence climate.

How can they stand up?

When you try to walk against a 20 mile an hour wind it's not easy. Just standing up is like walking really fast!

Local Winds

Local winds result from air moving between small low and high pressure systems. High and low pressure cells are created by a variety of conditions. Some local winds have very important effects on the weather and climate of some regions.

Land and Sea Breezes

Since water has a very high specific heat, it maintains its temperature well. So water heats and cools more slowly than land. If there is a large temperature difference between the surface of the sea (or a large lake) and the land next to it, high and low pressure regions form. This creates local winds.

- **Sea breezes** blow from the cooler ocean over the warmer land in summer. Where is the high pressure zone and where is the low pressure zone (**Figure** 7.14)? Sea breezes blow at about 10 to 20 km (6 to 12 miles) per hour and lower air temperature much as 5 to 10^{o}C (9 to 18^{o}F).
- **Land breezes** blow from the land to the sea in winter. Where is the high pressure zone and where is the low pressure zone? Some warmer air from the ocean rises and then sinks on land, causing the temperature over the land to become warmer.

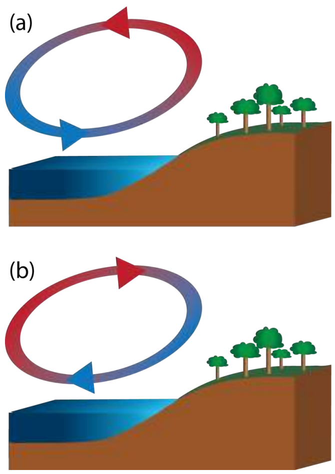

FIGURE 7.14
How do sea and land breezes moderate coastal climates?

Land and sea breezes create the pleasant climate for which Southern California is known. The effect of land and sea breezes are felt only about 50 to 100 km (30 to 60 miles) inland. This same cooling and warming effect occurs to a smaller degree during day and night, because land warms and cools faster than the ocean.

Monsoon Winds

Monsoon winds are larger scale versions of land and sea breezes; they blow from the sea onto the land in summer and from the land onto the sea in winter. Monsoon winds occur where very hot summer lands are next to the sea. Thunderstorms are common during monsoons (**Figure** 7.15).

FIGURE 7.15
In the southwestern United States relatively cool moist air sucked in from the Gulf of Mexico and the Gulf of California meets air that has been heated by scorching desert temperatures.

The most important monsoon in the world occurs each year over the Indian subcontinent. More than two billion residents of India and southeastern Asia depend on monsoon rains for their drinking and irrigation water. Back in the days of sailing ships, seasonal shifts in the monsoon winds carried goods back and forth between India and Africa.

Mountain and Valley Breezes

Temperature differences between mountains and valleys create mountain and valley breezes. During the day, air on mountain slopes is heated more than air at the same elevation over an adjacent valley. As the day progresses, warm air rises and draws the cool air up from the valley, creating a **valley breeze**. At night the mountain slopes cool more quickly than the nearby valley, which causes a **mountain breeze** to flow downhill.

Katabatic Winds

Katabatic winds move up and down slopes, but they are stronger mountain and valley breezes. Katabatic winds form over a high land area, like a high plateau. The plateau is usually surrounded on almost all sides by mountains. In winter, the plateau grows cold. The air above the plateau grows cold and sinks down from the plateau through gaps in the mountains. Wind speeds depend on the difference in air pressure over the plateau and over the surroundings. Katabatic winds form over many continental areas. Extremely cold katabatic winds blow over Antarctica and Greenland.

Chinook Winds (Foehn Winds)

Chinook winds (or **Foehn winds**) develop when air is forced up over a mountain range. This takes place, for example, when the westerly winds bring air from the Pacific Ocean over the Sierra Nevada Mountains in California. As the relatively warm, moist air rises over the windward side of the mountains, it cools and contracts. If the air is humid, it may form clouds and drop rain or snow. When the air sinks on the leeward side of the mountains, it forms a high pressure zone. The windward side of a mountain range is the side that receives the wind; the leeward side is the side where air sinks.

The descending air warms and creates strong, dry winds. Chinook winds can raise temperatures more than 20^{o}C (36^{o}F) in an hour and they rapidly decrease humidity. Snow on the leeward side of the mountain melts quickly. If precipitation falls as the air rises over the mountains, the air will be dry as it sinks on the leeward size. This dry, sinking air causes a **rainshadow effect** (**Figure** 7.16), which creates many of the world's deserts.

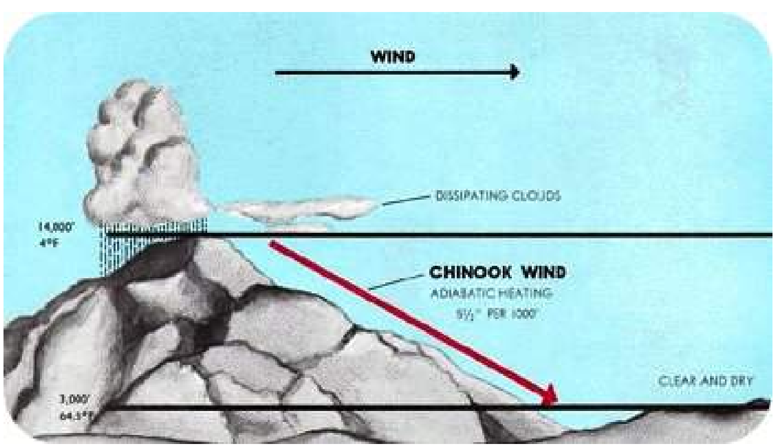

FIGURE 7.16
As air rises over a mountain it cools and loses moisture, then warms by compression on the leeward side. The resulting warm and dry winds are Chinook winds. The leeward side of the mountain experiences rainshadow effect.

Santa Ana Winds

Santa Ana winds are created in the late fall and winter when the Great Basin east of the Sierra Nevada cools, creating a high pressure zone. The high pressure forces winds downhill and in a clockwise direction (because of

Coriolis). The air pressure rises, so temperature rises and humidity falls. The winds blow across the Southwestern deserts and then race downhill and westward toward the ocean. Air is forced through canyons cutting the San Gabriel and San Bernardino mountains. (**Figure** 7.17).

FIGURE 7.17
The winds are especially fast through Santa Ana Canyon, for which they are named. Santa Ana winds blow dust and smoke westward over the Pacific from Southern California.

The Santa Ana winds often arrive at the end of California's long summer drought season. The hot, dry winds dry out the landscape even more. If a fire starts, it can spread quickly, causing large-scale devastation (**Figure** 7.18).

FIGURE 7.18
In October 2007, Santa Ana winds fueled many fires that together burned 426,000 acres of wild land and more than 1,500 homes in Southern California.

Desert Winds

High summer temperatures on the desert create high winds, which are often associated with monsoon storms. Desert winds pick up dust because there is not as much vegetation to hold down the dirt and sand. (**Figure** 7.19). A **haboob** forms in the downdrafts on the front of a thunderstorm.

FIGURE 7.19
A haboob in the Phoenix metropolitan area, Arizona.

Dust devils, also called whirlwinds, form as the ground becomes so hot that the air above it heats and rises. Air flows into the low pressure and begins to spin. Dust devils are small and short-lived, but they may cause damage.

Summary

- Water has high specific heat, so its temperature changes very slowly relative to the temperature of the land. This is the reason for sea and land breezes and monsoon winds.
- The cause of all of these winds is the differential heating of Earth's surface, whether it's due to the difference in water and land, the difference with altitude, or something else.
- Winds blow up and down slope, on and off land and sea, through deserts or over mountain passes.

Practice

Use these resources to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What are Chinook winds?
2. Where do Chinook winds occur?
3. Explain how Chinook winds work.

MEDIA
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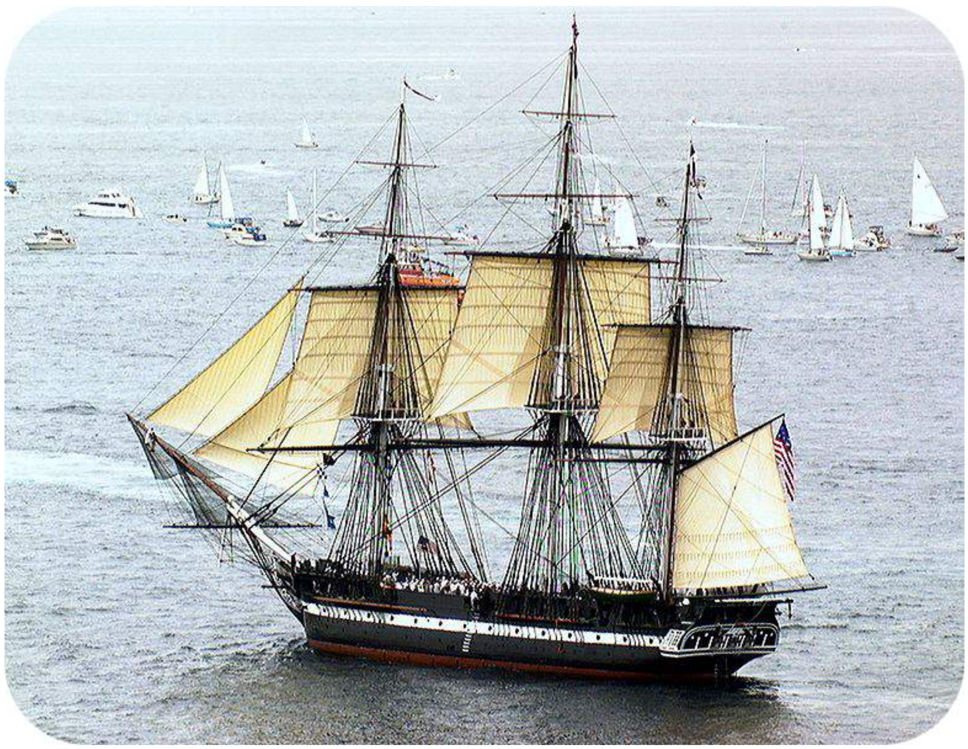
4. What are the Santa Ana winds?
5. Where do the Santa Ana winds occur?
6. What causes the Santa Ana winds?
7. Explain how the Santa Ana winds affects the weather.
8. What can be caused by the Santa Ana winds?

Review

1. How does the high specific heat of water result in the formation of sea and land breezes?
2. Describe the conditions that lead to Santa Ana winds.
3. How do Chinook winds lead to rainshadow effect?

7.14 Global Wind Belts

- Identify and define global winds.
- Explain how atmospheric circulation creates global winds, and how global winds influence climate.



Why were winds so important to the early explorers?

When Columbus sailed the ocean blue, and for centuries before and after, ocean travel depended on the wind. Mariners knew how to get where they were going and at what time of the year based on experience with the winds. Winds were named for their usefulness to sailors, such as the trade winds that facilitated commerce between people on opposite shores.

Global Wind Belts

Global winds blow in belts encircling the planet. Notice that the locations of these wind belts correlate with the atmospheric circulation cells. Air blowing at the base of the circulation cells, from high pressure to low pressure, creates the global wind belts.

The global wind belts are enormous and the winds are relatively steady (**Figure** 7.20).

The Global Winds

Let's look at the global wind belts in the Northern Hemisphere.

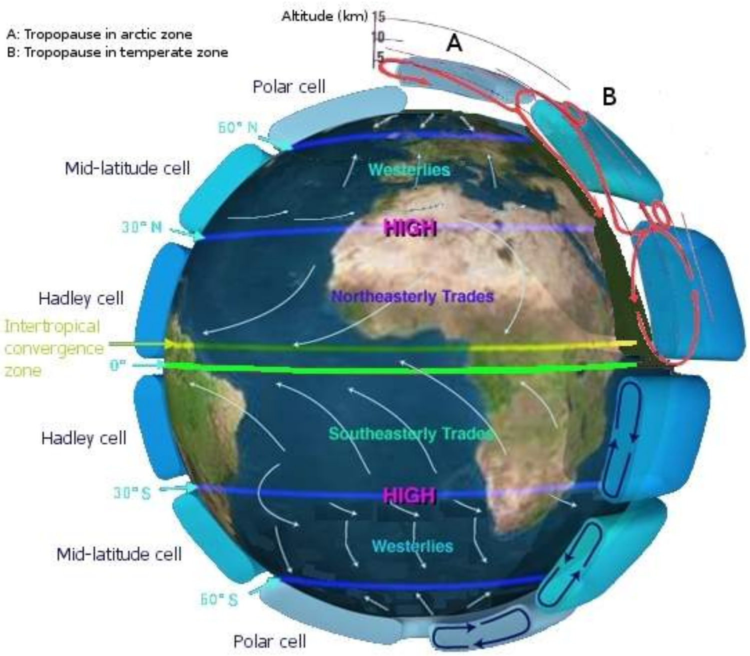
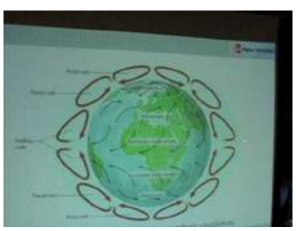


FIGURE 7.20
The major wind belts and the directions that they blow.

- In the Hadley cell air should move north to south, but it is deflected to the right by Coriolis. So the air blows from northeast to the southwest. This belt is the trade winds, so called because at the time of sailing ships they were good for trade.
- In the Ferrel cell air should move south to north, but the winds actually blow from the southwest. This belt is the westerly winds or westerlies.
- In the Polar cell, the winds travel from the northeast and are called the polar easterlies.

The wind belts are named for the directions from which the winds come. The westerly winds, for example, blow from west to east. These names hold for the winds in the wind belts of the Southern Hemisphere as well.

This video lecture discusses the 3-cell model of atmospheric circulation and the resulting global wind belts and surface wind currents: http://www.youtube.com/watch?v=HWFDKdxK75E (8:45).



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Global Winds and Precipitation

The high and low pressure areas created by the six atmospheric circulation cells also determine in a general way the amount of precipitation a region receives. Rain is common in low pressure regions due to rising air. Air sinking in high pressure areas causes evaporation; these regions are usually dry. These features have a great deal of influence on climate.

Polar Front

The **polar front** is the junction between the Ferrell and Polar cells. At this low pressure zone, relatively warm, moist air of the Ferrell Cell runs into relatively cold, dry air of the Polar cell. The weather where these two meet is extremely variable, typical of much of North America and Europe.

Jet Stream

The polar **jet stream** is found high up in the atmosphere where the two cells come together. A jet stream is a fast-flowing river of air at the boundary between the troposphere and the stratosphere. Jet streams form where there is a large temperature difference between two air masses. This explains why the polar jet stream is the world's most powerful (**Figure** 7.21).

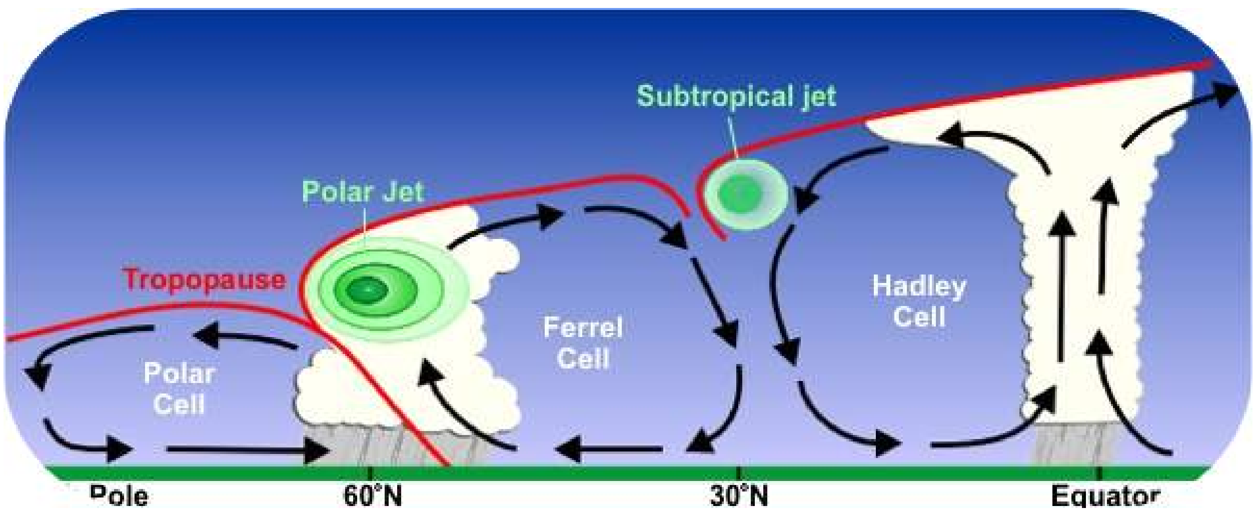


FIGURE 7.21
A cross section of the atmosphere with major circulation cells and jet streams. The polar jet stream is the site of extremely turbulent weather.

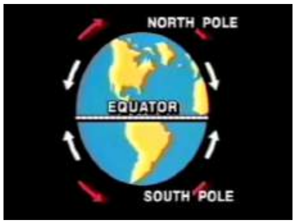
Jet streams move seasonally just as the angle of the Sun in the sky moves north and south. The polar jet stream, known as "the jet stream," moves south in the winter and north in the summer between about 30°N and 50° to 75°N.

Summary

- Global winds blow from high to low pressure at the base of the atmospheric circulation cells.
- The winds at the bases of the cells have names: the Hadley cell is the trade winds, the Ferrel Cell is the westerlies, and the polar cell is the polar easterlies.
- Where two cells meet, weather can be extreme, particularly at the polar front.

Practice

Use this resource to answer the questions that follow.



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1. What creates wind?
2. What are monsoons? How are they created?
3. What are local and regional winds?
4. What are the global wind patterns?
5. In what direction does the Earth rotate?
6. What is the Coriolis effect?
7. What are the Westerlies?

Review

1. What is a jet stream? What is "the" jet stream?
2. Why does a flight across the United States from San Francisco to New York City takes less time than the reverse trip?
3. Where on a circulation cell is there typically precipitation and where is there typically evaporation?

7.15 Precipitation

- Describe different types of precipitation and the conditions that create them.

Do you live in a place that gets lots of rain?

In some places it rains so much that people barely notice it. In others it rains so little that a rainy day is revered. Rain is not the only type of precipitation; see a few below.

Precipitation

Precipitation (**Figure** 7.22) is an extremely important part of weather. Water vapor condenses and usually falls to create precipitation.

Dew and Frost

Some precipitation forms in place. **Dew** forms when moist air cools below its dew point on a cold surface. **Frost** is dew that forms when the air temperature is below freezing.

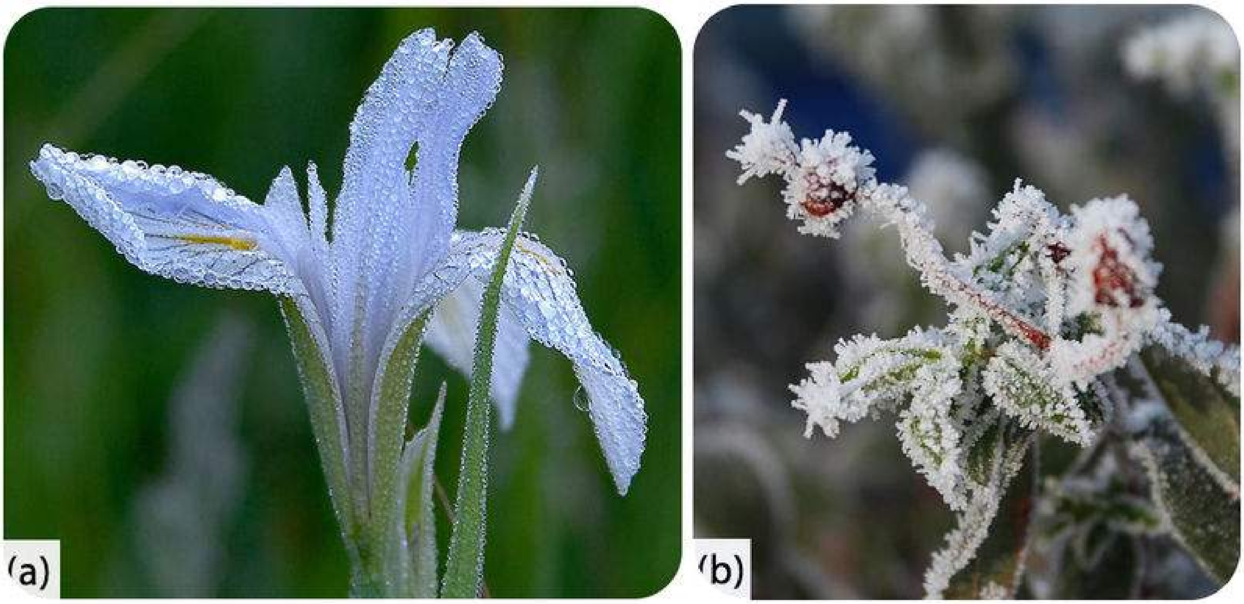


FIGURE 7.22
(a) Dew on a flower. (b) Hoar frost.

Precipitation From Clouds

The most common precipitation comes from clouds. **Rain** or snow droplets grow as they ride air currents in a cloud and collect other droplets (**Figure** 7.23). They fall when they become heavy enough to escape from the rising air currents that hold them up in the cloud. One million cloud droplets will combine to make only one rain drop! If temperatures are cold, the droplet will hit the ground as **snow**.

Other less common types of precipitation are **sleet** (**Figure** 7.24). Sleet is rain that becomes ice as it hits a layer of freezing air near the ground. If a frigid raindrop freezes on the frigid ground, it forms **glaze**. **Hail** forms in cumulonimbus clouds with strong updrafts. An ice particle travels until it finally becomes too heavy and it drops.

An online guide from the University of Illinois to different types of precipitation is seen here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cld/prcp/home.rxml .

Summary

- A surface can be colder than the surrounding air, causing the air to cool below its dew point.
- Rain droplets caught up in air currents within a cloud get larger by the addition of condensed droplets until they are too heavy and they fall.
- If the ground is very cold, rain can freeze to become sleet or glaze.

Practice

Use this resource to answer the questions that follow.

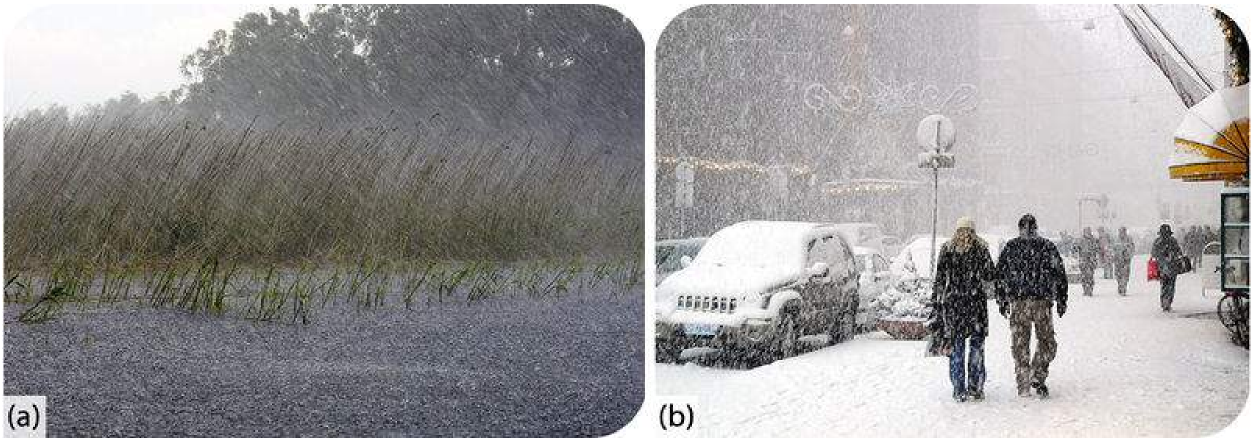


FIGURE 7.23
(a) Rain falls from clouds when the temperature is fairly warm. (b) Snow storm in Helsinki, Finland.

FIGURE 7.24
(a) Sleet. (b) Glaze. (c) Hail. This large hail stone is about 6 cm (2.5 inches) in diameter.

http://www.youtube.com/watch?v=kFFHo4T-g4E

MEDIA
Click image to the left for more content.

1. What is precipitation?
2. What is the most common form of precipitation?

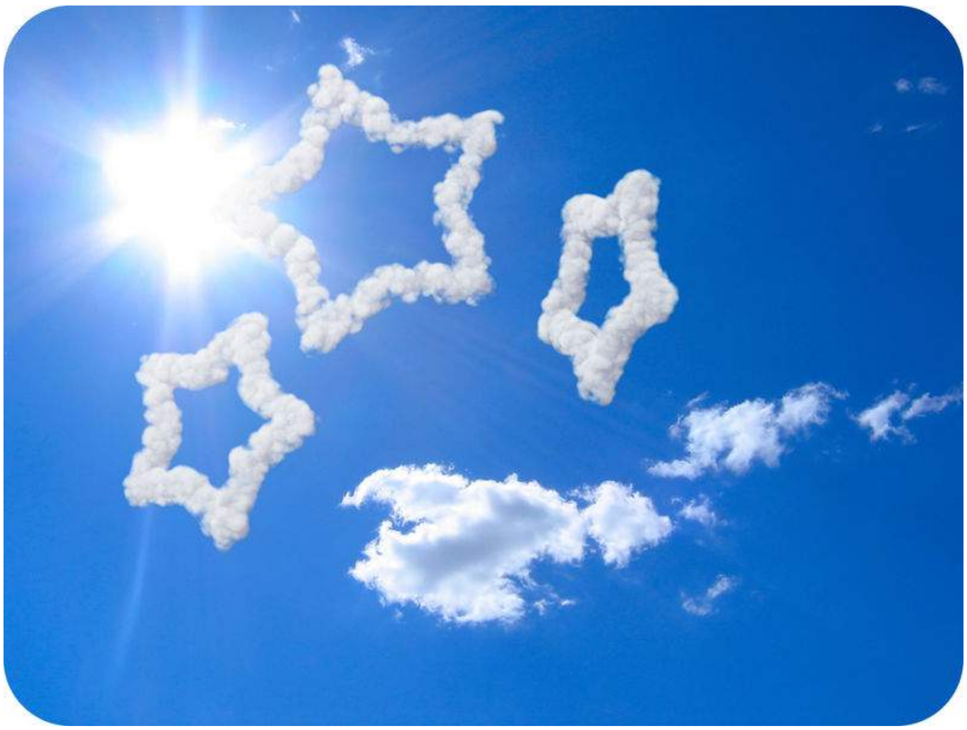
3. What is hail?
4. What is sleet?
5. What is snow?

Review

1. Describe how raindrops form.
2. Why does hail only come from cumulonimbus clouds?
3. How does sleet form?

7.16 Clouds

- Define humidity, and explain the relationship of humidity to cloud formation.
- Explain how clouds form and describe their influence on weather.
- Describe different types of clouds and fog.



Have you ever looked at the sky and found shapes in the clouds?

Clouds have a great effect on the weather and climate, but they can also be lovely (if they're not pouring rain on you). It's fun to sit and watch the clouds go by.

Humidity

Humidity is the amount of water vapor in the air in a particular spot. We usually use the term to mean **relative humidity**, the percentage of water vapor a certain volume of air is holding relative to the maximum amount it can contain. If the humidity today is 80%, it means that the air contains 80% of the total amount of water it can hold at that temperature. What will happen if the humidity increases to more than 100%? The excess water condenses and forms precipitation.

Since warm air can hold more water vapor than cool air, raising or lowering temperature can change air's relative humidity (**Figure** 7.25). The temperature at which air becomes saturated with water is called the air's **dew point**. This term makes sense, because water condenses from the air as dew if the air cools down overnight and reaches 100% humidity.

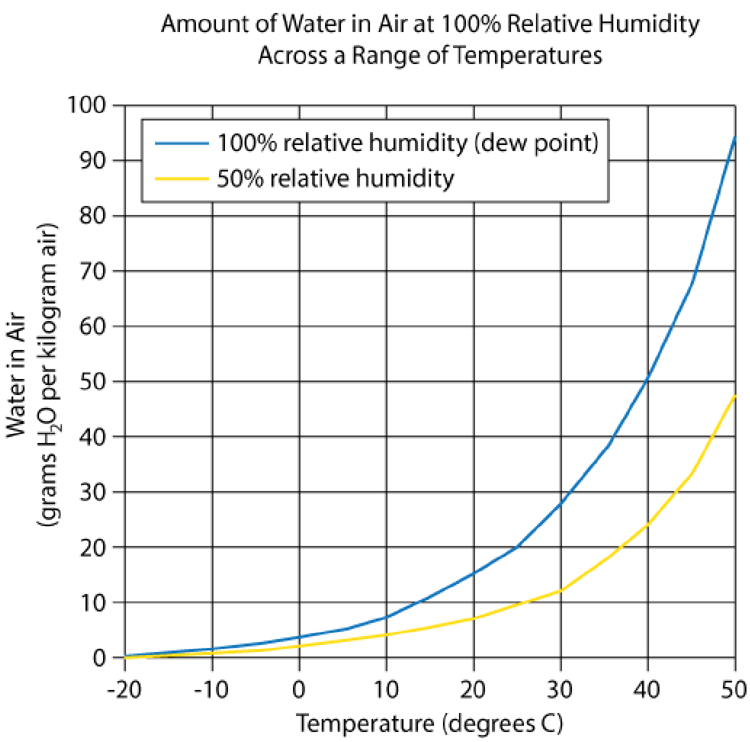


FIGURE 7.25
This diagram shows the amount of water air can hold at different temperatures. The temperatures are given in degrees Celsius.

Clouds

Water vapor is not visible unless it condenses to become a cloud. Water vapor condenses around a nucleus, such as dust, smoke, or a salt crystal. This forms a tiny liquid droplet. Billions of these water droplets together make a cloud.

Formation

Clouds form when air reaches its dew point. This can happen in two ways: (1) Air temperature stays the same but humidity increases. This is common in locations that are warm and humid. (2) Humidity remains the same, but temperature decreases. When the air cools enough to reach 100% humidity, water droplets form. Air cools when it comes into contact with a cold surface or when it rises.

Rising air creates clouds when it has been warmed at or near the ground level and then is pushed up over a mountain or mountain range or is thrust over a mass of cold, dense air.

Effects on Weather

Clouds have a big influence on weather:

- by preventing solar radiation from reaching the ground.
- by absorbing warmth that is re-emitted from the ground.
- as the source of precipitation.

When there are no clouds, there is less insulation. As a result, cloudless days can be extremely hot, and cloudless nights can be very cold. For this reason, cloudy days tend to have a lower range of temperatures than clear days.

Types of Clouds

Clouds are classified in several ways. The most common classification used today divides clouds into four separate cloud groups, which are determined by their altitude (**Figure** 7.26).

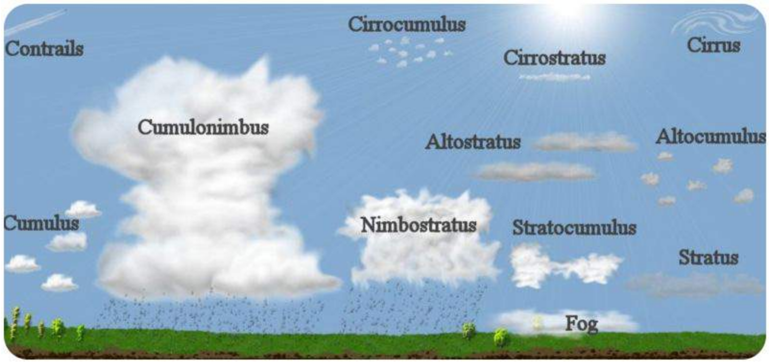


FIGURE 7.26
The four cloud types and where they are found in the atmosphere.

- High clouds form from ice crystals where the air is extremely cold and can hold little water vapor. Cirrus, cirrostratus, and cirrocumulus are all names of high clouds.
- Middle clouds, including altocumulus and altostratus clouds, may be made of water droplets, ice crystals or both, depending on the air temperatures. Thick and broad altostratus clouds are gray or blue-gray. They often cover the entire sky and usually mean a large storm, bearing a lot of precipitation, is coming.
- Low clouds are nearly all water droplets. Stratus, stratocumulus, and nimbostratus clouds are common low clouds. Nimbostratus clouds are thick and dark. They bring steady rain or snow.
- Vertical clouds, clouds with the prefix "cumulo-," grow vertically instead of horizontally and have their bases at low altitude and their tops at high or middle altitude. Clouds grow vertically when strong air currents are rising upward.

An online guide to cloud development and different cloud types from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cld/home.rxml .

Fog

Fog (**Figure** 7.27) is a cloud located at or near the ground . When humid air near the ground cools below its dew point, fog is formed. Each type of fog forms in a different way.

- Radiation fog forms at night when skies are clear and the relative humidity is high. As the ground cools, the bottom layer of air cools below its dew point. Tule fog is an extreme form of radiation fog found in some regions.
- San Francisco, California, is famous for its summertime advection fog. Warm, moist Pacific Ocean air blows over the cold California current and cools below its dew point. Sea breezes bring the fog onshore.
- Steam fog appears in autumn when cool air moves over a warm lake. Water evaporates from the lake surface and condenses as it cools, appearing like steam.
- Warm humid air travels up a hillside and cools below its dew point to create upslope fog.

Fog levels are declining along the California coast as climate warms. The change in fog may have big ecological changes for the state.

Learn more at http://www.kqed.org/quest/television/science-on-the-spot-science-of-fog .

FIGURE 7.27
(a) Tule fog in the Central Valley of California. (b) Advection fog in San Francisco. (c) Steam fog over a lake. (d) Upslope fog in Teresópolis city, Rio de Janeiro State, Brazil.

MEDIA
Click image to the left for more content.

Summary

- Air reaches its dew point when humidity increases or temperature decreases. Water droplets form when the air reaches 100% humidity.
- Clouds block solar radiation, absorb heat from the ground and are the source of snow and rain.
- Fog forms when there is a difference in temperature between the land and the air.

Making Connections

MEDIA

Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

http://www.atmosphere.mpg.de/enid/1__Clouds/-_Formation_of_clouds_t9.html

1. What is a cloud?
2. What causes clouds to form?
3. What is the Foehn effect?
4. What causes a front to form?
5. Explain what causes fog.

Review

1. Imagine a place with a daytime temperature of 45 degrees F. How will the nighttime temperature change if the sky is cloudy? How will it change if the sky is clear?
2. What set of conditions causes tule fog?
3. The low temperature a few degrees above freezing last night. Why is your car covered with frost this morning?

7.17 Weather Fronts

- Define different types of fronts.
- Explain how fronts create changes in weather.

How is a meteorological front like a military front?

In military usage, a front is where two opposing forces meet. This bayonet charge of French soldiers is opposing the Germans along the Western Front during World War I. How does a weather front resemble this?

Fronts

Two air masses meet at a **front**. At a front, the two air masses have different densities and do not easily mix. One air mass is lifted above the other, creating a low pressure zone. If the lifted air is moist, there will be condensation and precipitation. Winds are common at a front. The greater the temperature difference between the two air masses, the stronger the winds will be. Fronts are the main cause of stormy weather.

There are four types of fronts, three moving and one stationary. With cold fronts and warm fronts, the air mass at the leading edge of the front gives the front its name. In other words, a cold front is right at the leading edge of moving cold air and a warm front marks the leading edge of moving warm air.

Stationary Front

At a **stationary front** the air masses do not move (**Figure** 7.28). A front may become stationary if an air mass is stopped by a barrier, such as a mountain range. A stationary front may bring days of rain, drizzle, and fog. Winds usually blow parallel to the front, but in opposite directions. After several days, the front will likely break apart.

Cold Fronts

When a cold air mass takes the place of a warm air mass, there is a **cold front** (**Figure** 7.29).

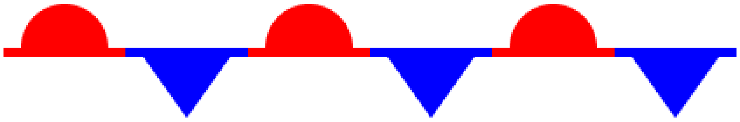


FIGURE 7.28
The map symbol for a stationary front has red domes for the warm air mass and blue triangles for the cold air mass.

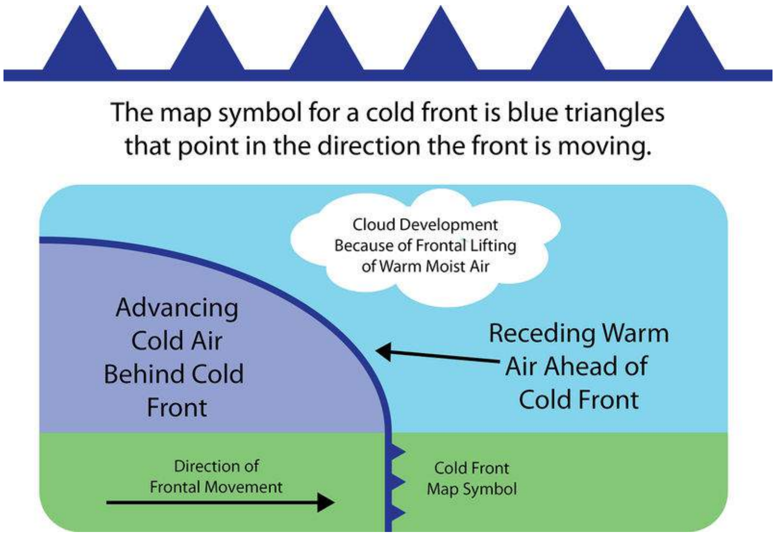


FIGURE 7.29
The cold air mass is dense, so it slides beneath the warm air mass and pushes it up.

Imagine that you are standing in one spot as a cold front approaches. Along the cold front, the denser, cold air pushes up the warm air, causing the air pressure to decrease (**Figure** 7.29). If the humidity is high enough, some types of cumulus clouds will grow. High in the atmosphere, winds blow ice crystals from the tops of these clouds to create cirrostratus and cirrus clouds. At the front, there will be a line of rain showers, snow showers, or thunderstorms with blustery winds (**Figure** 7.30). A **squall line** is a line of severe thunderstorms that forms along a cold front. Behind the front is the cold air mass. This mass is drier, so precipitation stops. The weather may be cold and clear or only partly cloudy. Winds may continue to blow into the low pressure zone at the front.

The weather at a cold front varies with the season.

- Spring and summer: the air is unstable so thunderstorms or tornadoes may form.
- Spring: if the temperature gradient is high, strong winds blow.
- Autumn: strong rains fall over a large area.
- Winter: the cold air mass is likely to have formed in the frigid arctic, so there are frigid temperatures and heavy snows.

Warm Fronts

At a **warm front**, a warm air mass slides over a cold air mass (**Figure** 7.31). When warm, less dense air moves over the colder, denser air, the atmosphere is relatively stable.

Imagine that you are on the ground in the wintertime under a cold winter air mass with a warm front approaching. The transition from cold air to warm air takes place over a long distance, so the first signs of changing weather appear long before the front is actually over you. Initially, the air is cold: the cold air mass is above you and the warm air mass is above it. High cirrus clouds mark the transition from one air mass to the other.

FIGURE 7.30
A squall line.

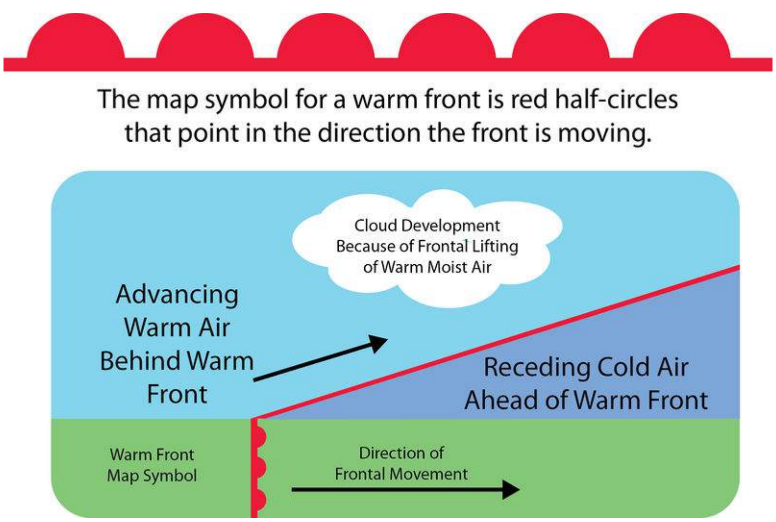


FIGURE 7.31
Warm air moves forward to take over the position of colder air.

Over time, cirrus clouds become thicker and cirrostratus clouds form. As the front approaches, altocumulus and altostratus clouds appear and the sky turns gray. Since it is winter, snowflakes fall. The clouds thicken and nimbostratus clouds form. Snowfall increases. Winds grow stronger as the low pressure approaches. As the front gets closer, the cold air mass is just above you but the warm air mass is not too far above that. The weather worsens. As the warm air mass approaches, temperatures rise and snow turns to sleet and freezing rain. Warm and cold air mix at the front, leading to the formation of stratus clouds and fog (**Figure** 7.32).

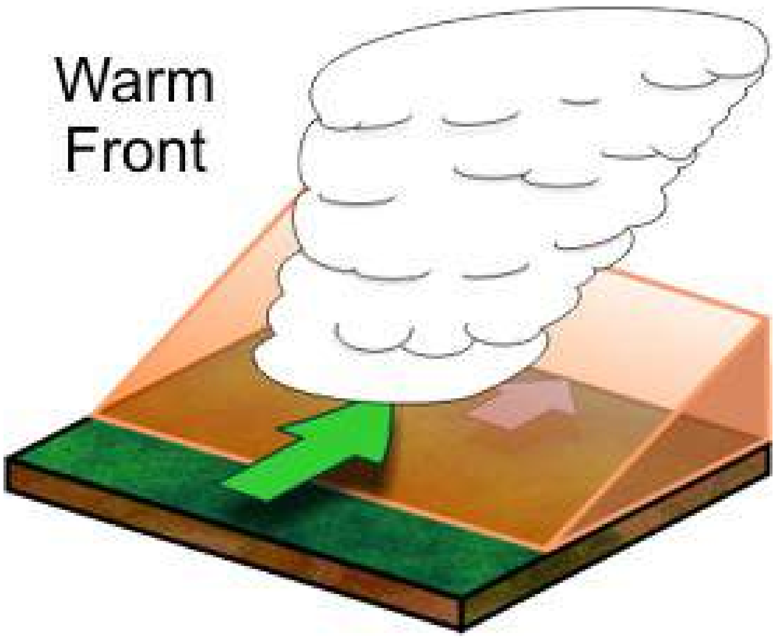


FIGURE 7.32
Cumulus clouds build at a warm front.

Occluded Front

An **occluded front** usually forms around a low pressure system (**Figure** 7.33). The occlusion starts when a cold front catches up to a warm front. The air masses, in order from front to back, are cold, warm, and then cold again.

FIGURE 7.33
The map symbol for an occluded front is mixed cold front triangles and warm front domes.

Coriolis effect curves the boundary where the two fronts meet towards the pole. If the air mass that arrives third is colder than either of the first two air masses, that air mass slip beneath them both. This is called a cold occlusion. If the air mass that arrives third is warm, that air mass rides over the other air mass. This is called a warm occlusion (**Figure** 7.34).

The weather at an occluded front is especially fierce right at the occlusion. Precipitation and shifting winds are typical. The Pacific Coast has frequent occluded fronts.

Summary

- Much of the weather occurs where at fronts where air masses meet.

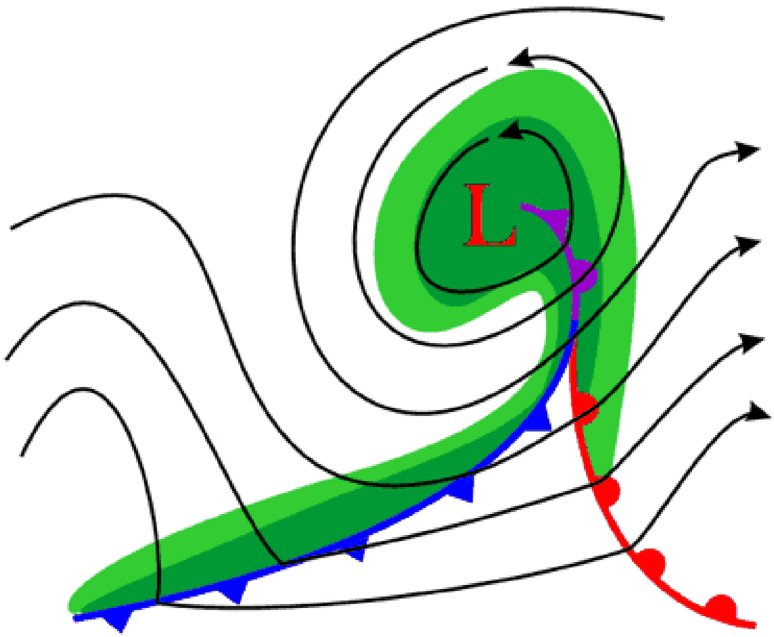


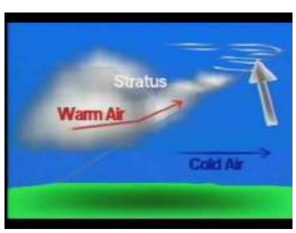
FIGURE 7.34
An occluded front with the air masses from front to rear in order as cold, warm, cold.

- In a warm front a warm air mass slides over a cold air mass. In a cold front a cold air mass slides under a warm air mass.
- An occluded front has three air masses, cold, warm, and cold.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=vPC5i6w3yDI



MEDIA
Click image to the left for more content.

1. What is a front?
2. How does a cold front form?
3. What forms along a cold front?
4. How does a warm front form?
5. What type of clouds form at warm fronts?
6. What type of precipitation is produced from a warm front?
7. What is a stationary front?
8. What type of weather can occur at an occluded front?

Review

1. What characteristics give warm fronts and cold fronts their names?
2. How does Coriolis effect create an occluded front?
3. Describe the cloud sequence that goes along with a warm front.

7.18 Predicting Weather

- Explain how meteorologists forecast the weather.

Does a picnic bring rain?

Weather forecasts are better than they ever have been. According to the World Meteorological Organization (WMO), a 5-day weather forecast today is as reliable as a 2-day forecast was 20 years ago. Now there's no excuse to be rained out on a picnic!

Numerical Weather Prediction

The most accurate weather forecasts are made by advanced computers, with analysis and interpretation added by experienced meteorologists. These computers have up-to-date mathematical models that can use much more data and make many more calculations than would ever be possible by scientists working with just maps and calculators. Meteorologists can use these results to give much more accurate weather forecasts and climate predictions.

In Numerical Weather Prediction (NWP), atmospheric data from many sources are plugged into supercomputers running complex mathematical models (**Figure** 7.35). The models then calculate what will happen over time at various altitudes for a grid of evenly spaced locations. The grid points are usually between 10 and 200 kilometers apart. Using the results calculated by the model, the program projects weather further into the future. It then uses these results to project the weather still further into the future, as far as the meteorologists want to go. Once a forecast is made, it is broadcast by satellites to more than 1,000 sites around the world.

NWP produces the most accurate weather forecasts, but as anyone knows, even the best forecasts are not always right.

Weather prediction is extremely valuable for reducing property damage and even fatalities. If the proposed track of a hurricane can be predicted, people can try to secure their property and then evacuate (**Figure** 7.36).

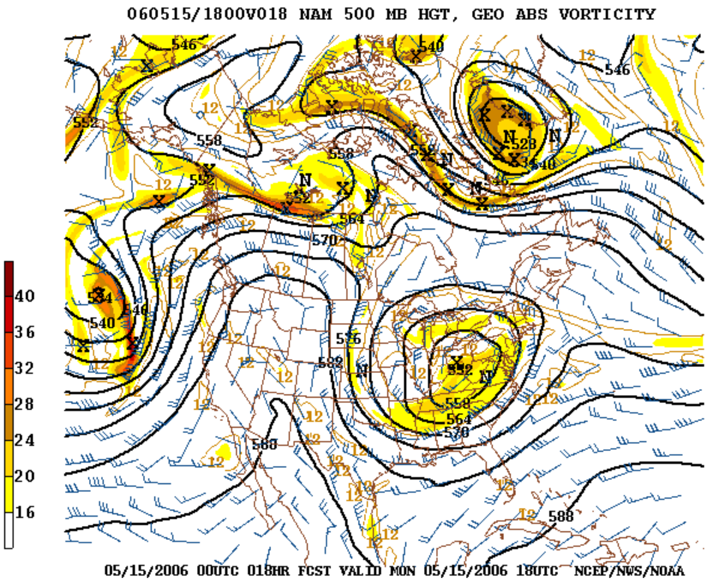


FIGURE 7.35
A weather forecast using numerical weather prediction.

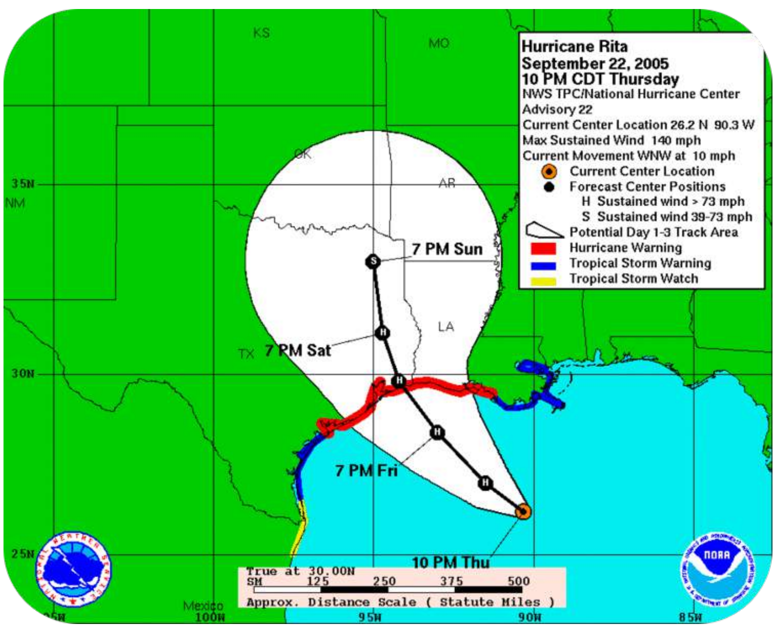


FIGURE 7.36
By predicting Hurricane Rita's path, it is likely that lives were saved.

Summary

- Meteorologists use computers to crank data through mathematical models to forecast the weather.
- Numerical weather prediction calculates what will happen to conditions horizontally and vertically over an area.
- Weather forecasts can go further into the future than ever.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=dqpFU5SRPgY

MEDIA
Click image to the left for more content.

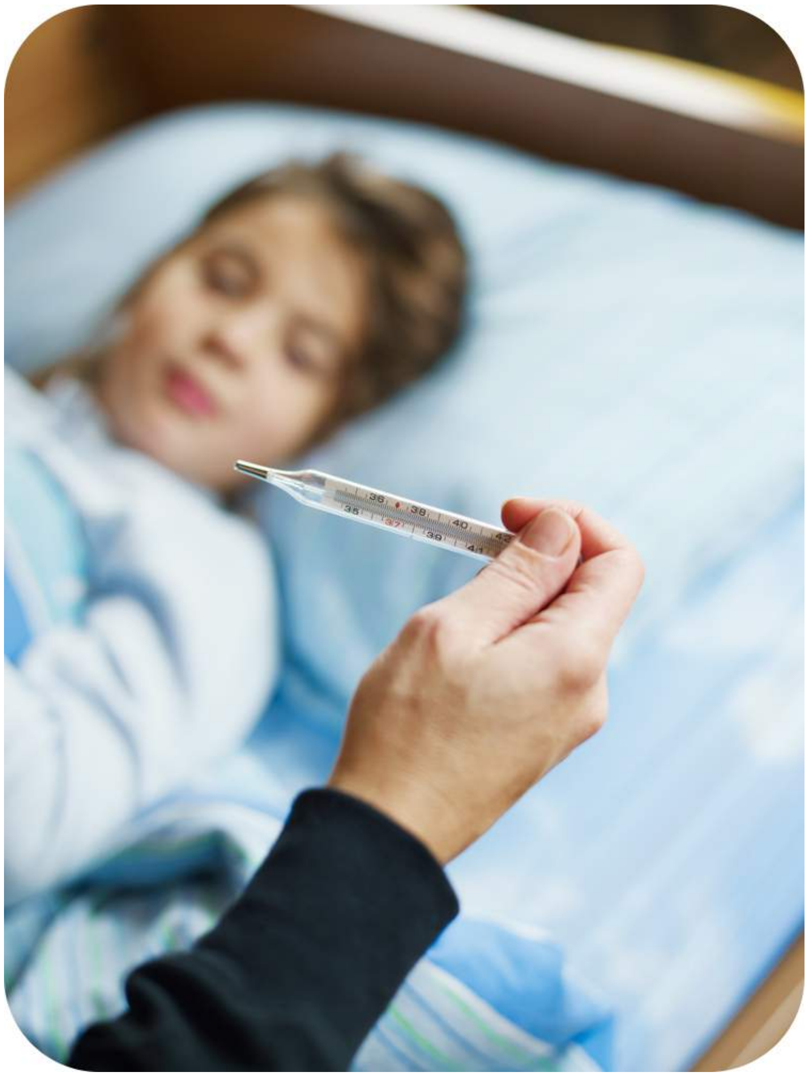
1. Why is weather difficult to predict?
2. What is the afternoon constellation? What does it do?
3. What are the basic shapes of clouds?
4. What is fog?
5. Why is it important to study clouds?
6. What will Cloudsat do? Why is this an improvement?

Review

1. What is numerical weather prediction?
2. Even with numerical weather prediction, meteorologists have a difficult time predicting the path of a hurricane more than a day or two into the future. Why?
3. One popular online weather prediction site goes 10 days out and another goes 15 days out. Why the discrepancy?

7.19 Collecting Weather Data

- Describe how scientists collect information about weather.



Can you forecast your health?

You can use a thermometer to better understand your health just like a meteorologist uses one to better understand the weather. A thermometer will help you forecast your health just as it will help to forecast the weather. Other tools, like barometers, also help with weather forecasting.

Collecting Weather Data

To make a weather forecast, the conditions of the atmosphere must be known for that location and for the surrounding area. Temperature, air pressure, and other characteristics of the atmosphere must be measured and the data collected.

Thermometer

Thermometers measure temperature. In an old-style mercury thermometer, mercury is placed in a long, very narrow tube with a bulb. Because mercury is temperature sensitive, it expands when temperatures are high and contracts when they are low. A scale on the outside of the thermometer matches up with the air temperature.

Some modern thermometers use a coiled strip composed of two kinds of metal, each of which conducts heat differently. As the temperature rises and falls, the coil unfolds or curls up tighter. Other modern thermometers measure infrared radiation or electrical resistance. Modern thermometers usually produce digital data that can be fed directly into a computer.

Barometer

Meteorologists use **barometers** to measure air pressure. A barometer may contain water, air, or mercury, but like thermometers, barometers are now mostly digital.

A change in barometric pressure indicates that a change in weather is coming. If air pressure rises, a high pressure cell is on the way and clear skies can be expected. If pressure falls, a low pressure cell is coming and will likely bring storm clouds. Barometric pressure data over a larger area can be used to identify pressure systems, fronts, and other weather systems.

Weather Stations

Weather stations contain some type of thermometer and barometer. Other instruments measure different characteristics of the atmosphere, such as wind speed, wind direction, humidity, and amount of precipitation. These instruments are placed in various locations so that they can check the atmospheric characteristics of that location (**Figure** 7.37). Weather stations are located on land, the surface of the sea, and in orbit all around the world.

FIGURE 7.37
A land-based weather station.

According to the World Meteorological Organization, weather information is collected from 15 satellites, 100 stationary buoys, 600 drifting buoys, 3,000 aircraft, 7,300 ships, and some 10,000 land-based stations.

Radiosondes

Radiosondes measure atmospheric characteristics, such as temperature, pressure, and humidity as they move through the air. Radiosondes in flight can be tracked to obtain wind speed and direction. Radiosondes use a radio to communicate the data they collect to a computer. Radiosondes are launched from about 800 sites around the globe twice daily to provide a profile of the atmosphere. Radiosondes can be dropped from a balloon or airplane to make measurements as they fall. This is done to monitor storms, for example, since they are dangerous places for airplanes to fly.

Radar

Radar stands for Radio Detection and Ranging (**Figure** 7.38). A transmitter sends out radio waves that bounce off the nearest object and then return to a receiver. Weather radar can sense many characteristics of precipitation: its location, motion, intensity, and the likelihood of future precipitation. Doppler radar can also track how fast the precipitation falls. Radar can outline the structure of a storm and can be used to estimate its possible effects.

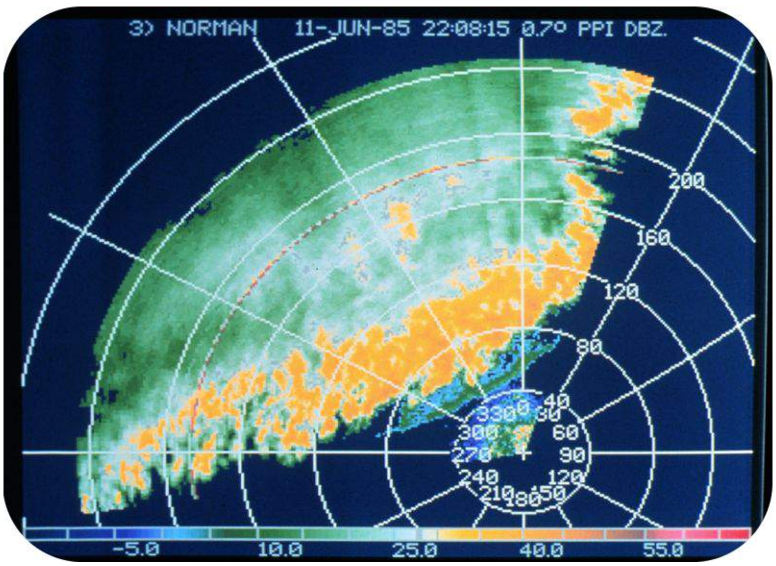


FIGURE 7.38
Radar view of a line of thunderstorms.

Satellites

Weather satellites have been increasingly important sources of weather data since the first one was launched in 1952. Weather satellites are the best way to monitor large-scale systems, such as storms. Satellites are able to record long-term changes, such as the amount of ice cover over the Arctic Ocean in September each year.

Weather satellites may observe all energy from all wavelengths in the electromagnetic spectrum. Visible light images record storms, clouds, fires, and smog. Infrared images record clouds, water and land temperatures, and features of the ocean, such as ocean currents (**Figure** 7.39).

An online guide to weather forecasting from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fcst/home.rxml .

Summary

- Various instruments measure weather conditions: thermometers measure air temperature, and barometers measure air pressure.
- Satellites monitor weather and also help with understanding long-term changes in climate.
- Radar is used to monitor precipitation.

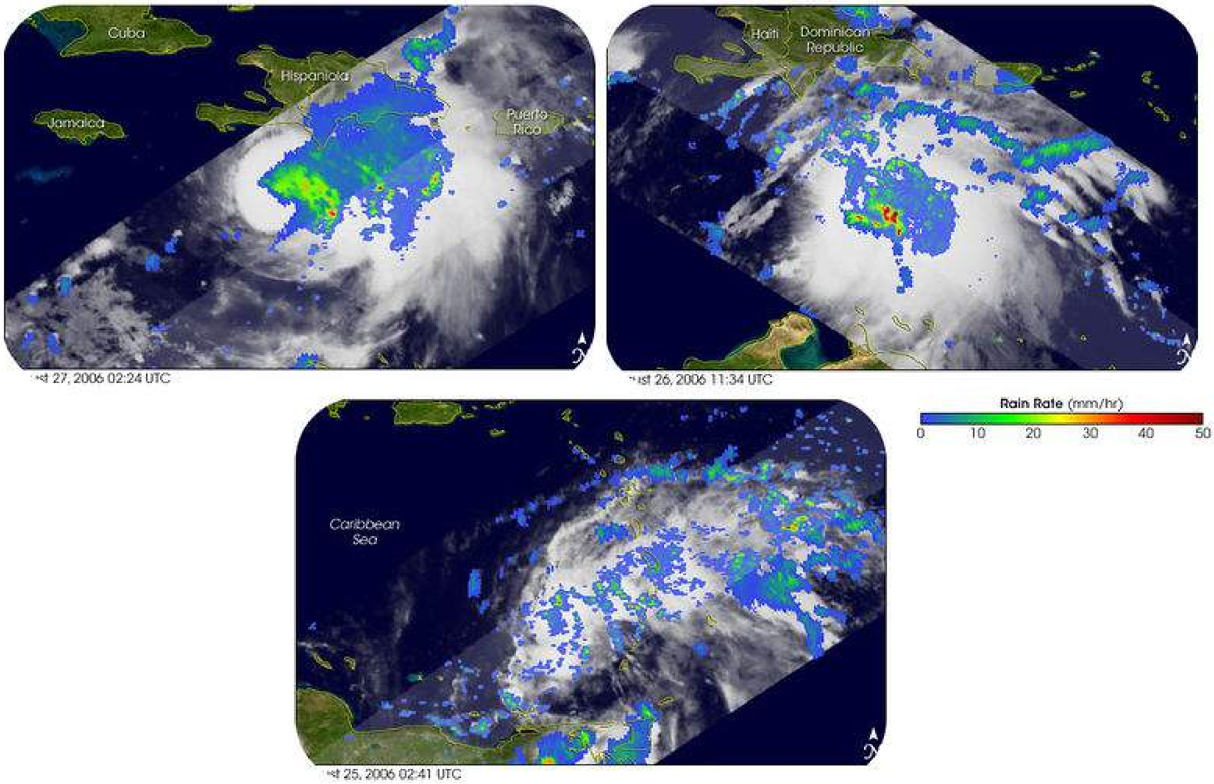


FIGURE 7.39
Infrared data superimposed on a satellite image shows rainfall patterns in Hurricane Ernesto in 2006.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=RTkPlhc3k-0

MEDIA

Click image to the left for more content.

1. What is contemporary weather forecasting based upon?
2. What gathers the data?
3. What do radisonde balloons do?
4. What data do satellites collect?
5. What data is collected by radar?
6. List other ways weather data is collected.

Review

1. What can a barometer tell you about the coming weather?
2. Weather prediction is now much better than it was 30 years ago. Can you figure out why?
3. Since there are weather satellites, why do you think weather forecasters still use radiosondes?

7.20 Weather Maps

- Describe the information depicted on weather maps.
- Analyze weather maps.

What can a weather map tell you about the weather?

A lot! A weather map indicates all sorts of things to let you know the forecast. It also may have some cute graphics associated with it.

Weather Maps

Weather maps simply and graphically depict meteorological conditions in the atmosphere. Weather maps may display only one feature of the atmosphere or multiple features. They can depict information from computer models or from human observations.

On a weather map, important meteorological conditions are plotted for each weather station. Meteorologists use many different symbols as a quick and easy way to display information on the map (**Figure** 7.40).

Once conditions have been plotted, points of equal value can be connected by isolines. Weather maps can have many types of connecting lines. For example:

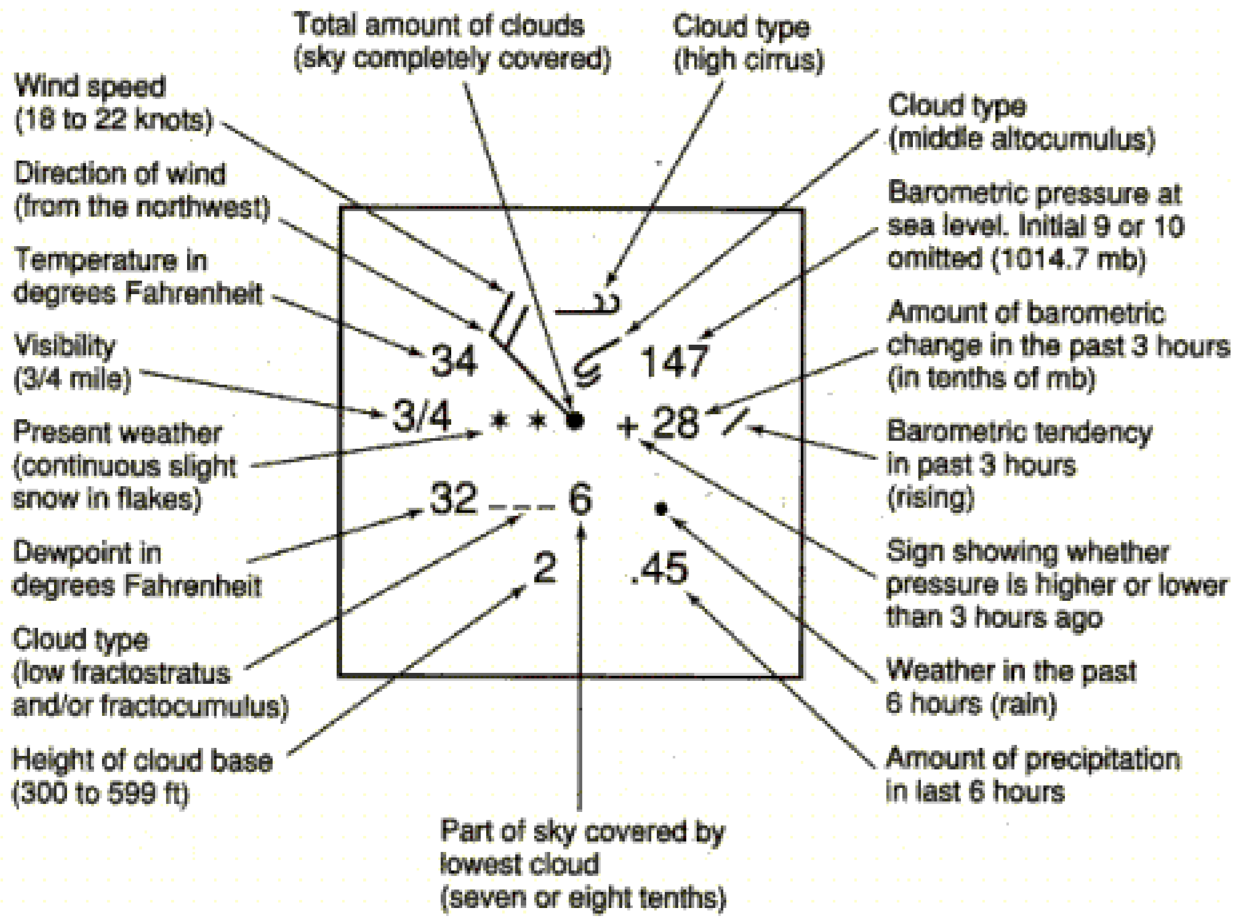


FIGURE 7.40

Explanation of some symbols that may appear on a weather map.

- Lines of equal temperature are called **isotherms**. Isotherms show temperature gradients and can indicate the location of a front. In terms of precipitation, what does the 0^{o}C (32^{o}F) isotherm show?

An animation on how to contour isotherms is seen here: Contouring isotherms https://courseware.e-education.psu.edu/public/meteo/meteo101demo/Examples/Shockwave/contouring0203.dcr .

- **Isobars** are lines of equal average air pressure at sea level (**Figure** 7.41). Closed isobars represent the locations of high and low pressure cells.

- **Isotachs** are lines of constant wind speed. Where the minimum values occur high in the atmosphere, tropical cyclones may develop. The highest wind speeds can be used to locate the jet stream.

Surface weather analysis maps are weather maps that only show conditions on the ground (**Figure** 7.42).

An online guide about to how to read weather maps from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/maps/home.rxml .

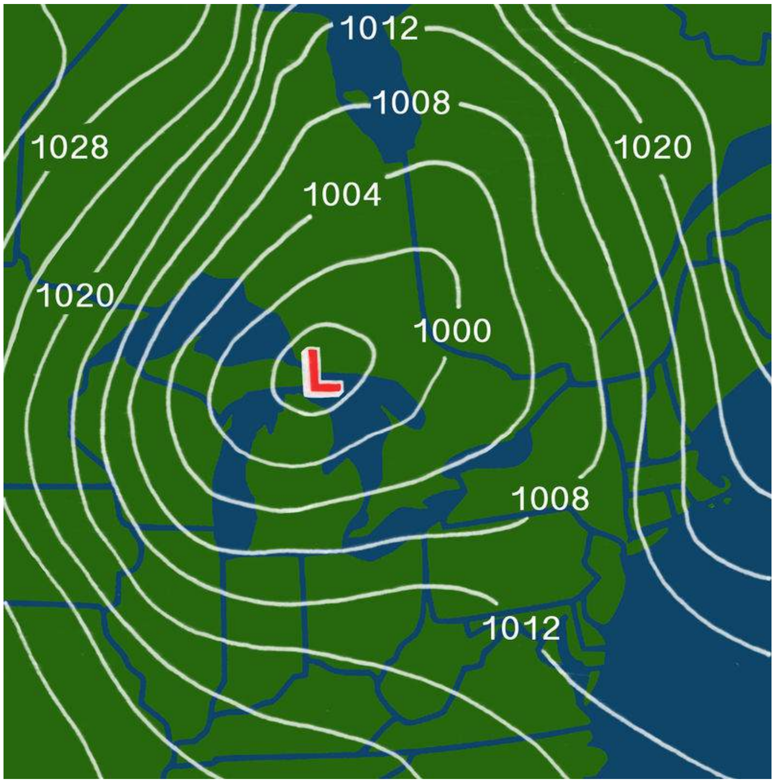


FIGURE 7.41
Isobars can be used to help visualize high pressure (H) and low pressure (L) cells.

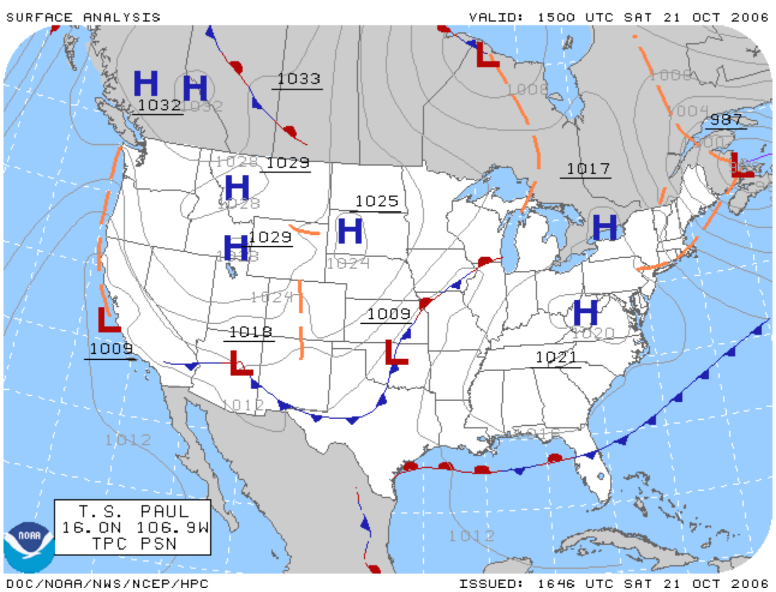


FIGURE 7.42
Surface analysis maps may show sea level mean pressure, temperature, and amount of cloud cover.

More about remote sensing of weather is discussed in this online guide: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/rs/home.rxml .

Summary

- Weather maps graphically depict weather conditions.

- Isotherms are lines of constant temperature; isobars are lines of constant pressure; isotachs are lines of constant wind speed.
- Isobars indicate pressure cells.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=ivSXkmL8ZbI

MEDIA

Click image to the left for more content.

1. What do weather maps on television usually tell you?
2. Where should you begin when analyzing weather maps?

How to read weather plots on a weather map

http://www.youtube.com/watch?v=h-JWgOKfjaA

MEDIA

Click image to the left for more content.

3. What website is an excellent source of weather information?
4. What is a weather station plot?
5. List the various items recorded on a weather station model plot.

Review

1. What is the purpose of isolines on a weather map?
2. Define isobar, isotach, and isotherm.
3. How are high and low pressure cells indicated on a weather map?

7.21 Mid-Latitude Cyclones

- Describe mid-latitude cyclones and explain how and where they form.

Where were you on Halloween 2011?

If you live along the northeastern United States you may remember Halloween being postponed in 2011. A large and atypically early nor'easter dropped as much as 32 inches of snow, caused over three million people to lose power, and brought on 39 deaths. Like hurricanes, nor'easters are cyclones, but they form much further north.

Mid-Latitude Cyclones

Cyclones can be the most intense storms on Earth. A **cyclone** is a system of winds rotating counterclockwise in the Northern Hemisphere around a low pressure center. The swirling air rises and cools, creating clouds and precipitation.

Mid-latitude cyclones form at the polar front when the temperature difference between two air masses is large. These air masses blow past each other in opposite directions. Coriolis effect deflects winds to the right in the Northern Hemisphere, causing the winds to strike the polar front at an angle. Warm and cold fronts form next to each other. Most winter storms in the middle latitudes, including most of the United States and Europe, are caused by mid-latitude cyclones (**Figure** 7.43).

The warm air at the cold front rises and creates a low pressure cell. Winds rush into the low pressure and create a rising column of air. The air twists, rotating counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Since the rising air is moist, rain or snow falls.

Mid-latitude cyclones form in winter in the mid-latitudes and move eastward with the westerly winds. These two- to five-day storms can reach 1,000 to 2,500 km (625 to 1,600 miles) in diameter and produce winds up to 125 km (75 miles) per hour.

Nor'easters

Mid-latitude cyclones are especially fierce in the mid-Atlantic and New England states, where they are called **nor'easters** because they come from the northeast. About 30 nor'easters strike the region each year. (**Figure** 7.44).

An online guide to mid-latitude cyclones from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cyc/home.rxml .

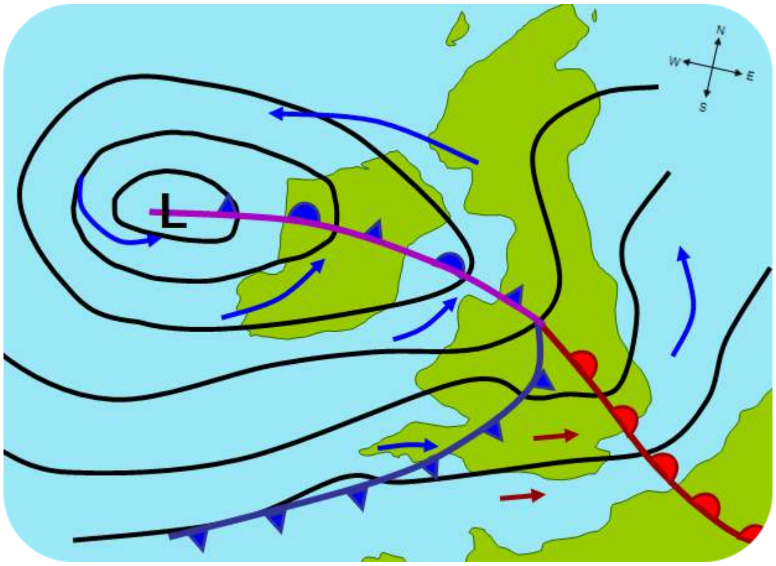


FIGURE 7.43
A hypothetical mid-latitude cyclone affecting the United Kingdom. The arrows point the wind direction and its relative temperature; L is the low pressure area. Notice the warm, cold, and occluded fronts.

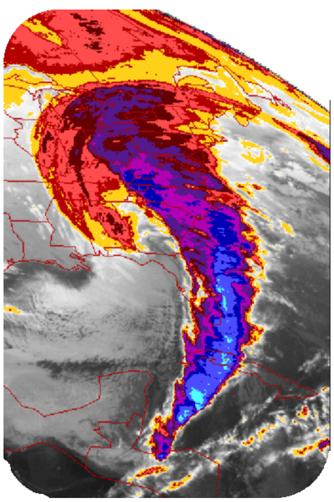


FIGURE 7.44
The 1993 "Storm of the Century" was a nor'easter that covered the entire eastern seaboard of the United States.

Summary

- A cyclone is a system of winds rotating counter-clockwise (in the Northern Hemisphere) around an area of low pressure.
- A mid-latitude cyclone forms at the polar front when the temperature difference between air masses is very large.
- Nor'easters are mid-latitude cyclones that come from the northeast.

Practice

Use this resource to answer the questions that follow.

http://www.slideshare.net/lschmidt1170/midlatitude-cyclones

MEDIA
Click image to the left for more content.

1. What is a midlatitude cyclone?
2. What is at the center of a midlatitude cyclone?
3. What does a mature midlatitude cyclone have?
4. Where is the heaviest precipication located in a midlatitude cyclone?
5. What does wind direction tell you?
6. What is a meteogram?

Review

1. Describe the circumstances that result in a nor'easter.
2. What is a cyclone?
3. What are the motions of air in a mid-latitude cyclone?

7.22 Thunderstorms

- Explain how thunderstorms form, grow, and produce lightning and thunder.

What lives fast and dies young?

That describes most thunderstorms. Thunderstorms can be very intense but may last for only a matter of minutes. They're fun (and dangerous) while they're active, though.

Thunderstorms

Thunderstorms are extremely common. Worldwide there are 14 million per year —that's 40,000 per day! Most drop a lot of rain on a small area quickly, but some are severe and highly damaging.

Thunderstorm Formation

Thunderstorms form when ground temperatures are high, ordinarily in the late afternoon or early evening in spring and summer. The two figures below show two stages of thunderstorm buildup (**Figure** 7.45).

Growth

As temperatures increase, warm, moist air rises. These updrafts first form cumulus and then cumulonimbus clouds. Winds at the top of the stratosphere blow the cloud top sideways to make the anvil shape that characterizes a cloud as a thunderhead. As water vapor condenses to form a cloud, the latent heat makes the air in the cloud warmer than the air outside the cloud. Water droplets and ice fly up through the cloud in updrafts. When these droplets get heavy enough, they fall.

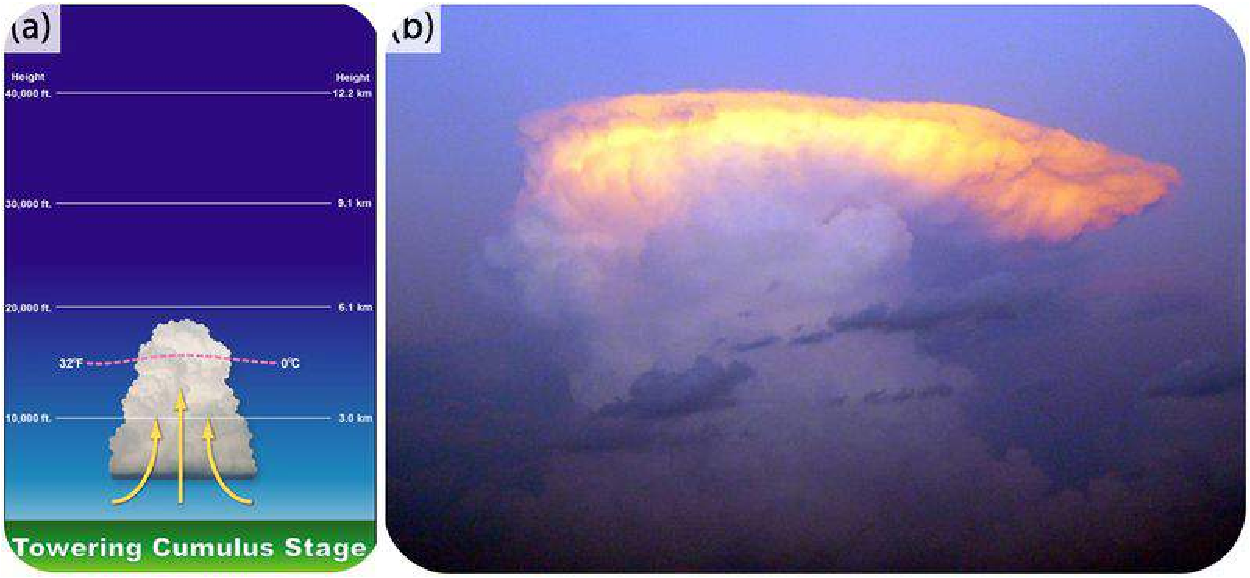


FIGURE 7.45
(a) Cumulus and cumulonimbus clouds. (b) A thunderhead.

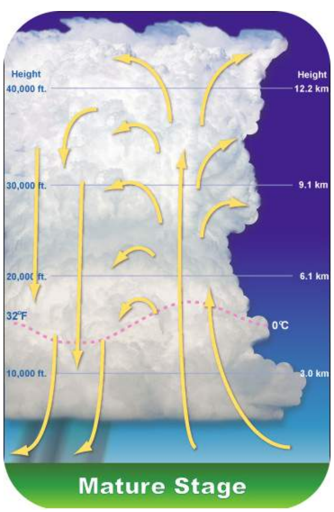


FIGURE 7.46
A mature thunderstorm with updrafts and downdrafts that reach the ground.

This starts a downdraft, and soon there is a convection cell within the cloud. The cloud grows into a cumulonimbus giant. Eventually, the drops become large enough to fall to the ground. At this time, the thunderstorm is mature, and it produces gusty winds, lightning, heavy precipitation, and hail (**Figure** 7.46).

The End

The downdrafts cool the air at the base of the cloud, so the air is no longer warm enough to rise. As a result, convection shuts down. Without convection, water vapor does not condense, no latent heat is released, and the thunderhead runs out of energy. A thunderstorm usually ends only 15 to 30 minutes after it begins, but other thunderstorms may start in the same area.

Severe Thunderstorms

With severe thunderstorms, the downdrafts are so intense that when they hit the ground, warm air from the ground is sent upward into the storm. The warm air gives the convection cells more energy. Rain and hail grow huge before gravity pulls them to Earth. Severe thunderstorms can last for hours and can cause a lot of damage because of high winds, flooding, intense hail, and tornadoes.

Squall Lines

Thunderstorms can form individually or in squall lines along a cold front. In the United States, squall lines form in spring and early summer in the Midwest, where the maritime tropical (mT) air mass from the Gulf of Mexico meets the continental polar (cP) air mass from Canada (**Figure** 7.47).

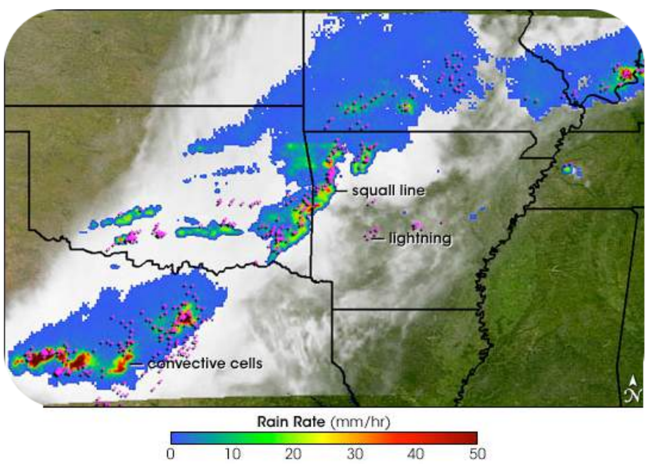


FIGURE 7.47
Cold air from the Rockies collided with warm, moist air from the Gulf of Mexico to form this squall line.

Lightning and Thunder

So much energy collects in cumulonimbus clouds that a huge release of electricity, called **lightning**, may result (**Figure** 7.48). The electrical discharge may be between one part of the cloud and another, two clouds, or a cloud and the ground.

Lightning heats the air so that it expands explosively. The loud clap is **thunder**. Light waves travel so rapidly that lightning is seen instantly. Sound waves travel much more slowly, so a thunderclap may come many seconds after the lightning is spotted.

Damage

Thunderstorms kill approximately 200 people in the United States and injure about 550 Americans per year, mostly from lightning strikes. Have you heard the common misconception that lightning doesn't strike the same place twice? In fact, lightning strikes the New York City's Empire State Building about 100 times per year (**Figure** 7.49).

FIGURE 7.48
Lightning behind the town of Diamond Head, Hawaii.

FIGURE 7.49
Lightning strikes some places many times a year, such as the Eiffel Tower in Paris.

An online guide to severe storms from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/svr/home.rxml .

Summary

- Thunderstorms grow where ground temperatures are extremely high.
- Convection in the cloud causes raindrops or hailstones to grow. Downdrafts ultimately end convection.
- Squall lines are long lines of thunderstorms that form along a cold front.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What causes thunderstorms to develop?
2. What determines the severity of the storm?
3. What causes the air to rise?
4. What causes the air mass to cool?
5. What causes lightning and thunder?

Review

1. Why are thunderstorms so common?
2. What is the energy source that feeds a thunderstorm?
3. What causes a thunderstorm to end?

7.23 Tornadoes

- Explain how and where tornadoes form.
- Describe how the severity of tornadoes is measured and the damage they can cause.

Who killed the Wicked Witch of the East?

Dorothy's house flies up in a tornado to the magical land of Oz. When the tornado ends, the house it falls on the witch. Dorothy becomes a hero for killing the tyrannical witch, but despite that yearns for home. In the real world, tornadoes do kill, but houses don't usually fly, and wicked witches usually avoid tornadoes.

Tornadoes

Tornadoes, also called twisters, are fierce products of severe thunderstorms (**Figure** 7.50). As air in a thunderstorm rises, the surrounding air races in to fill the gap. This forms a tornado, a funnel-shaped, whirling column of air extending downward from a cumulonimbus cloud.

A tornado lasts from a few seconds to several hours. The average wind speed is about 177 kph (110 mph), but some winds are much faster. A tornado travels over the ground at about 45 km per hour (28 miles per hour) and goes about 25 km (16 miles) before losing energy and disappearing (**Figure** 7.51).

FIGURE 7.50
The formation of this tornado outside Dimmit, Texas, in 1995 was well studied.

FIGURE 7.51
This tornado struck Seymour, Texas, in 1979.

Damage

An individual tornado strikes a small area, but it can destroy everything in its path. Most injuries and deaths from tornadoes are caused by flying debris (**Figure** 7.52). In the United States an average of 90 people are killed by tornadoes each year. The most violent two percent of tornadoes account for 70% of the deaths by tornadoes.

Location

Tornadoes form at the front of severe thunderstorms. Lines of these thunderstorms form in the spring where where maritime tropical (mT) and continental polar (cP) air masses meet. Although there is an average of 770 tornadoes annually, the number of tornadoes each year varies greatly (**Figure** 7.53).

April 2011

In late April 2011, severe thunderstorms pictured in the satellite image spawned the deadliest set of tornadoes in more than 25 years. In addition to the meeting of cP and mT mentioned above, the jet stream was blowing strongly

FIGURE 7.52

Tornado damage at Ringgold, Georgia in April 2011.

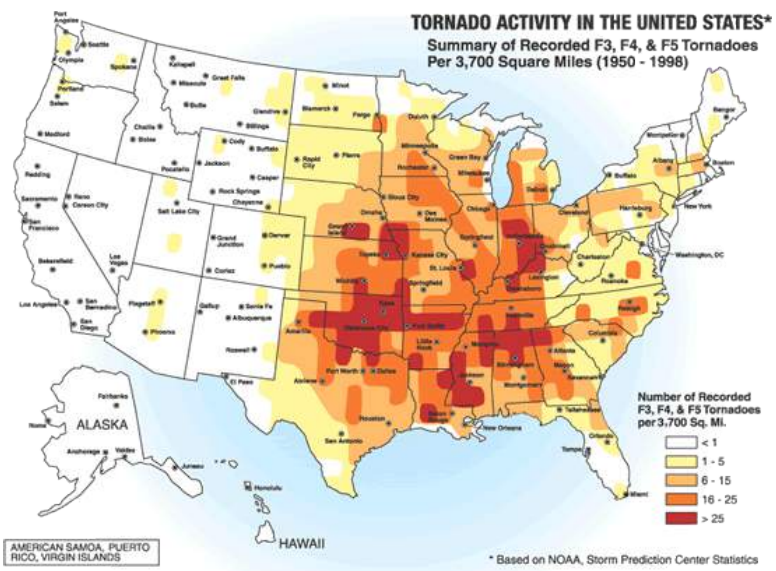


FIGURE 7.53

The frequency of F3, F4, and F5 tornadoes in the United States. The red region that starts in Texas and covers Oklahoma, Nebraska, and South Dakota is called Tornado Alley because it is where most of the violent tornadoes occur.

in from the west. The result was more than 150 tornadoes reported throughout the day (**Figure** 7.54).

The entire region was alerted to the possibility of tornadoes in those late April days. But meteorologists can only predict tornado danger over a very wide region. No one can tell exactly where and when a tornado will touch down. Once a tornado is sighted on radar, its path is predicted and a warning is issued to people in that area. The exact path is unknown because tornado movement is not very predictable.

Tornado catchers capture footage inside a tornado on this National Geographic video: http://ngm.nationalgeographic.com/ngm/0506/feature6/multimedia.html .

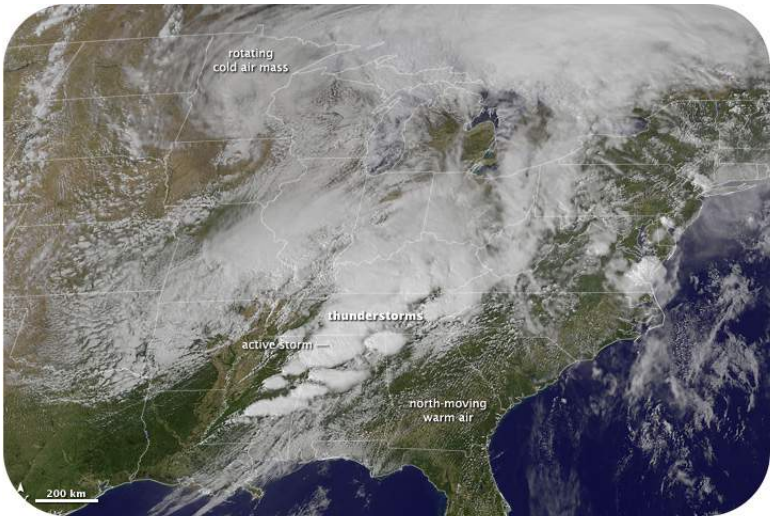


FIGURE 7.54
April 27-28, 2011. The cold air mass is shown by the mostly continuous clouds. Warm moist air blowing north from the Atlantic Ocean and Gulf of Mexico is indicated by small low clouds. Thunderstorms are indicated by bright white patches.

Fujita Scale

The intensity of tornadoes is measured on the Fujita Scale (see **Table** 7.2), which assigns a value based on wind speed and damage.

TABLE 7.2: The Fujita Scale (F Scale) of Tornado Intensity

F Scale	(km/hr)	(mph)	Damage
F0	64-116	40-72	Light - tree branches fall and chimneys may collapse
F1	117-180	73-112	Moderate - mobile homes, autos pushed aside
F2	181-253	113-157	Considerable - roofs torn off houses, large trees uprooted
F3	254-33	158-206	Severe - houses torn apart, trees uprooted, cars lifted
F4	333-419	207-260	Devastating - houses leveled, cars thrown
F5	420-512	261-318	Incredible - structures fly, cars become missiles
F6	>512	>318	Maximum tornado wind speed

Summary

- A tornado is a whirling funnel of air extending down from a cumulonimbus cloud.
- The Fujita scale measures tornado intensity based on wind speed and damage.
- Tornadoes can only be predicted over a wide region.

Making Connections

MEDIA

MEDIA
Click image to the left for more content.

1. What are tornadoes?
2. What is the normal life span of a tornado?
3. What is required for a tornado to form?
4. What is a wind shear?
5. What causes a tornado to touch the ground?
6. When do tornadoes usually occur?

Review

1. What causes the tornadoes of Tornado Alley?
2. How does the Fujita scale resemble the scales for assessing earthquake intensity? Which does it most resemble?
3. What circumstances led to the intensity of tornado activity in April 2011?

7.24 Hurricanes

- Explain how and where hurricanes form.
- Describe how hurricanes are measured and the damage that they can cause.

Why did New Orleans Mayor Ray Nagin call Hurricane Katrina "...a storm that most of us have long feared," as it approached New Orleans?

Hurricane Katrina nears its peak strength as it travels across the Gulf of Mexico. Hurricane Katrina was the most deadly and the most costly of the hurricanes that struck in the record-breaking 2005 season.

Hurricanes

Hurricanes —called typhoons in the Pacific —are also cyclones. They are cyclones that form in the tropics and so they are also called tropical cyclones. By any name, they are the most damaging storms on Earth.

Formation

Hurricanes arise in the tropical latitudes (between 10^o and 25^oN) in summer and autumn when sea surface temperature are 28^oC (82^oF) or higher. The warm seas create a large humid air mass. The warm air rises and forms a low pressure cell, known as a **tropical depression**. Thunderstorms materialize around the tropical depression.

If the temperature reaches or exceeds 28^oC (82^oF), the air begins to rotate around the low pressure (counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere). As the air rises, water vapor condenses, releasing energy from latent heat. If wind shear is low, the storm builds into a hurricane within two to three days.

Hurricanes are huge and produce high winds. The exception is the relatively calm eye of the storm, where air is rising upward. Rainfall can be as high as 2.5 cm (1") per hour, resulting in about 20 billion metric tons of water released daily in a hurricane. The release of latent heat generates enormous amounts of energy, nearly the total annual electrical power consumption of the United States from one storm. Hurricanes can also generate tornadoes.

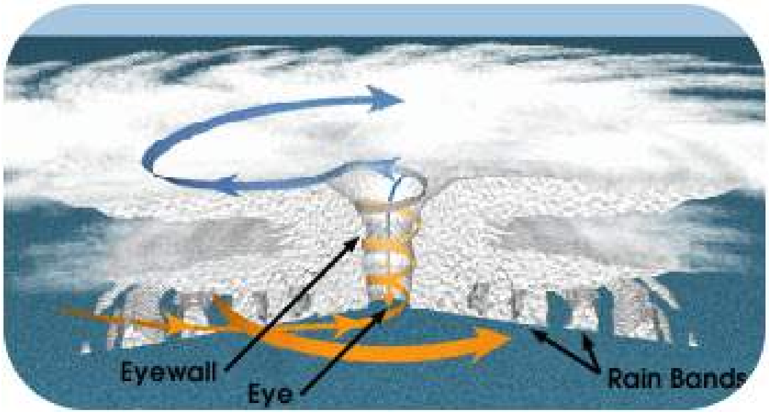


FIGURE 7.55
A cross-sectional view of a hurricane.

Hurricanes move with the prevailing winds. In the Northern Hemisphere, they originate in the trade winds and move to the west. When they reach the latitude of the westerlies, they switch direction and travel toward the north or northeast. Hurricanes may cover 800 km (500 miles) in one day.

Saffir-Simpson Scale

Hurricanes are assigned to categories based on their wind speed. The categories are listed on the Saffir-Simpson hurricane scale (**Table** 7.3).

TABLE 7.3: Saffir-Simpson Hurricane Scale

Category	Kph	Mph	Estimated Damage
1 (weak)	119-153	74-95	Above normal; no real damage to structures
2 (moderate)	154-177	96-110	Some roofing, door, and window damage, considerable damage to vegetation, mobile homes, and piers
3 (strong)	178-209	111-130	Some buildings damaged; mobile homes destroyed
4 (very strong)	210-251	131-156	Complete roof failure on small residences; major erosion of beach areas; major damage to lower floors of structures near shore
5 (devastating)	>251	>156	Complete roof failure on many residences and industrial buildings; some complete building failures

Damage

Damage from hurricanes comes from the high winds, rainfall, and storm surge. Storm surge occurs as the storm's low pressure center comes onto land, causing the sea level to rise unusually high. A storm surge is often made worse by the hurricane's high winds blowing seawater across the ocean onto the shoreline. Flooding can be devastating, especially along low-lying coastlines such as the Atlantic and Gulf Coasts. Hurricane Camille in 1969 had a 7.3 m

Hurricane Katrina

The 2005 Atlantic hurricane season was the longest, costliest, and deadliest hurricane season so far. Total damage from all the storms together was estimated at more than $128 billion, with more than 2,280 deaths. Hurricane Katrina was both the most destructive hurricane and the most costly (**Figure** 7.56).

FIGURE 7.56
Flooding in New Orleans after Hurricane Katrina caused the levees to break and water to pour through the city.

News about Hurricane Katrina from the New Orleans Times-Picayune: http://www.nola.com/katrina/graphics/flashflood.swf .

An animation of a radar image of Hurricane Katrina making landfall is seen here: http://upload.wikimedia.org/wikipedia/commons/9/97/Hurricane_Katrina_LA_landfall_radar.gif .

NASA's short video, "In Katrina's Wake": http://www.youtube.com/watch?v=HZjqvqaLltI .

Hurricanes are explored in a set of National Geographic videos found at National Geographic Video: http://video.nationalgeographic.com/video/environment/environment-natural-disasters/hurricanes . At this link, watch the following videos:

- "Hurricanes 101" is an introduction to the topic.
- "How Katrina Formed" looks at the history of Hurricane Katrina as it formed and passed through the Gulf coast.

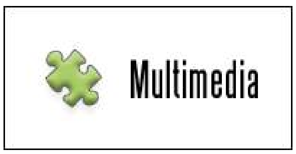
- Follow that up with "Doomed New Orleans," which explores how the devastation to the city is a man-made disaster.
- "The Hurricane Ike of 1900" looks at what happened in the days when there was little warning before a hurricane hit a coastal city.

Lots of information about hurricanes is found in this online guide from the University of Illinois: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/hurr/home.rxml .

Summary

- Hurricanes are actually tropical cyclones because they originate in the tropical latitudes.
- The damage hurricanes cause is due largely to storm surge, but high wind speeds and rain also cause damage.
- Hurricane Katrina was so damaging because the levees that protected New Orleans broke.

Making Connections



MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What are hurricanes?
2. Where do most hurricanes begin to form?
3. What three components are required for a hurricane to form?
4. What direction do hurricanes spin?
5. What is the eye?
6. What are typhoons and cyclones?

Review

1. What is the difference between a hurricane and a mid-latitude cyclone?
2. How does a hurricane form? Where does the storm get its energy?
3. Under what circumstances does a hurricane die?

7.25 Weather versus Climate

- Define weather and climate, and explain the relationship between them.

What's the weather like?

If someone across country asks you what the weather is like today, you need to consider several factors. Air temperature, humidity, wind speed, the amount and types of clouds, and precipitation are all part of a thorough weather report.

What is Weather?

All **weather** takes place in the atmosphere, virtually all of it in the lower atmosphere. Weather describes what the atmosphere is like at a specific time and place. A location's weather depends on:

- air temperature
- air pressure
- fog
- humidity
- cloud cover
- precipitation
- wind speed and direction

All of these characteristics are directly related to the amount of energy that is in the system and where that energy is. The ultimate source of this energy is the Sun.

Weather is the change we experience from day to day. Weather can change rapidly.

What is Climate?

Although almost anything can happen with the weather, **climate** is more predictable. The weather on a particular winter day in San Diego may be colder than on the same day in Lake Tahoe, but, on average, Tahoe's winter climate is significantly colder than San Diego's (**Figure** 7.57).

FIGURE 7.57
Winter weather at Lake Tahoe doesn't much resemble winter weather in San Diego even though they're both in California.

Climate is the long-term average of weather in a particular spot. Good climate is why we choose to vacation in Hawaii in February, even though the weather is not guaranteed to be good! A location's climate can be described by its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation.

The climate for a particular place is steady, and changes only very slowly. Climate is determined by many factors, including the angle of the Sun, the likelihood of cloud cover, and the air pressure. All of these factors are related to the amount of energy that is found in that location over time.

The climate of a region depends on its position relative to many things. These factors are described in the next sections.

Summary

- A region's weather depends on its air temperature, air pressure, humidity, precipitation, wind speed and direction, and other factors.
- Climate is the long-term average of weather.
- Weather can change in minutes, but climate changes very slowly.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/science/earth-sci/climate-weather-sci/

1. What is climate?

2. How many climate zones are there? List examples.

3. What did climate determine in the past?

4. Why doesn't climate have as much influence today?

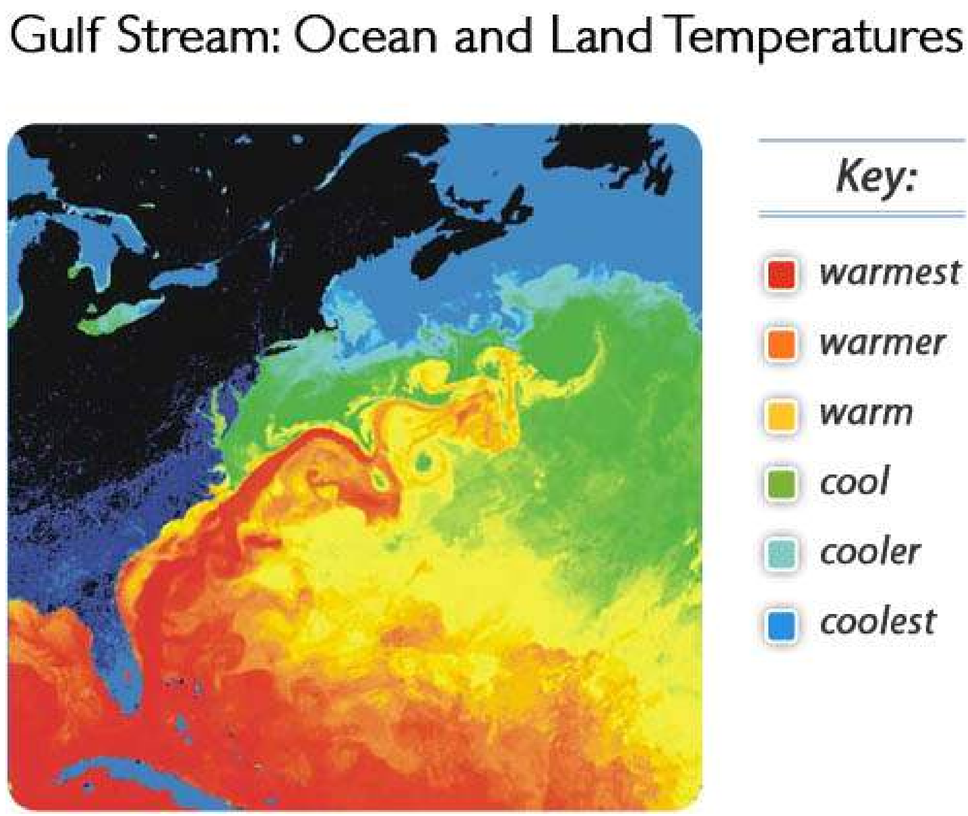
5. What is weather?
6. What problems can severe weather cause?
7. Why is an accurate weather forecast important?
8. What tools do meteorologists use?

Review

1. When you're in a cold place in December and you're planning a vacation for February, are you interested in a location's weather or climate? If it's a summer day and you want to take a picnic are you concerned with weather or climate?
2. What factors account for a location's weather?
3. If climate is the long-term average of weather, how can climate change?

7.26 How Ocean Currents Moderate Climate

- Explain how ocean currents like the Gulf Stream influence Earth's climate.



Why is northwestern Europe relatively warm?

The Gulf Stream waters do a lot for Europe. The equatorial warmth this current brings to the North Atlantic moderates temperatures in northern Europe. In a satellite image of water temperature in the western Atlantic it is easy to pick out the Gulf Stream, which brings warmer waters from the Equator up the coast of eastern North America.

Effect on Global Climate

Surface currents play an enormous role in Earth's climate. Even though the Equator and poles have very different climates, these regions would have more extremely different climates if ocean currents did not transfer heat from the equatorial regions to the higher latitudes.

The Gulf Stream is a river of warm water in the Atlantic Ocean, about 160 kilometers wide and about a kilometer deep. Water that enters the Gulf Stream is heated as it travels along the Equator. The warm water then flows up the east coast of North America and across the Atlantic Ocean to Europe (see opening image). The energy the Gulf Stream transfers is enormous: more than 100 times the world's energy demand.

The Gulf Stream's warm waters raise temperatures in the North Sea, which raises the air temperatures over land between 3 to 6°C (5 to 11°F). London, U.K., for example, is at about six degrees further south than Quebec, Canada.

However, London's average January temperature is 3.8°C (38°F), while Quebec's is only -12°C (10°F). Because air traveling over the warm water in the Gulf Stream picks up a lot of water, London gets a lot of rain. In contrast, Quebec is much drier and receives its precipitation as snow.

FIGURE 7.58
London, England in winter.

FIGURE 7.59
Quebec City, Quebec in winter.

Summary

- Water in the Gulf Stream travels along the Equator and is heated as it goes.
- The Gulf Stream brings warm water north along the Atlantic coast of the United States and then across the northern Atlantic to the British Isles.
- A tremendous amount of energy is transferred from the equatorial regions to the polar regions by ocean currents.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=Lb854zXy2IQ

MEDIA

Click image to the left for more content.

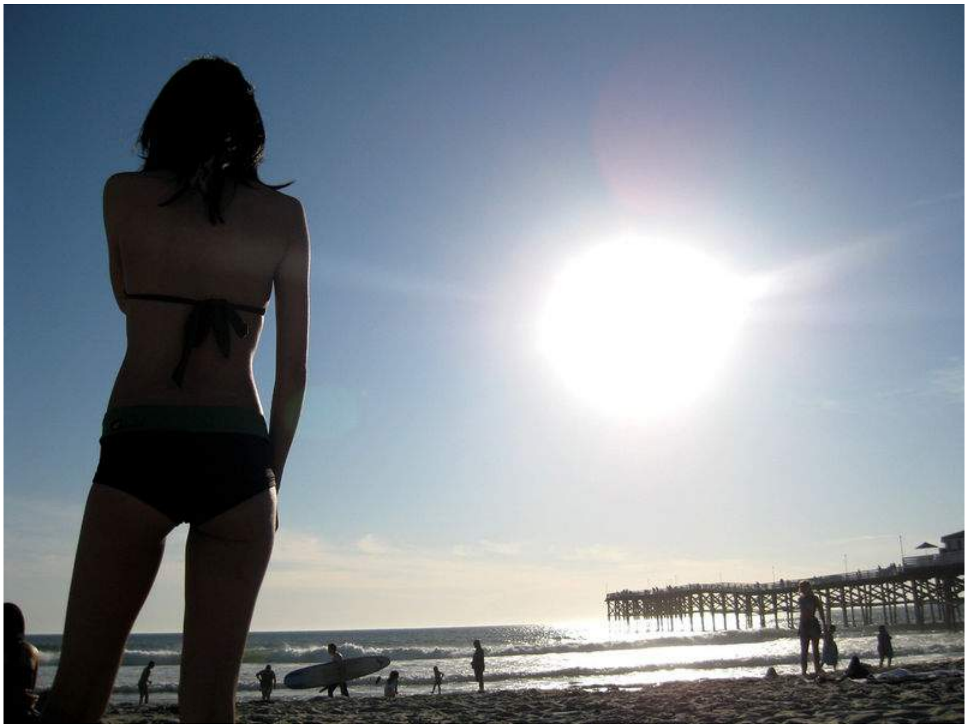
1. What occurred in the Atacoma desert in July 2011?
2. What was the weather like in Australia in August and September 2011?
3. What happened in the summer of 2011 in the United States?
4. How many temperature records were broken in 2011?
5. Why are scientists monitoring the Arctic ice?
6. What are the effects of the ice melt?
7. How is the Gulf Stream affected by the melting of the Arctic ice?

Review

1. Explain why England is relatively mild and rainy in winter but central Canada, at the same latitude and during the same season, is dry and frigid.
2. Where else do you think ocean currents might moderate global climate?
3. What would Earth be like if ocean water did not move?

7.27 Effect of Atmospheric Circulation on Climate

- Explain how major climate traits correlate with the positions of the atmospheric circulation cells.



Does it really never rain in California like the song says?

In California, the predominant winds are the westerlies blowing in from the Pacific Ocean, which bring in relatively cool air in summer and relatively warm air in winter. The winds do bring rain, quite a bit in northern California, but in San Diego there are only 10 inches a year on average.

Atmospheric Circulation Cells

The position of a region relative to the circulation cells and wind belts has a great affect on its climate. In an area where the air is mostly rising or sinking, there is not much wind.

The ITCZ

The **Intertropical Convergence Zone (ITCZ)** is the low pressure area near the Equator in the boundary between the two Hadley Cells. The air rises so that it cools and condenses to create clouds and rain (**Figure** 7.61). Climate along the ITCZ is therefore warm and wet. Early mariners called this region the doldrums because their ships were often unable to sail due to the lack of steady winds.

The ITCZ migrates slightly with the season. Land areas heat more quickly than the oceans. Because there are more land areas in the Northern Hemisphere, the ITCZ is influenced by the heating effect of the land. In Northern Hemisphere summer, it is approximately 5° north of the Equator, while in the winter it shifts back and is approximately at the Equator. As the ITCZ shifts, the major wind belts also shift slightly north in summer and south in winter, which causes the wet and dry seasons in this area (**Figure** 7.62).

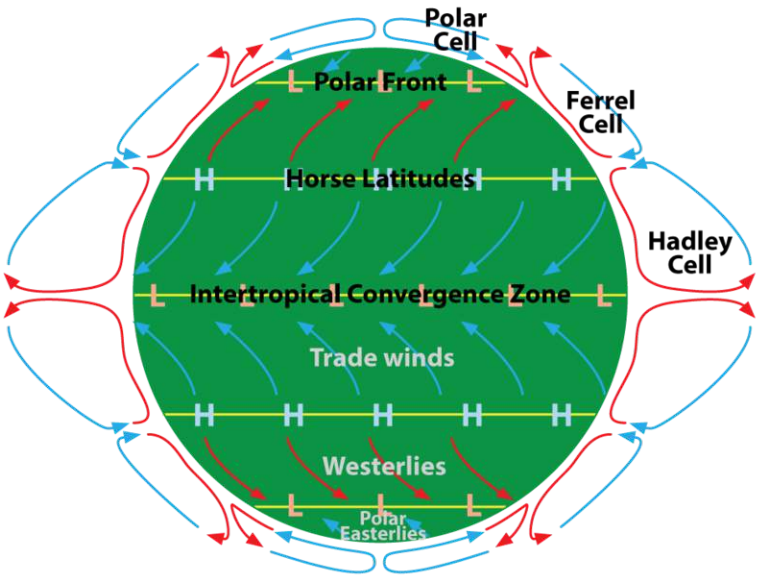


FIGURE 7.60
The atmospheric circulation cells and their relationships to air movement on the ground.

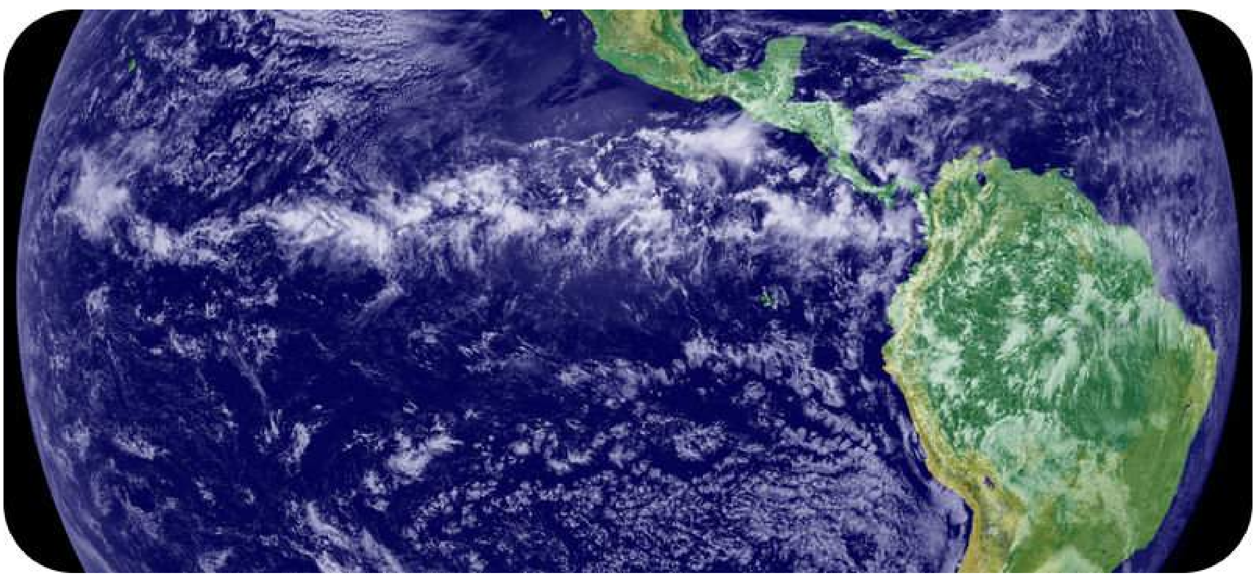


FIGURE 7.61
The ITCZ can easily be seen where thunderstorms are lined up north of the Equator.

Hadley Cell and Ferrell Cell Boundary

At about 30°N and 30°S, the air is fairly warm and dry because much of it came from the Equator, where it lost most of its moisture at the ITCZ. At this location the air is descending, and sinking air warms and causes evaporation.

Mariners named this region the horse latitudes. Sailing ships were sometimes delayed for so long by the lack of wind that they would run out of water and food for their livestock. Sailors tossed horses and other animals over the

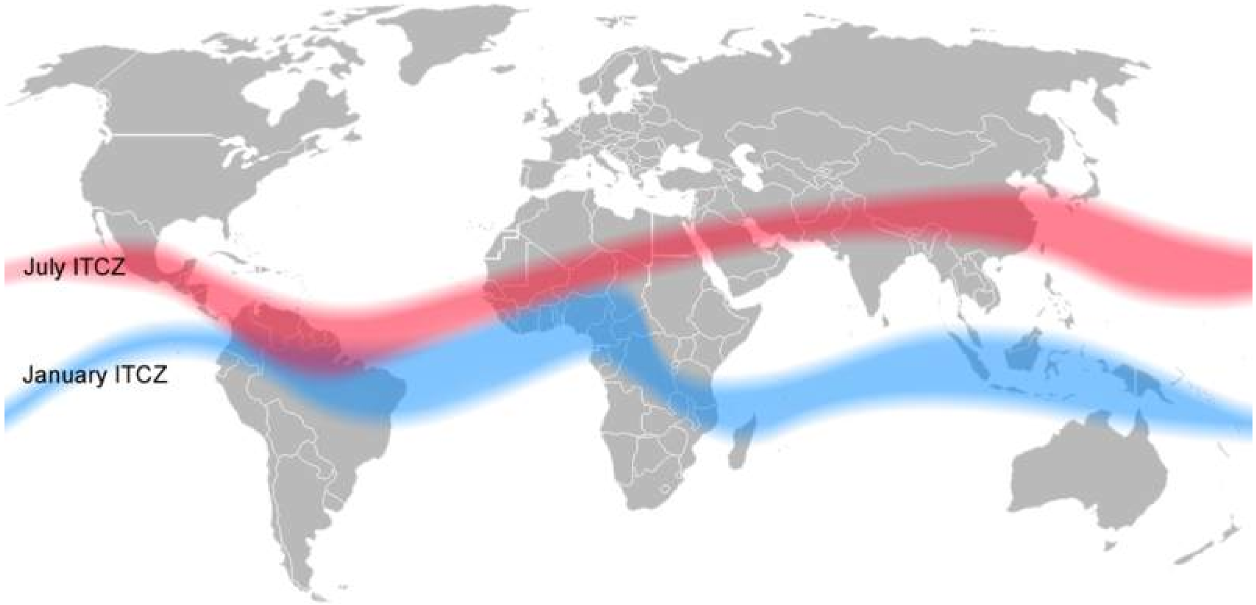


FIGURE 7.62
Seasonal differences in the location of the ITCZ are shown on this map.

side after they died. Sailors sometimes didn't make it either.

Ferrell Cell and Polar Cell Boundary

The polar front is around 50° to 60°, where cold air from the poles meets warmer air from the tropics. The meeting of the two different air masses causes the polar jet stream, which is known for its stormy weather. As the Earth orbits the Sun, the shift in the angle of incoming sunlight causes the polar jet stream to move. Cities to the south of the polar jet stream will be under warmer, moister air than cities to its north. Directly beneath the jet stream, the weather is often stormy and there may be thunderstorms and tornadoes.

Prevailing Winds

The prevailing winds are the bases of the Hadley, Ferrell, and polar cells. These winds greatly influence the climate of a region because they bring the weather from the locations they come from. Local winds also influence local climate. For example, land breezes and sea breezes moderate coastal temperatures.

Summary

- High and low pressure zones related to the atmospheric circulation cells are important in determining a region's climate.
- Prevailing winds influence the climate of a region because they bring in weather from the upwind area.
- Boundaries between cells are often known for winds and stormy weather due to the contact of different air masses.

Practice

Use this resource to answer the questions that follow.

http://earthguide.ucsd.edu/eoc/middle_school_t/teachers/earth/sp_atmosphere/p_atmo_circulation_composite.html

1. What is the atmosphere?
2. How are winds named?
3. What happens when surface winds converge?
4. What occurs when surface winds diverge?
5. What is the ITCZ? How does it change with the seasons?
6. What is air pressure? How does it vary by latitude?

Review

1. What are prevailing winds and how do they affect climate?
2. What is the ITCZ? How does its location affect weather?
3. Where is there not much wind?

7.28 Effect of Latitude on Climate

- Describe how latitude influences a region's climate, particularly its average temperature.

Where do you want to go on vacation?

If you live in a frigid climate you may want to go to lower latitudes for your mid-winter vacation. If you live in the desert, you may like to spend part of your summer at higher latitudes. Different climates are found at different latitudes.

Latitude

Many factors influence the climate of a region. The most important factor is latitude because different latitudes receive different amounts of solar radiation.

- The Equator receives the most solar radiation. Days are equally long year-round and the Sun is just about directly overhead at midday.
- The polar regions receive the least solar radiation. The night lasts six months during the winter. Even in summer, the Sun never rises very high in the sky. Sunlight filters through a thick wedge of atmosphere, making the sunlight much less intense. The high albedo, because of ice and snow, reflects a good portion of the Sun's light.

Temperature with Latitude

It's easy to see the difference in temperature at different latitudes in the **Figure** 7.63. But temperature is not completely correlated with latitude. There are many exceptions. For example, notice that the western portion of South America has relatively low temperatures due to the Andes Mountains. The Rocky Mountains in the United

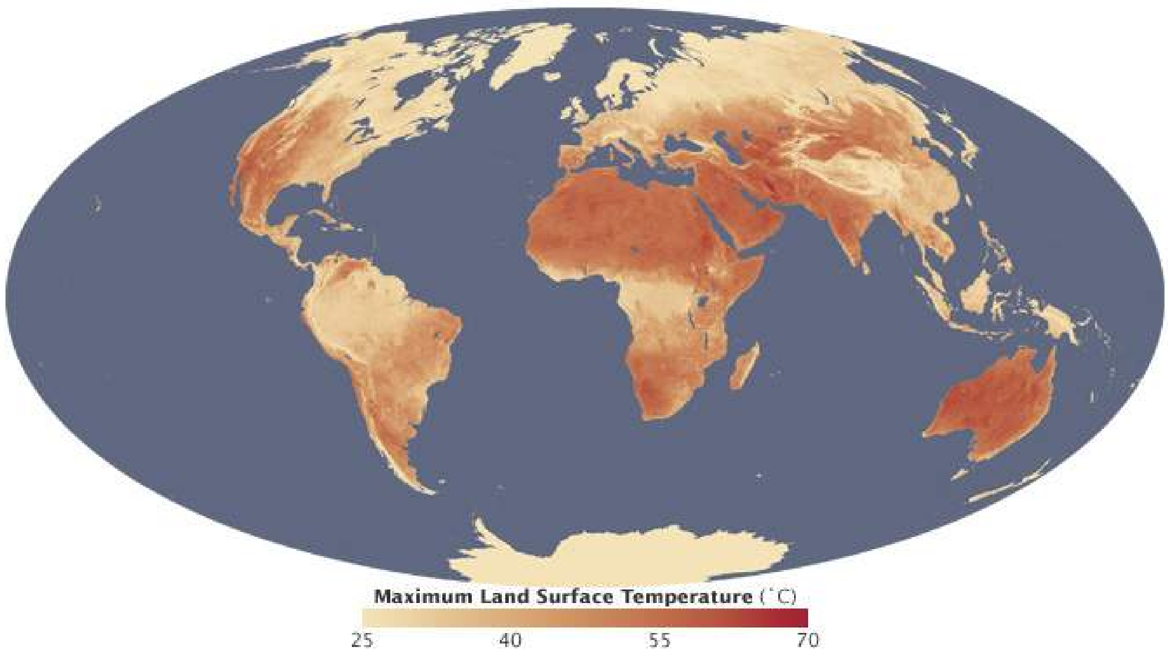


FIGURE 7.63
The maximum annual temperature of the Earth, showing a roughly gradual temperature gradient from the low to the high latitudes.

States also have lower temperatures due to high altitudes. Western Europe is warmer than it should be due to the Gulf Stream.

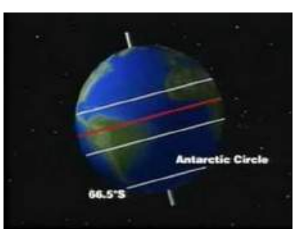
Summary

- The amount of solar radiation received by the planet is greatest at the Equator and lessens toward the poles.
- At the poles the Sun never rises very high in the sky and sunlight filters through a thick wedge of atmosphere.
- Latitude is not the only factor that determines the temperature of a region, as can be seen in the striped map above.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=95TtXYjOEv4



MEDIA
Click image to the left for more content.

1. What is climate?
2. What influences a regions climate?
3. What is latitude?
4. What is the climate at the Equator?
5. What is the tropic of Cancer and the tropic of Capricorn?
6. What is the area between the tropic of Cancer and tropic of Capricorn climate?
7. What are the middle latitudes?
8. Describe the polar regions.
9. What is elevation?
10. How does elevation affect climate?

Review

1. Why do the poles receive so much less solar radiation than the Equator considering that it's light for six months at the poles?
2. Why is latitude considered the most important factor in determining temperature?
3. Look at a map of geological features and look at the temperature map to try to determine why some of the exceptions exist. What's the big blue blob north of India?

7.29 Effect of Continental Position on Climate

- Define marine and continental climates, and explain how continental position and ocean currents affect climate.

What causes San Francisco's famous fog?

The California Current travels from the north and brings cold water to the region just offshore. The warm Mediterranean climate of coastal California contrasts with the cold water offshore and forms advection fog, which blows off the shore and up to a few miles inland. Fog under the Golden Gate Bridge is a common sight in the City by the Bay.

Continental Position

When a particular location is near an ocean or large lake, the body of water plays an extremely important role in affecting the region's climate.

- A **maritime climate** is strongly influenced by the nearby sea. Temperatures vary a relatively small amount seasonally and daily. For a location to have a true maritime climate, the winds must most frequently come off the sea.
- A **continental climate** is more extreme, with greater temperature differences between day and night and between summer and winter.

The ocean's influence in moderating climate can be seen in the following temperature comparisons. Each of these cities is located at 37^{o}N latitude, within the westerly winds (**Figure** 7.64).

The climate of San Francisco is influenced by the cool California current and offshore upwelling. Wichita has a more extreme continental climate. Virginia Beach, though, is near the Atlantic Ocean. Why is the climate there less influenced by the ocean than is the climate in San Francisco? Hint: Think about the direction the winds are going at that latitude. The weather in San Francisco comes from over the Pacific Ocean while much of the weather in Virginia comes from the continent.

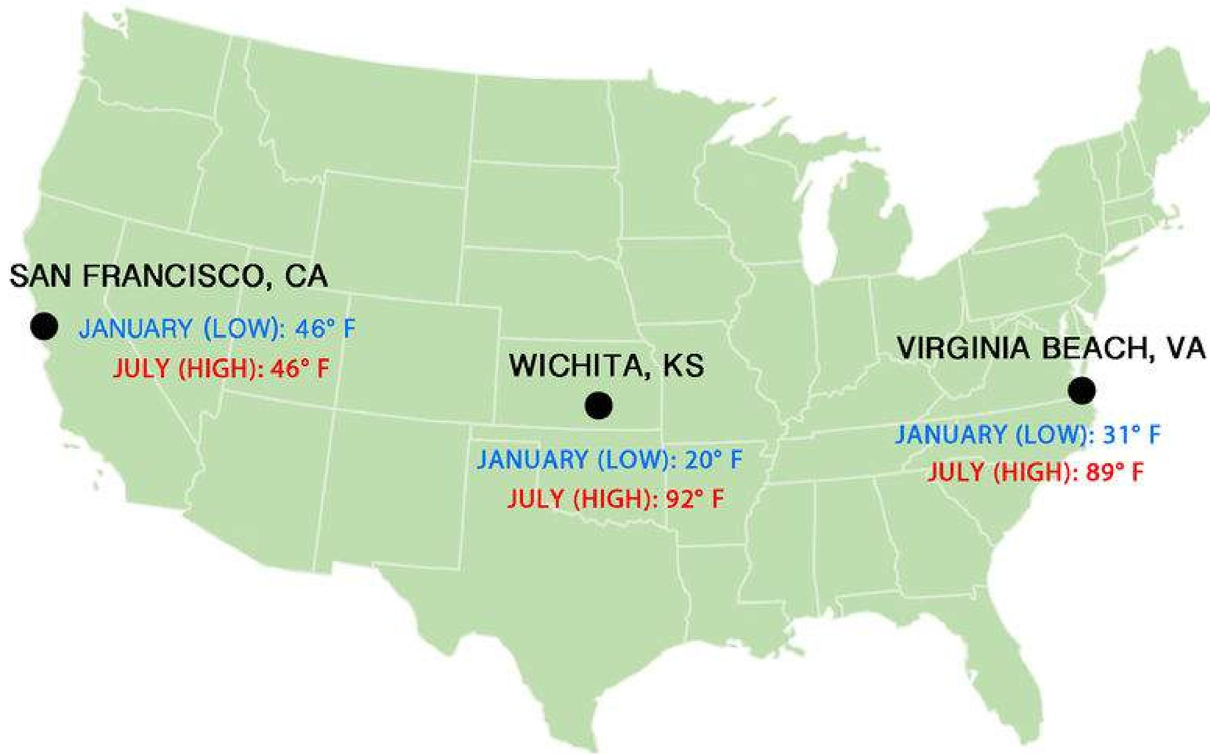


FIGURE 7.64
How does the ocean influence the climate of these three cities?

Ocean Currents

The temperature of the water offshore influences the temperature of a coastal location, particularly if the winds come off the sea. The cool waters of the California Current bring cooler temperatures to the California coastal region. Coastal upwelling also brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures. Further north, in southern Alaska, the upwelling actually raises the temperature of the surrounding land because the ocean water is much warmer than the land. The important effect of the Gulf Stream on the climate of northern Europe is described in the chapter Water on Earth.

Summary

- A maritime climate is influenced by a nearby ocean. A continental climate is influenced by nearby land.
- The temperature of offshore currents affect nearby land areas.
- A maritime climate is less extreme than a continental climate because the ocean moderates temperatures.

Practice

Use this resource to answer the questions that follow.

http://www.watchmojo.com/index.php?id=6521

MEDIA
Click image to the left for more content.

1. What does the temperature depend on?
2. What influences the weather in California?
3. What is the temperature variation between the coast and inland in the summer?
4. What is the temperature variation between the coast and inland in the winter?
5. How much rainfall does the redwood forest receive?

Review

1. If upwelling stopped off of California, how would climate be affected?
2. From which direction would weather come to a city at 65-degrees north?
3. Why is the climate of San Francisco so different from the climate of Virginia Beach when both are near an ocean?

7.30 Effect of Altitude and Mountains on Climate

- Explain how altitude and mountain ranges affect climate.
- Define rainshadow effect.

Are they worms crawling across the landscape?

This image shows the difference in climate between mountain ranges and the surrounding lands.

Altitude and Mountain Ranges

Air pressure and air temperature decrease with altitude. The closer molecules are packed together, the more likely they are to collide. Collisions between molecules give off heat, which warms the air. At higher altitudes, the air is less dense and air molecules are more spread out and less likely to collide. A location in the mountains has lower average temperatures than one at the base of the mountains. In Colorado, for example, Lakewood's (5,640 feet) average annual temperature is 62^{o}F (17^{o}C), while Climax Lake's (11,300 feet) is 42^{o}F (5.4^{o}C).

Mountain ranges have two effects on the climate of the surrounding region:

- rainshadow effect, which brings warm, dry climate to the leeward size of a mountain range (**Figure** 7.65).
- separation in the coastal region from the rest of the continent. Since a maritime air mass may have trouble rising over a mountain range, the coastal area will have a maritime climate but the inland area on the leeward side will have a continental climate.

FIGURE 7.65
The Bonneville Salt Flats are part of the very dry Great Basin of the Sierra Nevada of California. The region receives little rainfall.

Five factors that Affect Climate takes a very thorough look at what creates the climate zones. The climate of a region allows certain plants to grow, creating an ecological biome: http://www.youtube.com/watch?v=E7DLLxrrBV8 (5:23).

MEDIA
Click image to the left for more content.

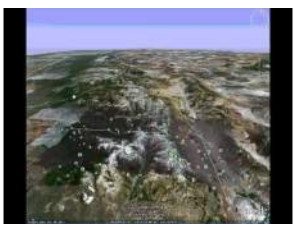
Summary

- Collisions between molecules increase temperature: where air is denser, the air temperature is higher.
- Rainshadow effect occurs on the leeward side of a mountain range.
- Maritime air may become stuck on the windward side of a mountain range and so is unable to bring cooler air further inland.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=yuvy4nLtWk4



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1. What two factors can affect climate on mountains?
2. What occurs on the windward side of a mountain?
3. Describe the climate on the windward side of the mountain.
4. Describe the climate on the leeward side of the mountain.
5. What are rain shadow deserts?
6. Describe the characteristics seen on the windward side of the Sierra Nevada Mountains.
7. Describe the characteristics see on the leeward side of the Sierra Nevada Mountains.

Review

1. Why does an increase in altitude cause a change in temperature?
2. What is rainshadow effect?
3. Besides rainshadow effect, how else do mountains affect weather downwind?

7.31 Climate Zones and Biomes

- Define biome and microclimate.
- Describe the major climate zones and explain how they relate to biomes.

How do plants that evolved without any genetic interaction end up being so similar?

Organisms evolve to fit the conditions they are in. There are only so many ways to minimize the use of water, so plants in arid climates evolve very similar structures for that purpose. There are many instances of parallel evolution in widely separated organisms.

Climate Zones and Biomes

The major factors that influence climate determine the different climate zones. In general, the same type of climate zone will be found at similar latitudes and in similar positions on nearly all continents, both in the Northern and Southern Hemispheres. The exceptions to this pattern are the climate zones called the continental climates, which are not found at higher latitudes in the Southern Hemisphere. This is because the Southern Hemisphere land masses are not wide enough to produce a continental climate.

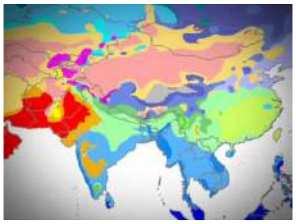
Classification

Climate zones are classified by the Köppen classification system. This system is based on the temperature, the amount of precipitation, and the times of year when precipitation occurs. Since climate determines the type of vegetation that grows in an area, vegetation is used as an indicator of climate type.

Biomes

A climate type and its plants and animals make up a **biome**. The organisms of a biome share certain characteristics around the world, because their environment has similar advantages and challenges. The organisms have adapted to that environment in similar ways over time. For example, different species of cactus live on different continents, but they have adapted to the harsh desert in similar ways.

The similarities between climate zones and biome types are displayed in this video: http://www.youtube.com/watch?v=Z_THTbynoRA (1:01).



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Major Climate Groups

The Köppen classification system recognizes five major climate groups. Each group is divided into subcategories. Some of these subcategories are forest, monsoon, and wet/dry types, based on the amount of precipitation and season when that precipitation occurs (**Figure** 7.66).

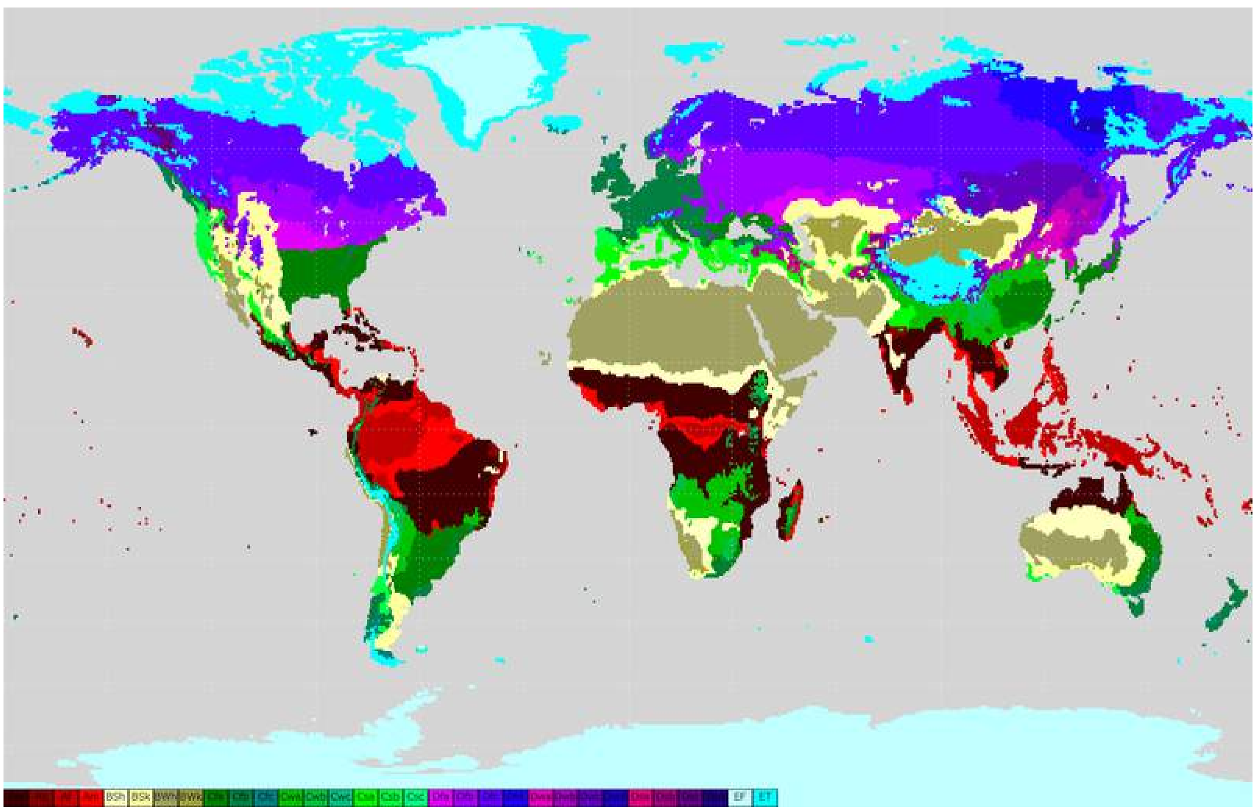


FIGURE 7.66

This world map of the Köppen classification system indicates where the climate zones and major biomes are located.

Tropical Moist Climates

Tropical moist climates are found in a band about 15^o to 25^o N and S of the Equator (**Figure** 7.66).

- Temperature: Intense sunshine. Each month has an average temperature of at least 18^oC (64^oF).
- Rainfall: Abundant, at least 150 cm (59 inches) per year.

The main vegetation for this climate is the tropical rainforest.

Dry Climates

Dry climates have less precipitation than evaporation.

- Temperature: Abundant sunshine. Summer temperatures are high; winters are cooler and longer than in tropical moist climates.
- Rainfall: Irregular; several years of drought are often followed by a single year of abundant rainfall. Dry climates cover about 26% of the world's land area.

Low latitude deserts are found at the Ferrell cell high pressure zone. Higher latitude deserts occur within continents or in rainshadows. Vegetation is sparse but well adapted to the dry conditions.

Moist Subtropical Mid-latitude

Moist subtropical mid-latitude climates are found along the coastal areas in the United States.

- Temperature: The coldest month ranges from just below freezing to almost balmy, between -3^oC and 18^oC (27^o to 64^oF). Summers are mild, with average temperatures above 10^oC (50^oF). Seasons are distinct.
- Rainfall: There is plentiful annual rainfall.

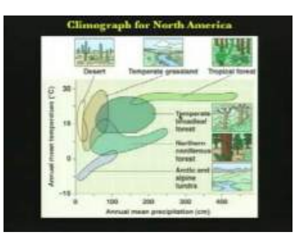
Continental Climates

Continental climates are found in most of the North American interior from about 40°N to 70°N.

- Temperature: The average temperature of the warmest month is higher than 10°C (50°F) and the coldest month is below -3°C (27°F).
- Precipitation: Winters are cold and stormy (look at the latitude of this zone and see if you can figure out why). Snowfall is common and snow stays on the ground for long periods of time.

Trees grow in continental climates, even though winters are extremely cold, because the average annual temperature is fairly mild. Continental climates are not found in the Southern Hemisphere because of the absence of a continent large enough to generate this effect.

This "Ecosystem Ecology" video lecture at U.C. Berkley outlines the factors that create climate zones and consequently the biomes: http://www.youtube.com/watch?v=3tY3aXgX4AM (46:46).



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Polar Climates

Polar climates are found across the continents that border the Arctic Ocean, Greenland, and Antarctica.

- Temperature: Winters are entirely dark and bitterly cold. Summer days are long, but the Sun is low on the horizon so summers are cool. The average temperature of the warmest month is less than 10^{o}C (50^{o}F). The annual temperature range is large.
- Precipitation: The region is dry, with less than 25 cm (10 inches) of precipitation annually; most precipitation occurs during the summer.

Microclimates

When climate conditions in a small area are different from those of the surroundings, the climate of the small area is called a **microclimate**. The microclimate of a valley may be cool relative to its surroundings since cold air sinks. The ground surface may be hotter or colder than the air a few feet above it, because rock and soil gain and lose heat readily. Different sides of a mountain will have different microclimates. In the Northern Hemisphere, a south-facing slope receives more solar energy than a north-facing slope, so each side supports different amounts and types of vegetation.

Altitude mimics latitude in climate zones. Climates and biomes typical of higher latitudes may be found in other areas of the world at high altitudes.

Summary

- A biome is a climate zone and the plants and animals that live in it.
- The Koppen classification system divides climates into five major types and many subtypes based on temperature and humidity characteristics.
- A microclimate has different climate conditions from the surrounding regions.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=ZouWWVyz9v8

MEDIA

Click image to the left for more content.

1. What determines the characteristics of the Moab desert?
2. Where are deserts often found?
3. Why are the poles cold?
4. How can the ocean heat the land?
5. What is the mean temperature at Reykjavik?
6. What brings the warm temperatures to Iceland?

7. How do greenhouse gases effect climate?
8. What are the principal factors in determining climate?

Review

1. How does a biome relate to a climate zone?
2. How does a region develop its own microclimate?
3. Where do you think dry climates are located? Where are subtropical climates located?

7.32 Climate Change in Earth History

- Explain how Earth's climate has changed in the past.

How important is climate in the history of life?

Dinosaurs lived a long time, geologically speaking, in part because the weather was favorable to them. Giant mammals lived during the ice ages because conditions were favorable. Earth's climate has been warmer and colder in Earth history, but mostly it's been warmer.

Climate Change in Earth History

Climate has changed throughout Earth history. Much of the time Earth's climate was hotter and more humid than it is today, but climate has also been colder, as when glaciers covered much more of the planet. The most recent ice ages were in the Pleistocene Epoch, between 1.8 million and 10,000 years ago (**Figure** 7.67). Glaciers advanced and retreated in cycles, known as glacial and interglacial periods. With so much of the world's water bound into the ice, sea level was about 125 meters (395 feet) lower than it is today. Many scientists think that we are now in a warm, interglacial period that has lasted about 10,000 years.

For the past 1500 years, climate has been relatively mild and stable when compared with much of Earth's history. Why has climate stability been beneficial for human civilization? Stability has allowed the expansion of agriculture and the development of towns and cities.

Fairly small temperature changes can have major effects on global climate. The average global temperature during glacial periods was only about 5.5^{o}C (10^{o}F) less than Earth's current average temperature. Temperatures during the interglacial periods were about 1.1^{o}C (2.0^{o}F) higher than today (**Figure** 7.68).

Since the end of the Pleistocene, the global average temperature has risen about 4^{o}C (7^{o}F). Glaciers are retreating and sea level is rising. While climate is getting steadily warmer, there have been a few more extreme warm and cool times in the last 10,000 years. Changes in climate have had effects on human civilization.

FIGURE 7.67
The maximum extent of Northern Hemisphere glaciers during the Pleistocene epoch.

- The Medieval Warm Period from 900 to 1300 A.D. allowed Vikings to colonize Greenland and Great Britain to grow wine grapes.
- The Little Ice Age, from the 14th to 19th centuries, the Vikings were forced out of Greenland and humans had to plant crops further south.

Summary

- Earth's climate has been warmer and colder, but mostly warmer, through Earth history.
- For the past 2,000 years, when human society has really blossomed, climate has been relatively stable.
- An increase in glaciers lowers sea level and a decrease in glaciers raises sea level.

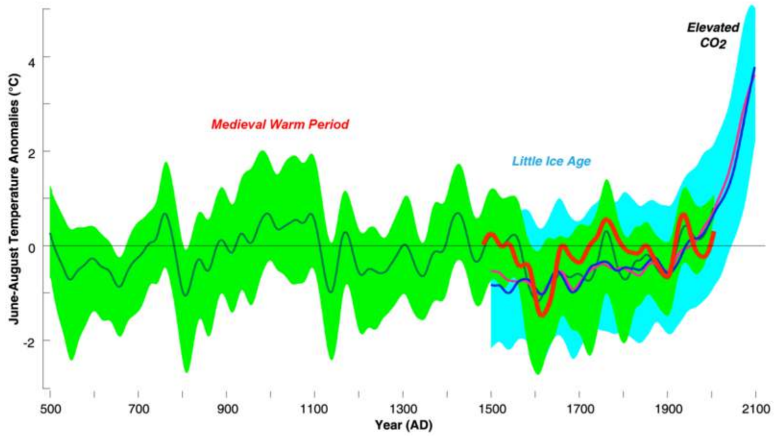


FIGURE 7.68

The graph is a compilation of 5 reconstructions (the green line is the mean of the five records) of mean temperature changes. This illustrates the high temperatures of the Medieval Warm Period, the lows of the Little Ice Age, and the very high (and climbing) temperature of this decade.

Practice

Use this resource to answer the questions that follow.

http://climate.nasa.gov/evidence/

1. When did the last ice age end?
2. What is most historical climate variation attributed to?
3. What has occurred in the last 1,300 years?
4. What have ice cores shown?
5. List the effects of global climate change.

Review

1. How has climate changed in the past 1,100 years?
2. What were the temperatures of the glacial and interglacial periods of the Pleistocene ice ages?
3. Why is the fact that climate has changed a lot during Earth history important to a discussion of climate change today?

7.33 Short-Term Climate Change

- Describe common short-term climate variations.

Why is El Niño important to a discussion on climate change?

In 1973 a severe El Niño shut off upwelling off of South America, resulting in the collapse of the anchovetta fishery. Without small fish to eat, larger marine organisms died off. Since then, severe El Niño events have become more frequent.

El Niño Southern Oscillation

Short-term changes in climate are common and they have many causes (**Figure** 7.69). The largest and most important of these is the oscillation between El Niño and La Niña conditions. This cycle is called the ENSO (El Niño Southern Oscillation). The ENSO drives changes in climate that are felt around the world about every two to seven years.

Normal Conditions

In a normal year, the trade winds blow across the Pacific Ocean near the Equator from east to west (toward Asia). A low pressure cell rises above the western equatorial Pacific. Warm water in the western Pacific Ocean raises sea levels by half a meter. Along the western coast of South America, the Peru Current carries cold water northward, and then westward along the Equator with the trade winds. Upwelling brings cold, nutrient-rich waters from the deep sea.

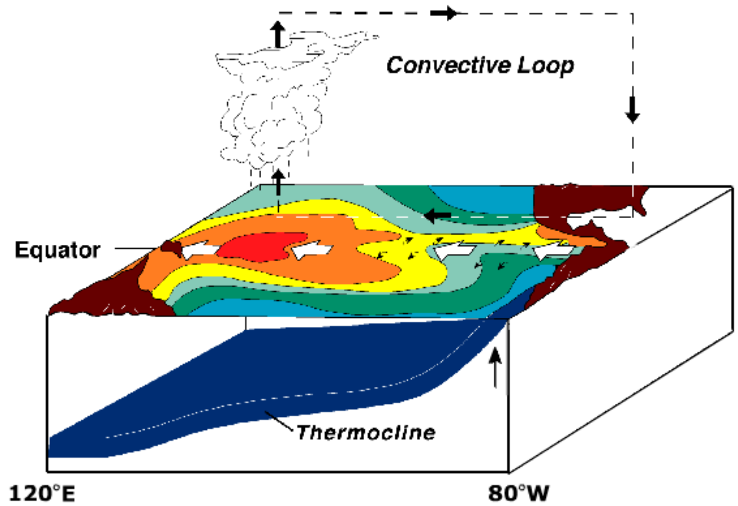


FIGURE 7.69
Under normal conditions, low pressure and warm water (shown in red) build up in the western Pacific Ocean. Notice that continents are shown in brown in the image. North and South America are on the right in this image.

El Niño

In an **El Niño** year, when water temperature reaches around 28^{o}C (82^{o}F), the trade winds weaken or reverse direction and blow east (toward South America) (**Figure** 7.70). Warm water is dragged back across the Pacific Ocean and piles up off the west coast of South America. With warm, low-density water at the surface, upwelling stops. Without upwelling, nutrients are scarce and plankton populations decline. Since plankton form the base of the food web, fish cannot find food, and fish numbers decrease as well. All the animals that eat fish, including birds and humans, are affected by the decline in fish.

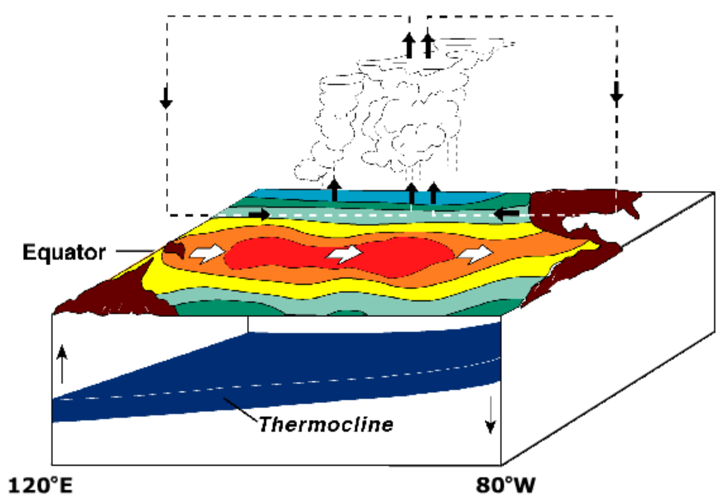


FIGURE 7.70
In El Niño conditions, the trade winds weaken or reverse directions. Warm water moves eastward across the Pacific Ocean and piles up against South America.

By altering atmospheric and oceanic circulation, El Niño events change global climate patterns.

- Some regions receive more than average rainfall, including the west coast of North and South America, the southern United States, and Western Europe.
- Drought occurs in other parts of South America, the western Pacific, southern and northern Africa, and

southern Europe.

An El Niño cycle lasts one to two years. Often, normal circulation patterns resume. Sometimes circulation patterns bounce back quickly and extremely (**Figure** 7.71). This is a **La Niña**.

La Niña

In a La Niña year, as in a normal year, trade winds moves from east to west and warm water piles up in the western Pacific Ocean. Ocean temperatures along coastal South America are colder than normal (instead of warmer, as in El Niño). Cold water reaches farther into the western Pacific than normal.

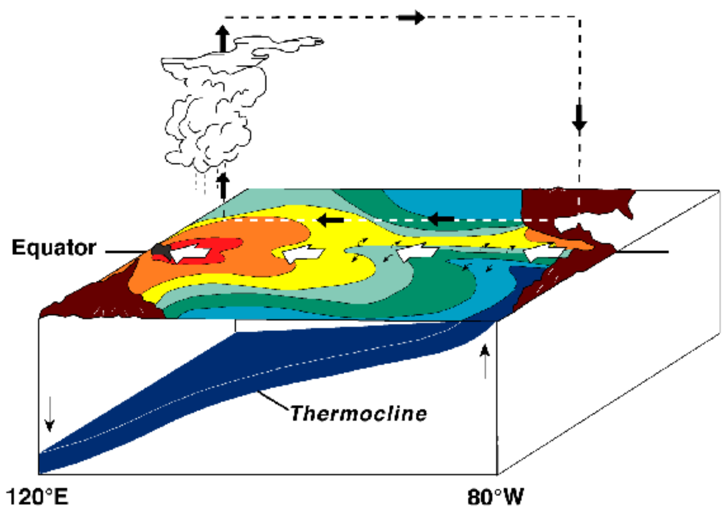


FIGURE 7.71
A La Niña year is like a normal year but the circulation patters are more extreme.

An online guide to El Niño and La Niña events from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/eln/home.rxml .

Other important oscillations are smaller and have a local, rather than global, effect. The North Atlantic Oscillation mostly alters climate in Europe. The Mediterranean also goes through cycles, varying between being dry at some times and warm and wet at others.

This ABC News video explores the relationship of El Niño to global warming. El Niño is named as the cause of strange weather across the United States in the winter of 2007 in this video: http://www.youtube.com/watch?v=5uk9nwtAOio (3:33).

MEDIA
Click image to the left for more content.

Summary

- El Niño and La Niña are two examples of short-term climate changes lasting one to a few years.

- In an El Niño, the trade winds reverse direction, as do the equatorial surface currents, causing warm water to pool off of South America and stop upwelling.
- A La Niña is like normal conditions only more so.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/player/environment/environment-natural-disasters/landslides-and-more/el-nino.html

1. What happened in 1998?

2. What is El Niño?

3. Where does the warm water gather?

4. What are the effects of El Niño?

5. What is La Niña?

6. What specific effects were seen due to the El Niño of 1997-1998 in North America?

7. What happened in the ocean?

8. How was animal life effected by the El Niño phenomenon?

Review

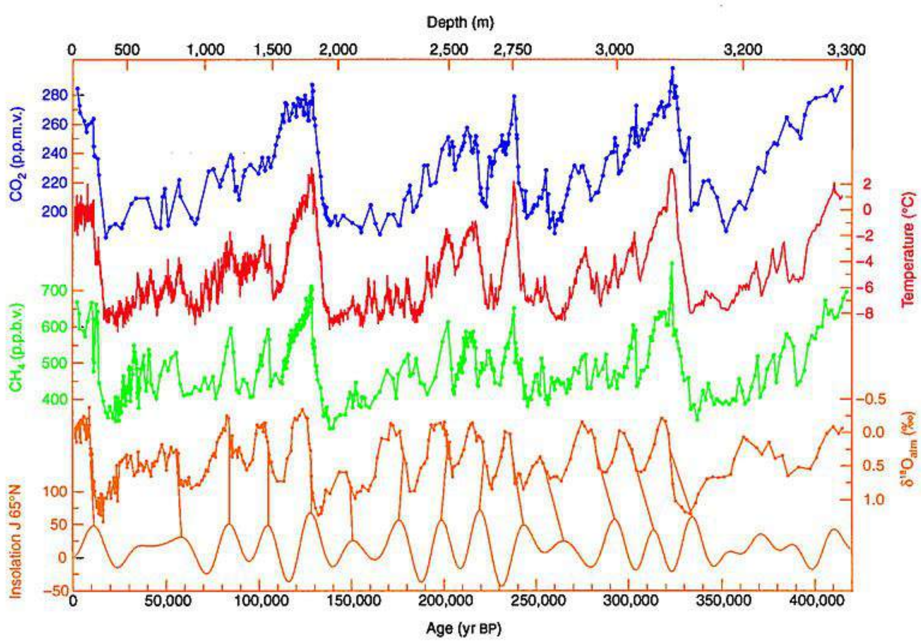
1. Describe what happens with wind and current directions during an El Niño event.

2. Why does an El Niño cause a collapse of the food chain off of South America?

3. How does a La Niña event compare with an El Niño event?

7.34 Long-Term Climate Change

- Explain mechanisms that can change climate over the long term.



Why do the blue, green and red lines go in the same direction at the same time?

This is a complicated graph, but extremely interesting. The data are from the 3600 meter-long Vostok ice core, which gave climate scientists an unprecedented look into the history of Earth's climate. The red line is temperature. You can see that carbon dioxide and methane are correlated with temperature. When these greenhouse gases are high, temperature is high. This holds true for the 440,000 years revealed in the core.

Causes of Long-term Climate Change

Many processes can cause climate to change. These include changes:

- In the amount of energy the Sun produces over years.
- In the positions of the continents over millions of years.
- In the tilt of Earth's axis and orbit over thousands of years.
- That are sudden and dramatic because of random catastrophic events, such as a large asteroid impact.
- In greenhouse gases in the atmosphere, caused naturally or by human activities.

Solar Variation

The amount of energy the Sun radiates is variable. **Sunspots** are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle (**Figure** 7.72). When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is, and there is no known 11-year cycle in climate variability. The Little Ice Age corresponded to a time when there were no sunspots on the Sun.

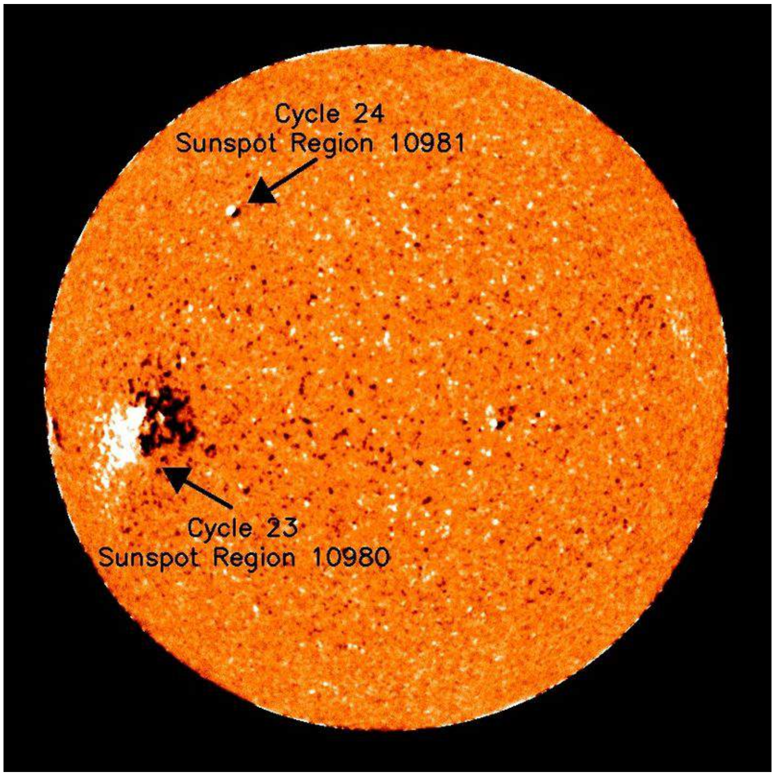


FIGURE 7.72
Sunspots on the face of the Sun.

Plate Tectonics

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents are joined into one supercontinent (such as Pangaea), nearly all locations experience a continental climate. When the continents separate, heat is more evenly distributed.

Plate tectonic movements may help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age.

Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather (**Figure** 7.73). Massive eruptions of the fluid lavas that create lava plateaus release much more gas and dust, and can change climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

Milankovitch Cycles

The most extreme climate of recent Earth history was the Pleistocene. Scientists attribute a series of ice ages to variation in the Earth's position relative to the Sun, known as **Milankovitch cycles**.

The Earth goes through regular variations in its position relative to the Sun:

1. The shape of the Earth's orbit changes slightly as it goes around the Sun. The orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.

2. The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun.

FIGURE 7.73
An eruption like Sarychev Volcano (Kuril Islands, northeast of Japan) in 2009 would have very little impact on weather.

This results in chilly summers and warmer winters.

3. The planet's tilt on its axis varies between 22.1^o and 24.5^o. Seasons are caused by the tilt of Earth's axis of rotation, which is at a 23.5^o angle now. When the tilt angle is smaller, summers and winters differ less in temperature. This cycle lasts 41,000 years.

When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Changes in Atmospheric Greenhouse Gas Levels

Since greenhouse gases trap the heat that radiates off the planet's surfaces, what would happen to global temperatures if atmospheric greenhouse gas levels decreased? What if greenhouse gases increased? A decrease in greenhouse gas levels decreases global temperature and an increase raises global temperature.

Greenhouse gas levels have varied throughout Earth history. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods (**Figure** 7.74).

Natural processes add and remove CO_2 from the atmosphere.

- Processes that add CO_2:
  - volcanic eruptions
  - decay or burning of organic matter.
- Processes that remove CO_2:
  - absorption by plant and animal tissue.

When plants are turned into fossil fuels, the CO_2 in their tissue is stored with them. So CO_2 is removed from the atmosphere. What does this do to Earth's average temperature?

What happens to atmospheric CO_2 when the fossil fuels are burned? What happens to global temperatures?

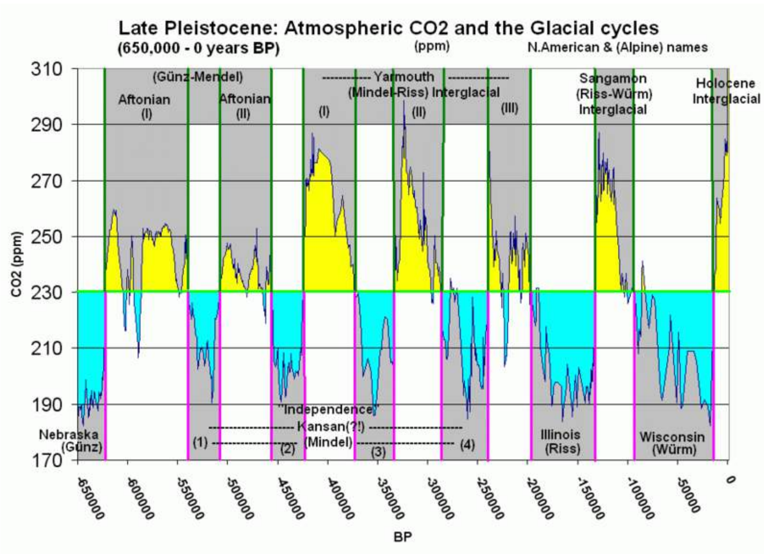


FIGURE 7.74

CO_2 levels during glacial (blue) and interglacial (yellow) periods. Are CO_2 levels relatively high or relatively low during interglacial periods? Current carbon dioxide levels are at 387 ppm, the highest level for the last 650,000 years. BP means years before present.

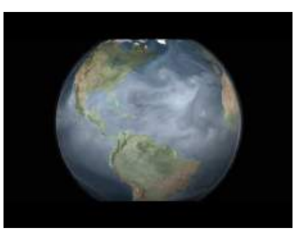
Summary

- The positions of continents, the sizes of oceans and the amount of volcanic activity that takes place are all ways that plate tectonics processes can affect climate.
- Milankovitch cycles affect the way Earth relates to the Sun due to the shape of the planet's orbit, its axial tilt, and its wobble.
- Atmospheric greenhouse gas levels correlate with average global temperatures.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=VlzQ1i2caj4



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1. What are Milankovitch cycles?
2. What is the Holecene?
3. What is happening to climate now?

Review

1. How do Milankovitch cycles affect global temperatures?
2. How do plate tectonics processes affect global climate?

3. How are atmospheric greenhouse gas levels correlated with global temperatures?

7.35 Greenhouse Effect

- Describe the greenhouse effect.
- Explain how human actions contribute to the greenhouse effect.

How does the atmosphere resemble a greenhouse?

To extend the growing season, many farmers use greenhouses. A greenhouse traps heat so that days that might be too cool for a growing plant can be made to be just right. Similar to a greenhouse, greenhouse gases in the atmosphere keep Earth warm.

The Greenhouse Effect

The exception to Earth's temperature being in balance is caused by greenhouse gases. But first the role of greenhouse gases in the atmosphere must be explained.

Greenhouse gases warm the atmosphere by trapping heat. Some of the heat that radiates out from the ground is trapped by greenhouse gases in the troposphere. Like a blanket on a sleeping person, greenhouse gases act as insulation for the planet. The warming of the atmosphere because of **insulation** by greenhouse gases is called the **greenhouse effect** (**Figure** 7.75). Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.

Greenhouse Gases

Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs. **Table** 7.4 shows how each greenhouse gas naturally enters the atmosphere.

TABLE 7.4: Greenhouse Gas Entering the Atmosphere

Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

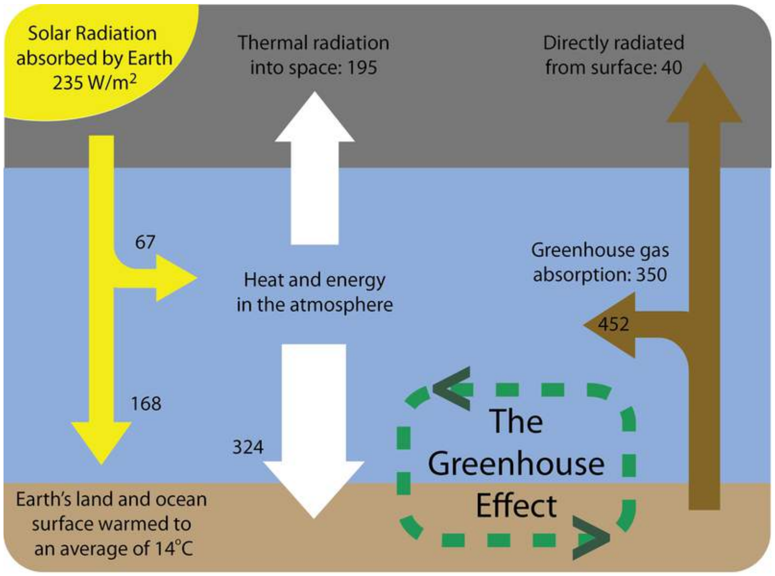


FIGURE 7.75

The Earth's heat budget shows the amount of energy coming into and going out of the Earth's system and the importance of the greenhouse effect. The numbers are the amount of energy that is found in one square meter of that location.

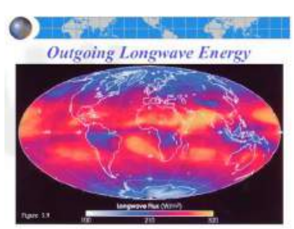
Different greenhouse gases have different abilities to trap heat. For example, one methane molecule traps 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) traps 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere.

Human Activity and Greenhouse Gas Levels

Human activity has significantly raised the levels of many of greenhouse gases in the atmosphere. Methane levels are about 2 1/2 times higher as a result of human activity. Carbon dioxide has increased more than 35%. CFCs have only recently existed.

What do you think happens as atmospheric greenhouse gas levels increase? More greenhouse gases trap more heat and warm the atmosphere. The increase or decrease of greenhouse gases in the atmosphere affect climate and weather the world over.

This PowerPoint review, *Atmospheric Energy and Global Temperatures*, looks at the movement of energy through the atmosphere: http://www.youtube.com/watch?v=p6xMF_FFUU0 (8:17).



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Summary

- Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs).
- Tropospheric greenhouse gases trap heat in the atmosphere; greenhouse gases vary in their heat-trapping abilities.

- Levels of greenhouse gases in the atmosphere are increasing due to human activities.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth Science → Environmental Science → Search: **Greenhouse Effects** (first resource, starts with "About 50% of solar radiation...")

1. How much solar radiation is absorbed by the surface of the Earth?
2. What reflects the radiation?
3. How is most radiation re-emitted?
4. What is the net effect of this heating?
5. What are the primary greenhouse gases?

Review

1. If you were trying to keep down global temperature and you had a choice between adding 100 methane molecules or 1 CFC-12 molecule to the atmosphere, which would you choose?
2. What is the greenhouse effect?
3. How does Earth's atmosphere resemble a greenhouse?

7.36 Global Warming

- Describe the consequences of global warming.

Do polar bears belong in garbage dumps?

Changes due to warmer temperatures are becoming more visible. The Arctic is covered with ice less of the year, so polar bears can't hunt and are raiding garbage dumps for food. Extreme weather events are becoming more common as weather becomes stranger. Sea level is rising, which is a problem during storms.

Global Warming

With more greenhouse gases trapping heat, average annual global temperatures are rising. This is known as **global warming**.

Global warming - How Humans are Affecting our Planet from NASA, discusses the basics of global warming science: http://www.youtube.com/watch?v=VXvGPbHXxtc (7:58).

MEDIA

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Increasing Temperatures

While temperatures have risen since the end of the Pleistocene, 10,000 years ago, this rate of increase has been more rapid in the past century, and has risen even faster since 1990. The 12 warmest years on record have all occurred since 2001, and the 20 warmest years have occurred since 1987 (through 2011) (**Figure** 7.76). The 2000s were the warmest decade yet.

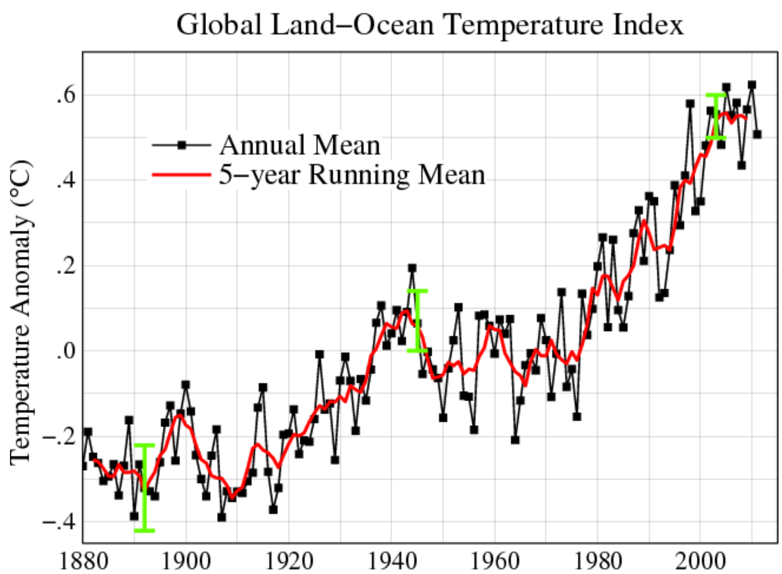

FIGURE 7.76
Recent temperature increases show how much temperature has risen since the Industrial Revolution began.

Annual variations aside, the average global temperature increased about 0.8^{o}C (1.5^{o}F) between 1880 and 2010, according to the Goddard Institute for Space Studies, NOAA. This number doesn't seem very large. Why is it important? http://www.giss.nasa.gov/research/news/20100121/

Greenhouse Gas Emissions

The United States has long been the largest emitter of greenhouse gases, with about 20% of total emissions in 2004. As a result of China's rapid economic growth, its emissions surpassed those of the United States in 2008. However, it's also important to keep in mind that the United States has only about one-fifth the population of China. What's the significance of this? The average United States citizen produces far more greenhouse gas emissions than the average Chinese person.

An animation of CO_2 released by different fossil fuels is seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/CO2BTU_3.MPG .

Changes Due to Warming Temperatures

The following images show changes in the Earth and organisms as a result of global warming: **Figure** 7.77, **Figure** 7.78, **Figure** 7.79.

The timing of events for species is changing. Mating and migrations take place earlier in the spring months. Species that can are moving their ranges uphill. Some regions that were already marginal for agriculture are no longer arable because they have become too warm or dry.

Modeled Climate-Induced Glacier Change in Glacier National Park, 1850-2100: http://www.nrmsc.usgs.gov/research/glacier_model.htm .

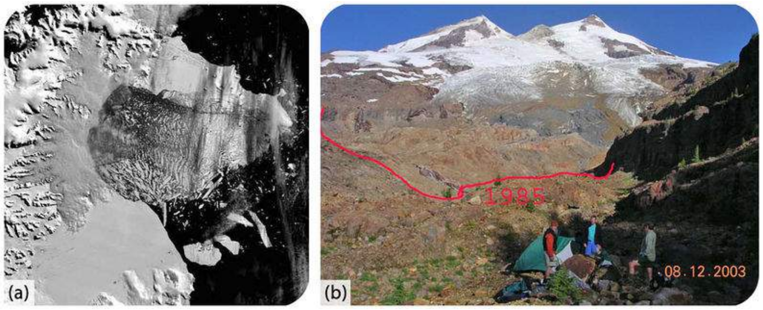

FIGURE 7.77

(a) Breakup of the Larsen Ice Shelf in Antarctica in 2002 was related to climate warming in the region. (b) The Boulder Glacier has melted back tremendously since 1985. Other mountain glaciers around the world are also melting.

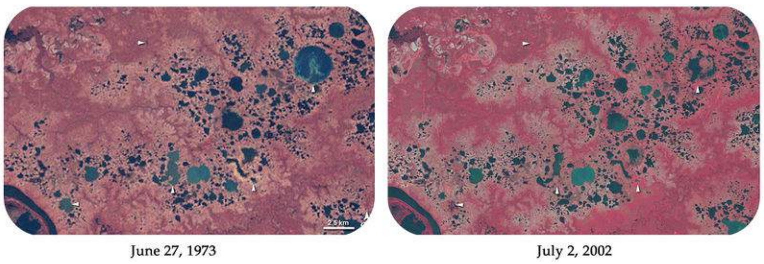

FIGURE 7.78

Permafrost is melting and its extent decreasing. There are now fewer summer lakes in Siberia.

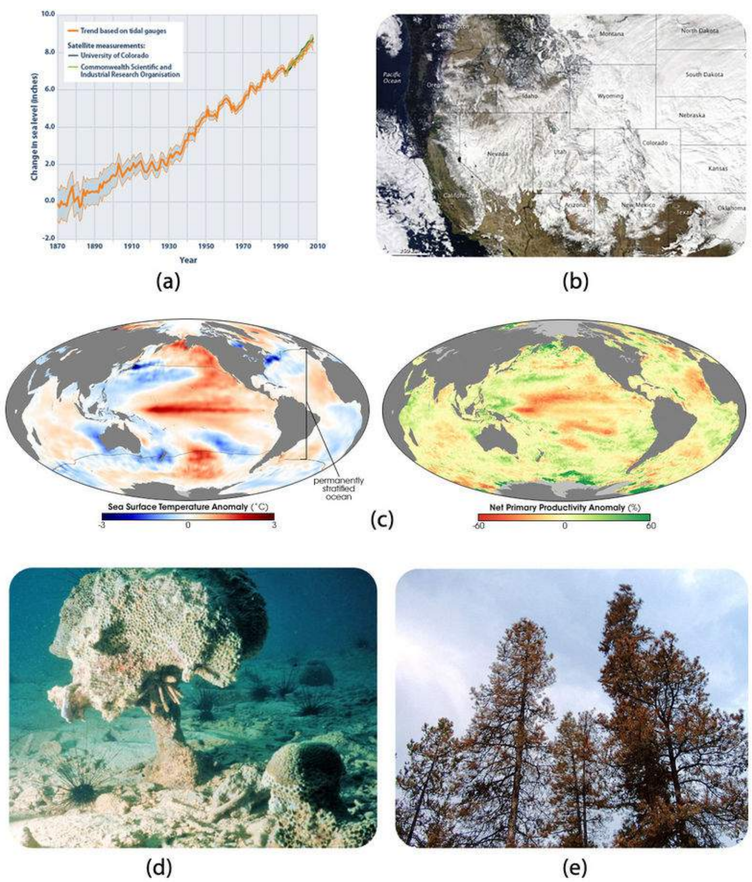

FIGURE 7.79

(a) Melting ice caps add water to the oceans, so sea level is rising. Remember that water slightly expands as it warms —this expansion is also causing sea level to rise. (b) Weather is becoming more variable with more severe storms and droughts. Snow blanketed the western United States in December 2009. (c) As surface seas warm, phytoplankton productivity has decreased. (d) Coral reefs are dying worldwide; corals that are stressed by high temperatures turn white. (e) Pine beetle infestations have killed trees in western North America The insects have expanded their ranges into areas that were once too cold.

What are the two major effects being seen in this animation? Glaciers are melting and vegetation zones are moving uphill. If fossil fuel use exploded in the 1950s, why do these changes begin early in the animation? Does this mean that the climate change we are seeing is caused by natural processes and not by fossil fuel use?

A number of videos on the National Geographic site deal with global warming: http://video.nationalgeographic.com/video/environment/global-warming-environment .

- A no-nonsense look at global warming and what we can do about it is found in "A Way Forward: Facing Climate Change."
- "Antarctic Ice" describes the changes that are already happening to Antarctica and what the consequences of future melting will be.
- "Glacier Melt" looks at melting in a large alpine glacier and the effects of glacier loss to Europe.
- In "Greenhouse Gases," researchers look at the effects of additional greenhouse gases on future forests.
- Researchers look for changes in the range of a mountain-top dwelling mammal, the pika, in "Hamster-like Pika in Peril."
- "State of Polar Bears" show how polar bears, in their specialized habitat in the Arctic, are among the species already affected by warming temperatures.

Warming temperatures are bringing changes to much of the planet, including California. Sea level is rising, snow pack is changing, and the ecology of the state is responding to these changes.

Find out more at http://science.kqed.org/quest/video/climate-watch-california-at-the-tipping-point/ .

MEDIA
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Summary

- Greenhouse gases trap heat in the atmosphere; burning fossil fuels and other human activities release greenhouse gases into the atmosphere; greenhouse gas levels in the atmosphere are increasing; and global temperatures are increasing.
- Average global temperature has been rising since the end of the ice ages but the rate of its rise has increased in recent decades.
- Changes due to increasing temperatures are seen around the globe but are most dramatic in the polar regions.

Practice

Use this resource to answer the questions that follow.

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

MEDIA
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1. How much has the global temperature risen in the last few decades?
2. What contributes to global warming?
3. What is the greenhouse effect?
4. What is the evidence for global warming?
5. What was the warmest recorded year?
6. What gases have been recorded at their highest levels in history?
7. What do researchers predict will happen?

Review

1. The first point in the summary above is a set of facts. Does it logically follow that human activities are causing global temperatures to rise? Is there a different explanation that fits with the facts?
2. Why is average global temperature the most important value when talking about climate change?
3. What are some of the effects of climate change that are already being seen?

7.37 Causes and Effects of Global Warming

- Describe what causes global warming.
- Describe the consequences of global warming.

What is the human cost of warmer temperatures?

Many lands are marginal for farming. When rainfall is normal or high, the lands can produce. When rainfall is low, no crops grow. Drought makes marginal lands unsuitable for farming. Drought can also make good lands more difficult to farm. These changes will increase as temperatures warm.

Causes of Global Warming

The average global temperature has been rising since the end of the Pleistocene. With some ups and downs, of course. Rising temperatures are natural for this time period. But natural causes cannot explain all the warming that's been happening. There is some other factor at work.

Recent **global warming** is due mainly to human actions. The actions involve releasing greenhouse gases into the atmosphere. Remember that greenhouse gases keep the atmosphere warm? And that carbon dioxide is a greenhouse gas? When you burn fossil fuels, carbon dioxide is released into the atmosphere. The more carbon dioxide in the atmosphere, the better the atmosphere can trap heat. In other words, an increase in greenhouse gases leads to greater greenhouse effect. The result is increased global warming. Pictured below is the increase in carbon dioxide since 1960 (**Figure** 7.80).

Burning forests also releases carbon dioxide into the atmosphere. Other human activities release greenhouse gases into the atmosphere. For example, growing rice and raising livestock both produce methane.

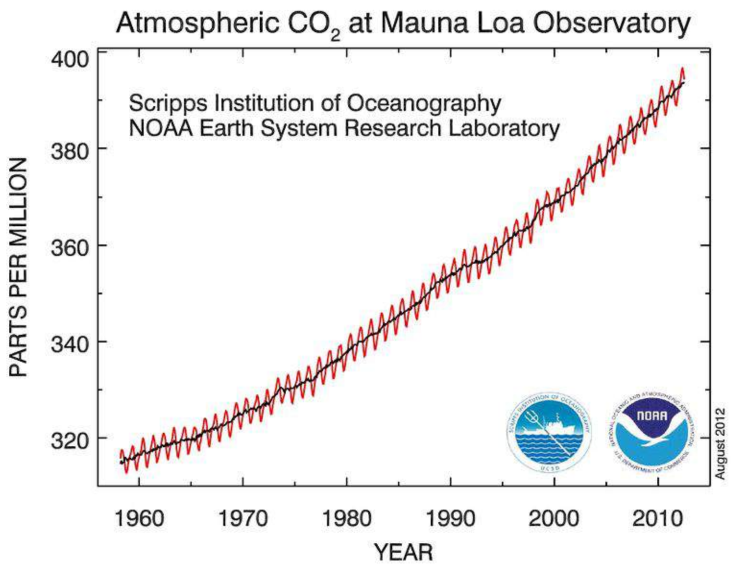


FIGURE 7.80
How much more carbon dioxide was in the air in 2010 than in 1960?

Effects of Global Warming

There are already many effects of global warming being seen. As Earth has gotten warmer, sea ice has melted. This has raised the level of water in the oceans (**Figure** 7.81).

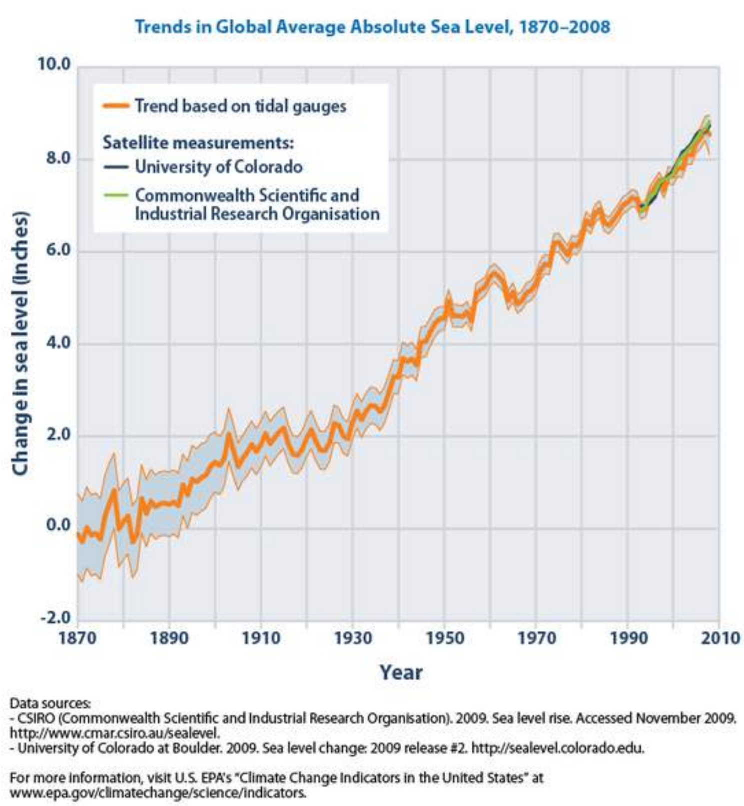


FIGURE 7.81
The overall trend in sea level since 1870; it has risen about 9 inches.

The extent of Arctic sea ice in summer has been decreasing rapidly. The ice pictured below is the sea ice minimum in 2011 (**Figure** 7.82). The yellow line is the median minimum ice extent for 1979–2000.

FIGURE 7.82
The sea ice minimum for 2011 was the second lowest on record.

Other effects of global warming include more extreme weather. Earth now has more severe storms, floods, heat waves, and droughts than it did just a few decades ago. Many living things cannot adjust to the changing climate. Coral reefs in many parts of the world are struggling to survive. Species are moving uphill where temperatures are cooler. Those at the top of the mountain are being run off. Migration and egg-laying behaviors in birds are off of their normal. There are many more examples of the effects of changing climate.

Vocabulary

- **global warming**: Warming of Earth's atmosphere because of the addition of greenhouse gases; the increase in average global temperature is caused by human activities.

Summary

- Greenhouse gases trap heat in the atmosphere. Burning fossil fuels and other human activities release greenhouse gases into the atmosphere.
- Greenhouse gas levels in the atmosphere are increasing. Global temperatures are increasing.
- Changes due to increasing temperatures are seen around the globe. Living organisms and humans are also affected.

Practice

Use the resource below to answer the questions that follow.

- **NASA Global Climate Change - Effects** at http://climate.nasa.gov/effects/

1. What is the evidence that climate change is occurring?
2. What do scientists expect to see in the coming decades?
3. What is the expected temperature change for the next century?
4. What changes are expected to be seen in North America?

5. What phenomenon is virtually certain to occur in the future?

Review

1. What do you expect to happen if you increase the amount of greenhouse gases in the atmosphere?
2. What has happened to the level of carbon dioxide in the atmosphere in the past several decades (use numbers and units)?
3. What has happened to sea level since 1870 (use numbers and units)?
4. What are some of the effects of climate change that are already being seen?

7.38 Impact of Continued Global Warming

- Describe likely impacts of continued global warming.

"The Inuit see this and the world should know this..."

"It's happening right before our eyes. If we're going to be ignored, it's like putting a shotgun in our mouth and pulling the trigger." —23-year-old Jordan Konek, one of the native people of the Canadian Arctic, to the 2011 Climate Change Conference in Durban, South Africa.

Future Warming

The amount CO_2 levels will rise in the next decades is unknown. What will this number depend on in the developed nations? What will it depend on in the developing nations? In the developed nations it will depend on technological advances or lifestyle changes that decrease emissions. In the developing nations, it will depend on how much their lifestyles improve and how these improvements are made.

If nothing is done to decrease the rate of CO_2 emissions, by 2030, CO_2 emissions are projected to be 63% greater than they were in 2002.

Temperature Scenarios

Computer models are used to predict the effects of greenhouse gas increases on climate for the planet as a whole and also for specific regions. If nothing is done to control greenhouse gas emissions and they continue to increase at current rates, the surface temperature of the Earth can be expected to increase between 0.5^{o}C and 2.0^{o}C (0.9^{o}F and 3.6^{o}F) by 2050 and between 2^o and 4.5^{o}C (3.5^o and 8^{o}F) by 2100, with CO_2 levels over 800 parts per million (ppm). On the other hand, if severe limits on CO_2 emissions begin soon, temperatures could rise less than 1.1^{o}C (2^{o}F) by 2100.

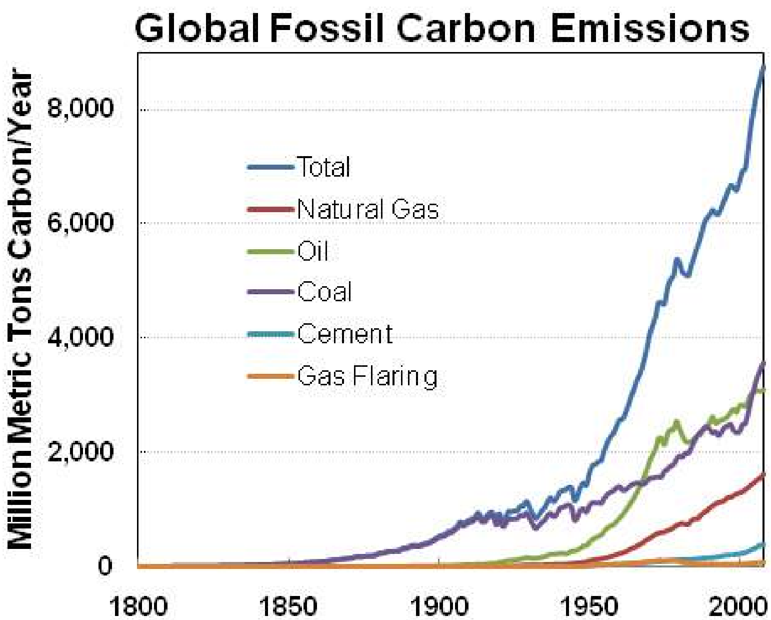
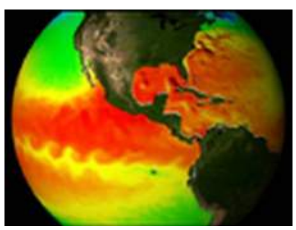


FIGURE 7.83
Global CO_2 emissions are rising rapidly. The industrial revolution began about 1850 and industrialization has been accelerating.

This video explores the tools NASA scientists use to determine how the climate is changing: http://www.youtube.com/watch?v=JRayIgKublg (4:00).



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Whatever the temperature increase, it will not be uniform around the globe. A rise of 2.8^{o}C (5^{o}F) would result in 0.6^o to 1.2^{o}C (1^o to 2^{o}F) at the Equator, but up to 6.7^{o}C (12^{o}F) at the poles. So far, global warming has affected the North Pole more than the South Pole, but temperatures are still increasing at Antarctica (**Figure** 7.84).

Animations of temperature anomalies for 5- and 10-year periods: http://data.giss.nasa.gov/gistemp/animations/ .

Global Changes

As greenhouse gases increase, changes will be more extreme. Oceans will become slightly more acidic, making it more difficult for creatures with carbonate shells to grow, and that includes coral reefs. A study monitoring ocean acidity in the Pacific Northwest found ocean acidity increasing ten times faster than expected and 10% to 20% of shellfish (mussels) being replaced by acid-tolerant algae.

Plant and animal species seeking cooler temperatures will need to move poleward 100 to 150 km (60 to 90 miles) or upward 150 m (500 feet) for each 1.0^{o}C (8^{o}F) rise in global temperature. There will be a tremendous loss of biodiversity because forest species can't migrate that rapidly. Biologists have already documented the extinction of high-altitude species that have nowhere higher to go.

Decreased snow packs, shrinking glaciers, and the earlier arrival of spring will all lessen the amount of water available in some regions of the world, including the western United States and much of Asia. Ice will continue

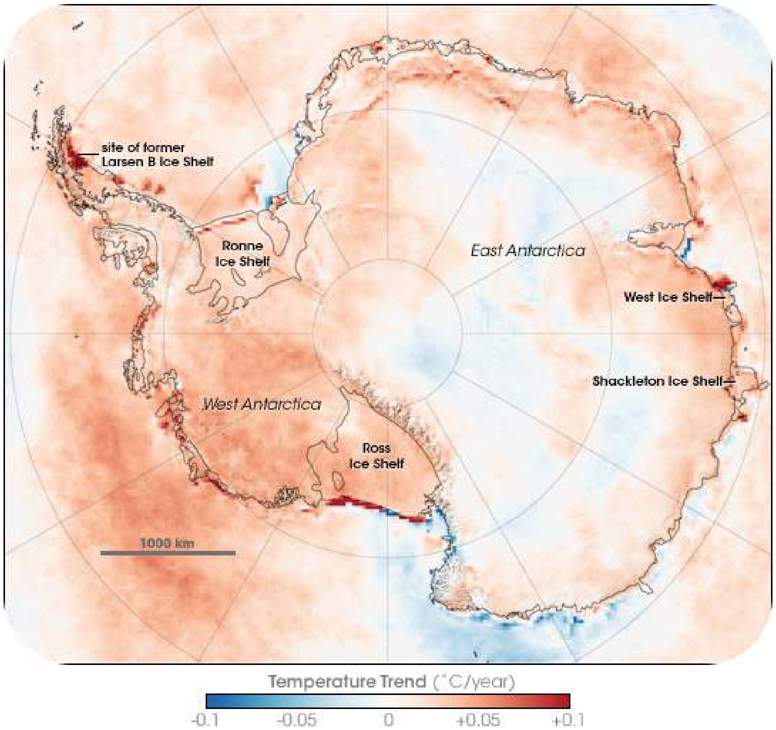


FIGURE 7.84
Temperature changes over Antarctica.

to melt and sea level is predicted to rise 18 to 97 cm (7 to 38 inches) by 2100 (**Figure** 7.85). An increase this large will gradually flood coastal regions, where about one-third of the world's population lives, forcing billions of people to move inland.

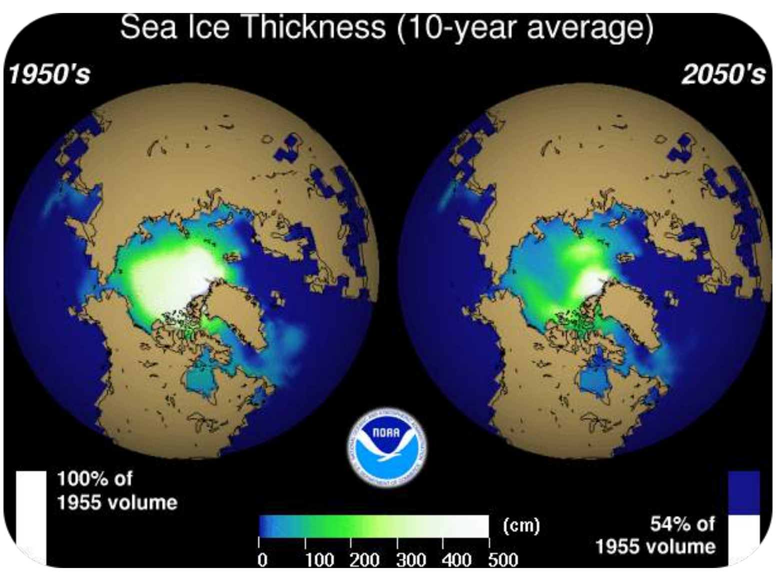


FIGURE 7.85
Sea ice thickness around the North Pole has been decreasing in recent decades and will continue to decrease in the coming decades.

Weather will become more extreme, with more frequent and more intense heat waves and droughts. Some modelers predict that the midwestern United States will become too dry to support agriculture and that Canada will become the new breadbasket. In all, about 10% to 50% of current cropland worldwide may become unusable if CO_2 doubles.

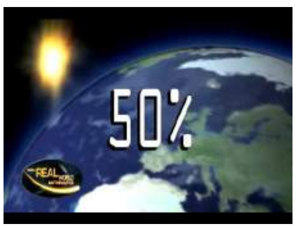
Although scientists do not all agree, hurricanes are likely to become more severe and possibly more frequent.

Tropical and subtropical insects will expand their ranges, resulting in the spread of tropical diseases such as malaria, encephalitis, yellow fever, and dengue fever.

You may notice that the numerical predictions above contain wide ranges. Sea level, for example, is expected to rise somewhere between 18 and 97 cm —quite a wide range. What is the reason for this uncertainty? It is partly because scientists cannot predict exactly how the Earth will respond to increased levels of greenhouses gases. How quickly greenhouse gases continue to build up in the atmosphere depends in part on the choices we make.

An important question people ask is this: Are the increases in global temperature natural? In other words, can natural variations in temperature account for the increase in temperature that we see? The answer is no. Changes in the Sun's irradiance, El Niño and La Niña cycles, natural changes in greenhouse gas, and other atmospheric gases cannot account for the increase in temperature that has already happened in the past decades.

This video discusses how, by using the CERES satellite, scientists monitor energy in the atmosphere, including incoming solar energy and reflected and absorbed energy. Greenhouse warming that results from atmospheric greenhouse gasses is also monitored: http://www.youtube.com/watch?v=JFfD6jn_OvA (4:31).



MEDIA

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Along with the rest of the world's oceans, San Francisco Bay is rising. Changes are happening slowly in the coastal arena of the San Francisco Bay Area and even the most optimistic estimates about how high and how quickly this rise will occur indicate potentially huge problems for the region.

Find out more at http://science.kqed.org/quest/video/going-up-sea-level-rise-in-san-francisco-bay/ .

MEDIA

Click image to the left for more content.

How Bad Could a Few Degrees Be?

How bad could a few degrees be? National Geographic has a set of videos about what to expect if temperature rises by each of these amounts by degree Celsius.

- 1^o: http://www.youtube.com/watch?v=2_ZQRIsn2pA
- 2^o: http://www.youtube.com/watch?v=P-0_gDXqYeQ
- 3^o: http://www.youtube.com/watch?v=6rdLu7wiZOE
- 4^o: http://www.youtube.com/watch?v=skFrR3g4BRQ
- 5^o: http://www.youtube.com/watch?v=7nRf2RTqANg
- 6^o: http://www.youtube.com/watch?v=O8qmaAMK4cM

Summary

- An increase in greenhouse gases will increase the changes that are already being seen including in ocean acidity.
- A decrease in snow pack will cause a shortage of water in a lot of regions that depend on a summer melt to supply water in the dry months.
- Temperature changes are not uniform around the globe. The largest changes are being seen in the polar regions.

Practice

Use this resource to answer the questions that follow.

NASA Global Climate Change - Effects

http://climate.nasa.gov/effects/

1. What is the evidence that climate change is occurring?

2. What do scientists expect to see in the coming decades?

3. What is the expected temperature change for the next century?

4. What changes are expected to be seen in North America?

5. What phenomenon is virtually certain to occur in the future?

Review

1. What does a computer model that predicts environmental changes due to increases in atmospheric greenhouse gases need to take into account?

2. Why does a small change in average global temperature have a large effect on the planet?

3. Why do you think that scientists do not have a firm understanding of how Earth will respond to increases in global temperature in the future?

7.39 Air Quality

- Explain how air pollution affects air quality.

What is this in the air?

People have euphemisms for smog; sometimes it's fog, sometimes it's haze. It's hard to know sometimes whether the air is full of something natural, like water vapor, or something man-made, like ozone. But in cities like this the air is often being marred by air pollution.

Air Quality

Pollutants include materials that are naturally occurring but are added to the atmosphere so that they are there in larger quantities than normal. Pollutants may also be human-made compounds that have never before been found in the atmosphere. Pollutants dirty the air, change natural processes in the atmosphere, and harm living things.

Problems with Air Quality

Air pollution started to be a problem when early people burned wood for heat and cooking fires in enclosed spaces such as caves and small tents or houses. But the problems became more widespread as fossil fuels such as coal began to be burned during the Industrial Revolution.

Smog

Air pollution started to be a problem when early people burned wood for heat and cooking fires in enclosed spaces such as caves and small tents or houses. But the problems became more widespread as fossil fuels such as coal began to be burned during the Industrial Revolution (**Figure** 7.86).

FIGURE 7.86
The 2012 Olympic Games in London opening ceremony contained a reenactment of the Industrial Revolution - complete with pollution streaming from smokestacks.

Photochemical Smog

Photochemical smog, a different type of air pollution, first became a problem in Southern California after World War II. The abundance of cars and sunshine provided the perfect setting for a chemical reaction between some of the molecules in auto exhaust or oil refinery emissions and sunshine (**Figure** 7.87). Photochemical smog consists of more than 100 compounds, most importantly ozone.

FIGURE 7.87
Smog over Los Angeles as viewed from the Hollywood Hills.

The Clean Air Act

The terrible events in Pennsylvania and London, plus the recognition of the hazards of photochemical smog, led to the passage of the Clean Air Act in 1970 in the United States. The act now regulates 189 pollutants. The six most important pollutants regulated by the Act are ozone, particulate matter, sulfur dioxide, nitrogen dioxide, carbon monoxide, and the heavy metal lead. Other important regulated pollutants include benzene, perchloroethylene, methylene chloride, dioxin, asbestos, toluene, and metals such as cadmium, mercury, chromium, and lead compounds.

What is the result of the Clean Air Act? In short, the air in the United States is much cleaner. Visibility is better and people are no longer incapacitated by industrial smog. However, despite the Act, industry, power plants, and vehicles put 160 million tons of pollutants into the air each year. Some of this smog is invisible and some contributes to the orange or blue haze that affects many cities.

Regional Air Quality

Air quality in a region is not just affected by the amount of pollutants released into the atmosphere in that location but by other geographical and atmospheric factors. Winds can move pollutants into or out of a region and a mountain range can trap pollutants on its leeward side. Inversions commonly trap pollutants within a cool air mass. If the inversion lasts long enough, pollution can reach dangerous levels.

Pollutants remain over a region until they are transported out of the area by wind, diluted by air blown in from another region, transformed into other compounds, or carried to the ground when mixed with rain or snow.

Table 7.5 lists the smoggiest cities in 2011: eight of the 10 are in California. Why do you think California cities are among those with the worst air pollution?

The state has the right conditions for collecting pollutants including mountain ranges that trap smoggy air, arid and sometimes windless conditions, agriculture, industry, and lots and lots of cars.

TABLE 7.5: Smoggiest U.S. Cities, 2011

Rank	City, State
1	Los Angeles, California
2	Bakersfield, California
3	Visalia-Porterville, California
4	Fresno, California
5	Sacramento, California
6	Hanford, California
7	San Diego, California
8	Houston, Texas
9	Merced, California
10	Charlotte, North Carolina

Summary

- Air is polluted by natural compounds in unnatural quantities or by unnatural compounds.
- Some pollutants enter the air directly and others are created by chemical reactions, such as those that are part of photochemical smog.
- Regions that are chronically polluted experience the release of a lot of pollutants into the air. The effects of pollution may also be amplified by geographical and atmospheric factors.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=CRmR9MDjPK4

MEDIA

Click image to the left for more content.

1. What causes air quality problems on the East Coast?
2. What is NASA trying to do with this mission?
3. What problems do satellites have?
4. What 5 pollutants can be seen from space?
5. Why does the airplane spiral up and down?
6. What is the goal of the research?

Review

1. How does photochemical smog differ from other types of air pollution?
2. What does the Clean Air Act regulate?
3. Why do parts of California have such bad air pollution?

7.40 Types of Air Pollution

- Distinguish between primary and secondary pollutants and identify examples of each.

Why is there a lid over that smog?

The gray smog pictured above is stuck between two layers of air. The bottom layer is more dense than the top layer, so there is no mixing between the two layers. In winter, an inversion traps all of the pollutants that are emitted into the air over a region.

Types of Air Pollution

The two types of air pollutants are primary pollutants, which enter the atmosphere directly, and secondary pollutants, which form from a chemical reaction.

Primary Pollutants

Some primary pollutants are natural, such as volcanic ash. Dust is natural but exacerbated by human activities; for example, when the ground is torn up for agriculture or development. Most primary pollutants are the result of human activities, the direct emissions from vehicles and smokestacks. Primary pollutants include:

- Carbon oxides include carbon monoxide (CO) and carbon dioxide (CO_2) (**Figure** 7.88). Both are colorless, odorless gases. CO is toxic to both plants and animals. CO and CO_2 are both greenhouse gases.

- Nitrogen oxides are produced when nitrogen and oxygen from the atmosphere come together at high temperatures. This occurs in hot exhaust gas from vehicles, power plants, or factories. Nitrogen oxide (NO) and nitrogen dioxide (NO_2) are greenhouse gases. Nitrogen oxides contribute to acid rain.
- Sulfur oxides include sulfur dioxide (SO_2) and sulfur trioxide (SO_3). These form when sulfur from burning coal reaches the air. Sulfur oxides are components of acid rain.
- Particulates are solid particles, such as ash, dust, and fecal matter (**Figure** 7.89). They are commonly formed from combustion of fossil fuels, and can produce smog. Particulates can contribute to asthma, heart disease, and some types of cancers.

- Lead was once widely used in automobile fuels, paint, and pipes. This heavy metal can cause brain damage or blood poisoning.

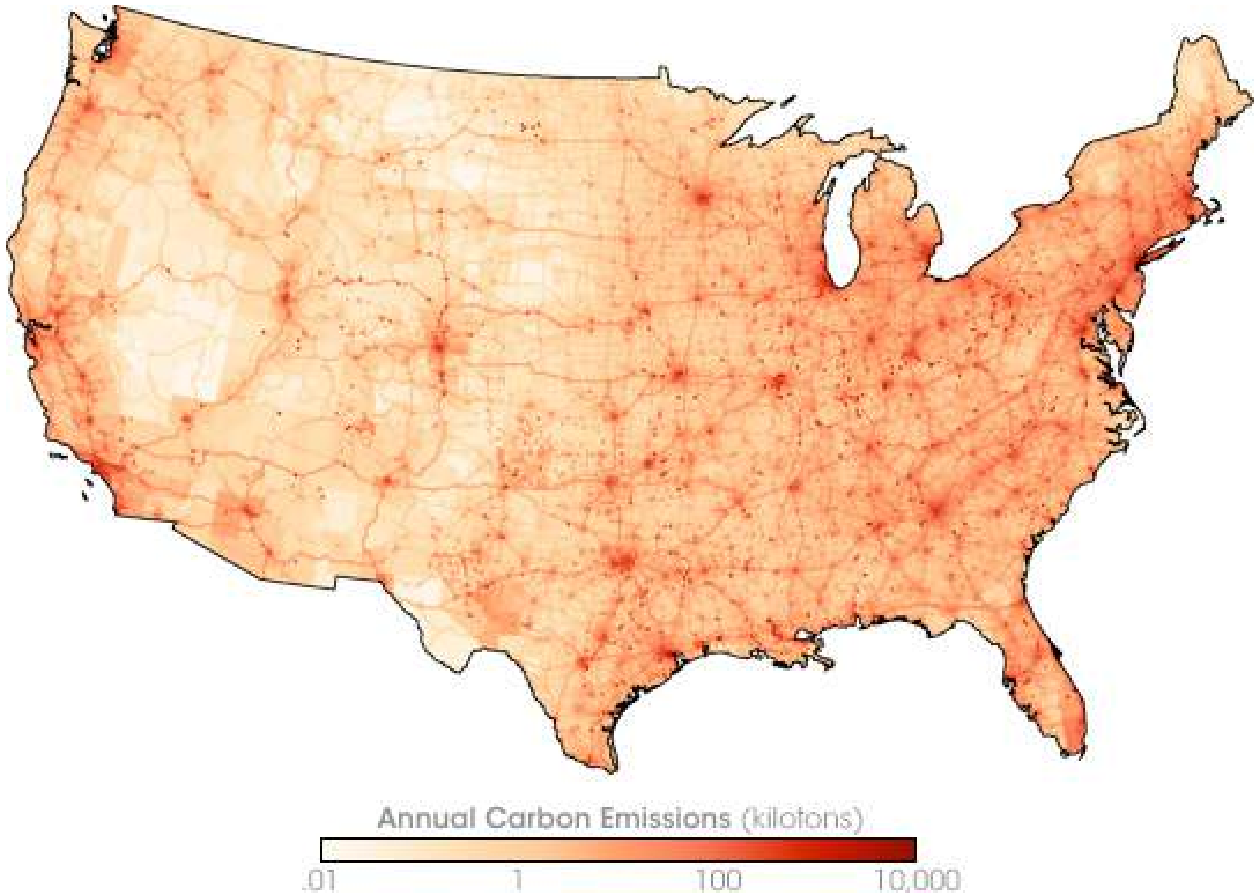


FIGURE 7.88

High CO_2 levels are found in major metropolitan areas and along the major interstate highways.

FIGURE 7.89

Particulates from a brush fire give the sky a strange glow in Arizona.

- Volatile organic compounds (VOCs) are mostly hydrocarbons. Important VOCs include methane (a naturally occurring greenhouse gas that is increasing because of human activities), chlorofluorocarbons (human-made compounds that are being phased out because of their effect on the ozone layer), and dioxin (a byproduct of chemical production that serves no useful purpose, but is harmful to humans and other organisms).

Secondary Pollutants

Any city can have photochemical smog, but it is most common in sunny, dry locations. A rise in the number of vehicles in cities worldwide has increased photochemical smog. Nitrogen oxides, ozone, and several other compounds are some of the components of this type of air pollution.

Photochemical smog forms when car exhaust is exposed to sunlight. Nitrogen oxide is created by gas combustion in cars and then into the air (**Figure** 7.90). In the presence of sunshine, the NO_2 splits and releases an oxygen ion (O). The O then combines with an oxygen molecule (O_2) to form ozone (O_3). This reaction can also go in reverse: Nitric oxide (NO) removes an oxygen atom from ozone to make it O_2. The direction the reaction goes depends on how much NO_2 and NO there is. If NO_2 is three times more abundant than NO, ozone will be produced. If nitric oxide levels are high, ozone will not be created.

FIGURE 7.90
The brown color of the air behind the Golden Gate Bridge is typical of California cities, because of nitrogen oxides.

Ozone is one of the major secondary pollutants. It is created by a chemical reaction that takes place in exhaust and in the presence of sunlight. The gas is acrid-smelling and whitish. Warm, dry cities surrounded by mountains, such as Los Angeles, Phoenix, and Denver, are especially prone to photochemical smog. Photochemical smog peaks at midday on the hottest days of summer. Ozone is also a greenhouse gas.

Summary

- There are many types of primary pollutants, including carbon oxides, nitrogen oxides, sulfur oxides, particulates, lead, and volatile organic compounds.
- Secondary pollutants form from chemical reactions that occur when pollution is exposed to sunlight.
- Ozone is a secondary pollutant that is also a greenhouse gas.

Practice

Use this resource to answer the questions that follow.

http://science.howstuffworks.com/environmental/green-science/air-pollution-info1.htm

1. List the most significant air pollutants.
2. What makes up the largest group of pollutants?
3. What is carbon monoxide? What produces it?
4. What are the most dangerous of the air pollutants? How are they produced?
5. How are nitrogen oxides produced?
6. What produces hydrocarbons?

Review

1. How are primary and secondary pollutants different?
2. Explain how nitrogen oxide pollutants form.
3. What is ozone and how does it form?

7.41 Effects of Air Pollution on the Environment

- Explain how air pollution damages the environment.

Did you ever see a sky without contrails?

In the three days after the terrorists attacks on September 11, 2001, jet airplanes did not fly over the United States. Without the gases from jet contrails blocking sunlight, air temperature increased 1°C (1.8°F) across the United States. This is just one of the effects air pollution has on the environment.

Smog Effects on the Environment

All air pollutants cause some damage to living creatures and the environment. Different types of pollutants cause different types of harm.

Particulates

Particulates reduce visibility. In the western United States, people can now ordinarily see only about 100 to 150 kilometers (60 to 90 miles), which is one-half to two-thirds the natural (pre-pollution) range on a clear day. In the East, people can only see about 40 to 60 kilometers (25-35 miles), about one-fifth the distance they could see without any air pollution (**Figure** 7.91).

Particulates reduce the amount of sunshine that reaches the ground, which may reduce photosynthesis. Since particulates form the nucleus for raindrops, snowflakes, or other forms of precipitation, precipitation may increase when particulates are high. An increase in particles in the air seems to increase the number of raindrops, but often decreases their size.

FIGURE 7.91
Smog in New York City.

By reducing sunshine, particulates can also alter air temperature as mentioned above. Imagine how much all of the sources of particulates combine to reduce temperatures. What affect might this have on global warming?

Ozone

Ozone damages some plants. Since ozone effects accumulate, plants that live a long time show the most damage. Some species of trees appear to be the most susceptible. If a forest contains ozone-sensitive trees, they may die out and be replaced by species that are not as easily harmed. This can change an entire ecosystem, because animals and plants may not be able to survive without the habitats created by the native trees.

Some crop plants show ozone damage (**Figure** 7.92). When exposed to ozone, spinach leaves become spotted. Soybeans and other crops have reduced productivity. In developing nations, where getting every last bit of food energy out of the agricultural system is critical, any loss is keenly felt.

FIGURE 7.92
The spots on this leaf are caused by ozone damage.

Oxides

Oxide air pollutants also damage the environment. NO_2 is a toxic, orange-brown colored gas that gives air a distinctive orange color and an unpleasant odor. Nitrogen and sulfur-oxides in the atmosphere create acids that fall as acid rain.

Lichen get a lot of their nutrients from the air so they may be good indicators of changes in the atmosphere such as increased nitrogen. In Yosemite National Park, this could change the ecosystem of the region and lead to fires and other problems.

Find out more at http://science.kqed.org/quest/audio/lichen-point-to-pollution/.

MEDIA

Click image to the left for more content.

Summary

- An increase in particulates may reduce photosynthesis, increase precipitation, and reduce temperatures.
- Ozone may damage native plants and some crop plants by slowing growth or damaging leaves.
- Nitrogen and sulfur-oxides are pollutants. They also create acids in the atmosphere that fall as acid rain.

Practice

Use this resource to answer the questions that follow.

http://www.mass.gov/dep/air/aq/env_effects.htm

1. What is haze?
2. What effects has air pollution had on animals?
3. Why is persistent air pollution a problem in aquatic ecosystems?
4. How can UV radiation damage crops?
5. How have forests been damaged by air pollution?

Review

1. What is the effect of an increase in particulates on the environment?
2. What is the effect of ozone on native and crop plants?
3. What colors do different pollutants have and how could you recognize them on a smoggy day?

7.42 Reducing Air Pollution

- Describe ways to reduce air pollution.

What does a catalytic converter do anyway?

In the days before catalytic converters, cars spewed lots of smoke. Laws governing emissions have helped to clean up the air.

The Clean Air Act

The Clean Air Act of 1970 and the amendments since then have done a great job in requiring people to clean up the air over the United States. Emissions of the six major pollutants regulated by the Clean Air Act —carbon monoxide, lead, nitrous oxides, ozone, sulfur dioxide, and particulates —have decreased by more than 50%. Cars, power plants, and factories individually release less pollution than they did in the mid-20th century. But there are many more cars, power plants, and factories. Many pollutants are still being released and some substances have been found to be pollutants that were not known to be pollutants in the past. There is still much work to be done to continue to clean up the air.

Reducing Air Pollution from Vehicles

Reducing air pollution from vehicles can be done in a number of ways.

- Breaking down pollutants before they are released into the atmosphere. Motor vehicles emit less pollution than they once did because of **catalytic converters** (**Figure** 7.93). Catalytic converters contain a **catalyst** that speeds up chemical reactions and breaks down nitrous oxides, carbon monoxide, and VOCs. Catalytic converters only work when they are hot, so a lot of exhaust escapes as the car is warming up.

FIGURE 7.93
Catalytic converters are placed on modern cars in the United States.

- Making a vehicle more fuel efficient. Lighter, more streamlined vehicles need less energy. **Hybrid vehicles** have an electric motor and a rechargeable battery. The energy that would be lost during braking is funneled into charging the battery, which then can power the car. The internal combustion engine only takes over when power in the battery has run out. Hybrids can reduce auto emissions by 90% or more, but many models do not maximize the possible fuel efficiency of the vehicle.

A plug-in hybrid is plugged into an electricity source when it is not in use, perhaps in a garage, to make sure that the battery is charged. Plug-in hybrids run for a longer time on electricity and so are less polluting than regular hybrids. Plug-in hybrids began to become available in 2010.

- Developing new technologies that do not use fossil fuels. Fueling a car with something other than a liquid organic-based fuel is difficult. A **fuel cell** converts chemical energy into electrical energy. Hydrogen fuel cells harness the energy released when hydrogen and oxygen come together to create water (**Figure** 7.94). Fuel cells are extremely efficient and they produce no pollutants. But developing fuel-cell technology has had many problems and no one knows when or if they will become practical.

Reducing Industrial Air Pollution

Pollutants are removed from the exhaust streams of power plants and industrial plants before they enter the atmosphere. Particulates can be filtered out, and sulfur and nitric oxides can be broken down by catalysts. Removing these oxides reduces the pollutants that cause acid rain.

Particles are relatively easy to remove from emissions by using motion or electricity to separate particles from the gases. Scrubbers remove particles and waste gases from exhaust using liquids or neutralizing materials (**Figure** 7.95). Gases, such as nitrogen oxides, can be broken down at very high temperatures.

FIGURE 7.94
A hydrogen fuel-cell car looks like a gasoline-powered car.

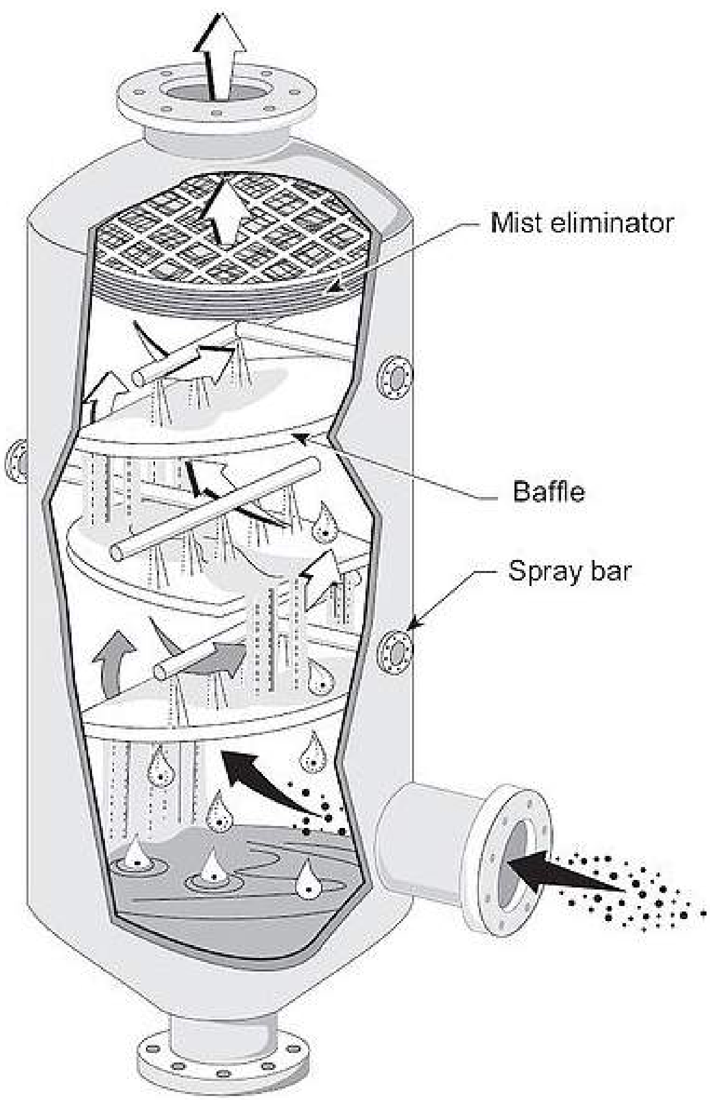


FIGURE 7.95
Scrubbers remove particles and waste gases from exhaust.

Gasification

Gasification is a developing technology. In gasification, coal (rarely is another organic material used) is heated to extremely high temperatures to create syngas, which is then filtered. The energy goes on to drive a generator. Syngas releases about 80% less pollution than regular coal plants, and greenhouse gases are also lower. Clean coal plants do not need scrubbers or other pollution control devices. Although the technology is ready, clean coal plants are more expensive to construct and operate. Also, heating the coal to high enough temperatures uses a great deal of energy, so the technology is not energy efficient. In addition, large amounts of the greenhouse gas CO_2 are still released with clean coal technology. Nonetheless, a few of these plants are operating in the United States and around the world.

Ways You Can Reduce Air Pollution

How can air pollution be reduced? Using less fossil fuel is one way to lessen pollution. Some examples of ways to conserve fossil fuels are:

- Riding a bike or walking instead of driving.
- Taking a bus or carpooling.
- Buying a car that has greater fuel efficiency.
- Turning off lights and appliances when they are not in use.
- Using energy efficient light bulbs and appliances.
- Buying fewer things that are manufactured using fossil fuels.

All these actions reduce the amount of energy that power plants need to produce.

Developing alternative energy sources is important. What are some of the problems facing wider adoption of alternative energy sources?

- The technologies for several sources of alternative energy, including solar and wind, are still being developed.
- Solar and wind are still expensive relative to using fossil fuels. The technology needs to advance so that the price falls.
- Some areas get low amounts of sunlight and are not suited for solar. Others do not have much wind. It is important that regions develop what best suits them. While the desert Southwest will need to develop solar, the Great Plains can use wind energy as its energy source. Perhaps some locations will rely on nuclear power plants, although current nuclear power plants have major problems with safety and waste disposal.

Sometimes technological approaches are what is needed.

National Geographic videos exploring energy conservation are found in Environment Videos, Energy: http://video.nationalgeographic.com/video/environment/energy-environment .

- Alternative Energy
- Fuel Cells
- Solar Power

What you can do to your home to help reduce energy use: http://www.youtube.com/watch?v=6h8QjZvcp0I .

A very simple thing you can do to conserve energy is discussed in "This Bulb": http://www.youtube.com/watch?v=FvOBHMb6Cqc .

Summary

- Catalytic converters break down some pollutants, but only when they are hot.

- Hybrid vehicles use the energy that is usually wasted as a car slows to charge a battery that then powers the car.
- Different types of clean energy can be developed for different locations, such as solar for the desert southwest and wind for coastal regions.

Practice

Use this resource to answer the questions that follow.

http://www.epa.gov/air/caa/40th_highlights.html

1. How have lead levels changed in ambient air?
2. How has reducing acid rain helped the environment?
3. How much has acid deposition been reduced?
4. How much have toxic emissions from industry been reduced?
5. Explain the technologies that have improved vehicle emissions.

Review

1. How do fuel cells work, what are their advantages, and why are they not used in every vehicle?
2. What is gasification technology and what role could it play in reducing air pollution?
3. What can you do to reduce the amount of air pollution you produce?

7.43 Reducing Greenhouse Gas Pollution

- Describe how greenhouse gas pollution can be reduced.

"The chance of averting catastrophic climate change is slipping through our hands with every passing year that nations fail to agree on a rescue plan for the planet." —Greenpeace International director Kumi Naidoo, at the Durban, South Africa Climate Change Conference in 2011.

Reducing Greenhouse Gases

Climate scientists agree that climate change is a global problem that must be attacked by a unified world with a single goal. All nations must come together to reduce greenhouse gas emissions. However, getting nations to agree on anything has proven to be difficult. A few ideas have been proposed and in some nations are being enacted.

International Agreements

The first attempt to cap greenhouse gas emissions was the Kyoto Protocol, which climate scientists agree did not do enough in terms of cutting emissions or in getting nations to participate. The Kyoto Protocol set up a **cap-and-trade system**. Cap-and-trade provides a monetary incentive for nations to develop technologies that will reduce emissions and to conserve energy. Some states and cities within the United States have begun their own cap-and-trade systems.

The United Nations Climate Change Conference meets in a different location annually. Although recommendations are made each year, the group has not gotten the nations to sign on to a binding agreement. By doing nothing we are doing something - continuing to raise greenhouse gas levels and failing to prepare for the coming environmental changes.

Carbon Tax

The easiest and quickest way is to reduce greenhouse gas emissions is to increase energy efficiency. One effective way to encourage efficiency is financial. A **carbon tax** can be placed on CO_2 emissions to encourage conservation. The tax would be placed on gasoline, carbon dioxide emitted by factories, and home energy bills so people or businesses that emit more carbon would pay more money. This would encourage conservation since when people purchase a new car, for example, they would be more likely to purchase an energy-efficient model. The money from the carbon tax would be used for research into alternative energy sources. All plans for a carbon tax allow a tax credit for people who cannot afford to pay more for energy so that they do not suffer unfairly.

New technologies can be developed, such as renewable sources that were discussed in the chapter Natural Resources. **Biofuels** can replace gasoline in vehicles, but they must be developed sensibly (**Figure** 7.96). So far much of the biofuel is produced from crops such as corn. But when food crops are used for fuel, the price of food goes up. Modern agriculture is also extremely reliant on fossil fuels for pesticides, fertilizers, and the work of farming. This means that not much energy is gained from using a biofuel over using the fossil fuels directly. More promising crops for biofuels are now being researched. Surprisingly, algae is being investigated as a source of fuel! The algae can be grown in areas that are not useful for agriculture, and it also contains much more usable oil than crops such as corn.

FIGURE 7.96
A bus that runs on soybean oil shows the potential of biofuels.

Carbon Capture and Sequestration

If climate change becomes bad enough, people can attempt to remove greenhouse gases from the atmosphere after they are emitted. **Carbon sequestration** occurs naturally when carbon dioxide is removed from the atmosphere by trees in a forest. One way to remove carbon would be to plant more trees, but unfortunately, more forest land is currently being lost than gained.

Carbon can also be artificially sequestered. For example, carbon can be captured from the emissions from gasification plants and then stored underground in salt layers or coal seams. While some small sequestration projects are in development, large-scale sequestration has not yet been attempted.

This type of carbon capture and sequestration comes under the heading of geoengineering. There are many other fascinating ideas in geoengineering that people have proposed that are worth looking at. One wild example is to shadow the planet with large orbiting objects. A large mirror in orbit could reflect about 2% of incoming solar radiation back into space. These sorts of solutions would be expensive in cost and energy.

Just as individuals can diminish other types of air pollution, people can fight global warming by conserving energy. Also, people can become involved in local, regional, and national efforts to make sound choices on energy policy.

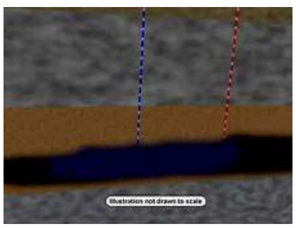
Summary

- A cap-and-trade system gives nations a cap on the greenhouse gas emissions they're allowed and allows them to trade allowances with other nations so that they can meet their cap.
- A carbon tax taxes carbon emissions to encourage conservation.
- Carbon capture and sequestration is a geoengineering solution for removing excess carbon dioxide from the atmosphere.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=OtfuYlhDjw4



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1. What is the purpose of carbon sequestration?
2. What are the three pillars of the Global Climate Change Initiative?
3. What is CCS?
4. What is CCS being used for today?
5. What type of stone is carbon dioxide pumped into? Why?
6. What are cap rocks? Why are they important?

Review

1. Why would a carbon tax be effective at reducing greenhouse gas emissions?
2. How does a carbon tax not penalize people who can't afford to pay more for fuel and other items?
3. What are the advantages and disadvantages of using geoengineering solutions to reduce climate change rather than things like cap-and-trade or a carbon tax?

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CHAPTER 8 Natural Resource Management

Chapter Outline

8.1 Biological Communities

- Identify and define the component parts of biological communities and ecosystems.

How is a community of people like a community of organisms?

Different species have different jobs within their community. Some are the farmers, some are traders, some are the janitors, and others have different roles.

Biological Communities

A **population** consists of all individuals of a single **species** that exist together at a given place and time. A species is a single type of organism that can interbreed and produce fertile offspring. All of the populations living together in the same area make up a **community**.

Ecosystems

An **ecosystem** is made up of the living organisms in a community and the nonliving things, the physical and chemical factors, that they interact with. The living organisms within an ecosystem are its **biotic** factors (**Figure** 8.1). Living things include bacteria, algae, fungi, plants, and animals, including invertebrates, animals without backbones, and vertebrates, animals with backbones.

FIGURE 8.1

(a) The horsetail Equisetum is a primitive plant. (b) Insects are among the many different types of invertebrates. (c) A giraffe is an example of a vertebrate.

Physical and chemical features are **abiotic** factors. Abiotic factors include resources living organisms need, such as light, oxygen, water, carbon dioxide, good soil, and nitrogen, phosphorous, and other nutrients. Nutrients cycle through different parts of the ecosystem and can enter or leave the ecosystem at many points. Abiotic factors also include environmental features that are not materials or living things, such as living space and the right temperature range. Energy moves through an ecosystem in one direction.

Niches

Organisms must make a living, just like a lawyer or a ballet dancer. This means that each individual organism must acquire enough food energy to live and reproduce. A species' way of making a living is called its **niche**. An example of a niche is making a living as a top carnivore, an animal that eats other animals, but is not eaten by any other animals (**Figure** 8.2). Every species fills a niche, and niches are almost always filled in an ecosystem.

Habitat

An organism's **habitat** is where it lives (**Figure** 8.3). The important characteristics of a habitat include climate, the availability of food, water, and other resources, and other factors, such as weather.

Summary

- All of the individuals of a species that exist together at a given place and time make up a population. A community is made up of all of the populations in an area.
- The living and nonliving factors that living organisms need plus the communities of organisms themselves make up an ecosystem.
- A habitat is where an organism lives and a niche is what it does to make a living.

FIGURE 8.2
The top carnivore niche is filled by lions on the savanna, wolves in the tundra, and tuna in the oceans.

FIGURE 8.3
Birds living in a saguaro cactus. A habitat may be a hole in a cactus or the underside of a fern in a rainforest. It may be rocks and the nearby sea.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=O3CZFfyed3M

MEDIA
Click image to the left for more content.

1. What are the biotic components of an ecosystem?
2. What is a species?

3. What is a population?
4. List two examples of populations.
5. What is a community?
6. How can a natural community vary in size?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Abiotic Factors Affecting Living Systems**

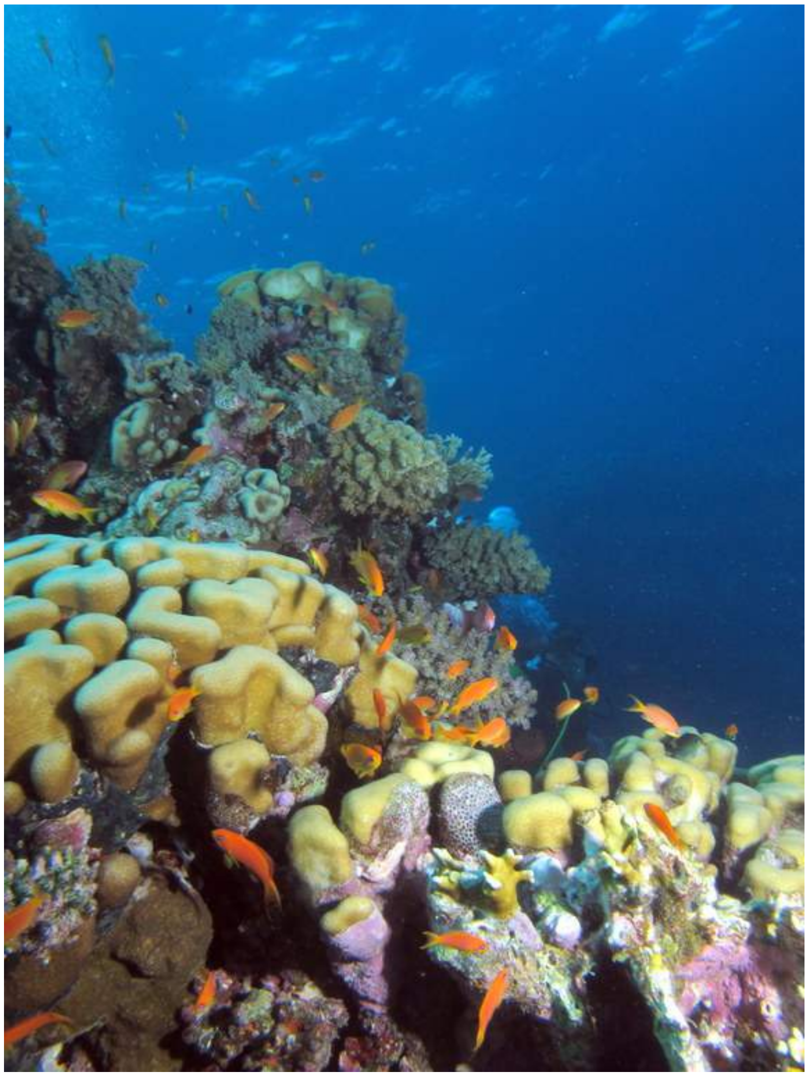
7. What does abiotic mean?
8. What effects do the abiotic tractors have on the populations that live there?
9. How does the Earth's tilt effect life?

Review

1. Define species, population, community, niche, habitat, biotic factor, and abiotic factor.
2. Diagram how the words listed above relate to each other.
3. Choose a type of wild organism that you're familiar with and list the biotic and abiotic factors that it needs to live.

8.2 Roles in an Ecosystem

- Define and describe the common roles and relationships of organisms in an ecosystem.



What roles do coral reef organisms have?

Corals are not rocks or plants, but little animals that live in a carbonate shell they create. They have a symbiotic relationship with zooxanthellae, tiny photosynthesizing organisms. The zooxanthellae provide food for the coral and the coral provides a safe home for the zooxanthellae. Together they form the base of a complex ecosystem.

Roles in Ecosystems

There are many different types of ecosystems. Climate conditions determine which ecosystems are found in a particular location. A biome encompasses all of the ecosystems that have similar climate and organisms.

Different organisms live in different types of ecosystems because they are adapted to different conditions. Lizards thrive in deserts, but no reptiles are found in any polar ecosystems. Amphibians can't live too far from the water.

Large animals generally do better in cold climates than in hot climates.

Despite this, every ecosystem has the same general roles that living creatures fill. It's just the organisms that fill those niches that are different. For example, every ecosystem must have some organisms that produce food in the form of chemical energy. These organisms are primarily algae in the oceans, plants on land, and bacteria at hydrothermal vents.

Producers and Consumers

The organisms that produce food are extremely important in every ecosystem. Organisms that produce their own food are called **producers**. There are two ways of producing food energy:

- Photosynthesis: plants on land, phytoplankton in the surface ocean, and some other organisms.
- Chemosynthesis: bacteria at hydrothermal vents.

Organisms that use the food energy that was created by producers are named **consumers**. There are many types of consumers:

- **Herbivores** eat producers directly. These animals break down the plant structures to get the materials and energy they need.
- **Carnivores** eat animals; they can eat herbivores or other carnivores.
- **Omnivores** eat plants and animals as well as fungi, bacteria, and organisms from the other kingdoms.

FIGURE 8.4
A llama grazes near Machu Picchu, Peru

Feeding Relationships

There are many types of feeding relationships (**Figure** 8.5) between organisms. A **predator** is an animal that kills and eats another animal, known as its **prey**. **Scavengers** are animals, such as vultures and hyenas, that eat organisms that are already dead. **Decomposers** break apart dead organisms or the waste material of living organisms, returning the nutrients to the ecosystem.

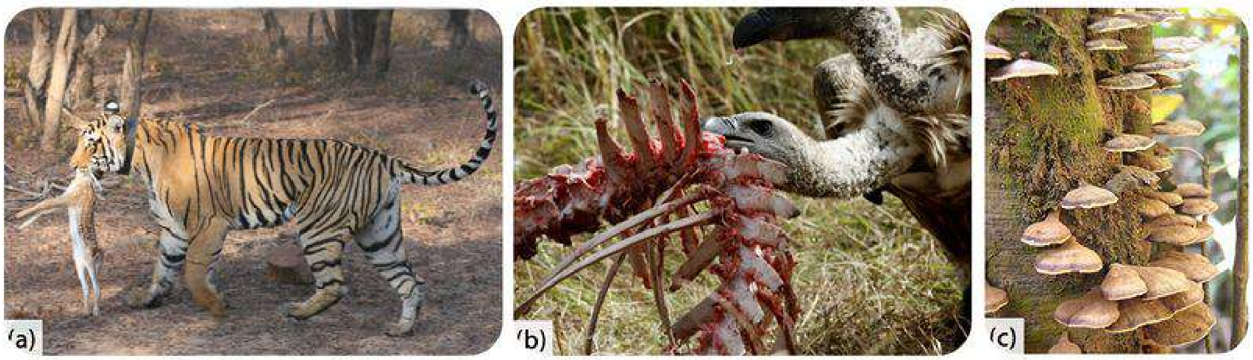


FIGURE 8.5
(a) Predator and prey; (b) Scavengers; (c) Bacteria and fungi, acting as decomposers.

Relationships Between Species

Species have different types of relationships with each other. **Competition** occurs between species that try to use the same resources. When there is too much competition, one species may move or adapt so that it uses slightly different resources. It may live at the tops of trees and eat leaves that are somewhat higher on bushes, for example. If the competition does not end, one species will die out. Each niche can only be inhabited by one species.

Some relationships between species are beneficial to at least one of the two interacting species. These relationships are known as **symbiosis** and there are three types:

- In **mutualism**, the relationship benefits both species. Most plant-pollinator relationships are mutually beneficial. What does each get from the relationship?
- In **commensalism**, one organism benefits and the other is not harmed.
- In **parasitism**, the parasite species benefits and the host is harmed. Parasites do not usually kill their hosts because a dead host is no longer useful to the parasite. Humans host parasites, such as the flatworms that cause schistosomiasis.

Choose which type of relationship is described by each of the images and captions below (**Figure** 8.6).

Summary

- Herbivores eat plants, carnivores eat meat, and omnivores eat both.
- Predators are animals that eat a prey animal. Scavengers eat organisms that are already dead. Decomposers break down dead plants and animals into component parts, including nutrients.

FIGURE 8.6

(a) The pollinator gets food; the plant's pollen gets caught in the bird's feathers so it is spread to far away flowers. (b) The barnacles receive protection and get to move to new locations; the whale is not harmed. (c) These tiny mites are parasitic and consume the insect called a harvestman.

- Relationships between species can be one of competition or one of symbiosis, in which one or both species benefits. Mutualism, commensalism, and parasitism are the three types of symbiotic relationships.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=D1aRSeT-mQE

MEDIA

Click image to the left for more content.

1. What is competition?
2. What is predation?
3. What is symbiosis?
4. How do stable communities develop?
5. What is succession?
6. What is a niche?
7. What does a niche include?
8. What causes competition?

Review

1. Compare and contrast the two different ways of producing food energy, photosynthesis and chemosynthesis.
2. After a producer produces food energy, follow its path until it ends up being used by another producer.
3. What kind of symbiotic relationship do zooxanthellae and corals have?

8.3 Population Size

- Describe the factors that regulate population size.

How many penguins are the right number for this beach?

As many as can survive and have healthy offspring! A population will tend to grow as big as it can for the resources it needs. Once it is too large, some of its members will die off. This keeps the population size at the right number.

Populations

Biotic and abiotic factors determine the population size of a species in an ecosystem. What are some important biotic factors? Biotic factors include the amount of food that is available to that species and the number of organisms that also use that food source. What are some important abiotic factors? Space, water, and climate all help determine a species population.

When does a population grow? A population grows when the number of births is greater than the number of deaths. When does a population shrink? When deaths exceed births.

What causes a population to grow? For a population to grow there must be ample resources and no major problems. What causes a population to shrink? A population can shrink either because of biotic or abiotic limits. An increase in predators, the emergence of a new disease, or the loss of habitat are just three possible problems that will decrease a population. A population may also shrink if it grows too large for the resources required to support it.

Carrying Capacity

When the number of births equals the number of deaths, the population is at its **carrying capacity** for that habitat. In a population at its carrying capacity, there are as many organisms of that species as the habitat can support. The carrying capacity depends on biotic and abiotic factors. If these factors improve, the carrying capacity increases. If the factors become less plentiful, the carrying capacity drops. If resources are being used faster than they are being replenished, then the species has exceeded its carrying capacity. If this occurs, the population will then decrease in size.

Limiting Factors

Every stable population has one or more factors that limit its growth. A **limiting factor** determines the carrying capacity for a species. A limiting factor can be any biotic or abiotic factor: nutrient, space, and water availability are examples (**Figure** 8.7). The size of a population is tied to its limiting factor.

FIGURE 8.7
In a desert such as this, what is the limiting factor on plant populations? What would make the population increase? What would make the population decrease?

What happens if a limiting factor increases a lot? Is it still a limiting factor? If a limiting factor increases a lot, another factor will most likely become the new limiting factor.

This may be a bit confusing, so let's look at an example of limiting factors. Say you want to make as many chocolate chip cookies as you can with the ingredients you have on hand. It turns out that you have plenty of flour and other ingredients, but only two eggs. You can make only one batch of cookies, because eggs are the limiting factor. But then your neighbor comes over with a dozen eggs. Now you have enough eggs for seven batches of cookies, but only two pounds of butter. You can make four batches of cookies, with butter as the limiting factor. If you get more butter, some other ingredient will be limiting.

Species ordinarily produce more offspring than their habitat can support (**Figure** 8.8). If conditions improve, more young survive and the population grows. If conditions worsen, or if too many young are born, there is competition between individuals. As in any competition, there are some winners and some losers. Those individuals that survive to fill the available spots in the niche are those that are the most fit for their habitat.

Summary

- Biotic factors that a population needs include food availability. Abiotic factors may include space, water, and climate.
- The carrying capacity of an environment is reached when the number of births equal the number of deaths.
- A limiting factor determines the carrying capacity for a species.

FIGURE 8.8
A frog in frog spawn. An animal produces many more offspring than will survive.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Population Growth**

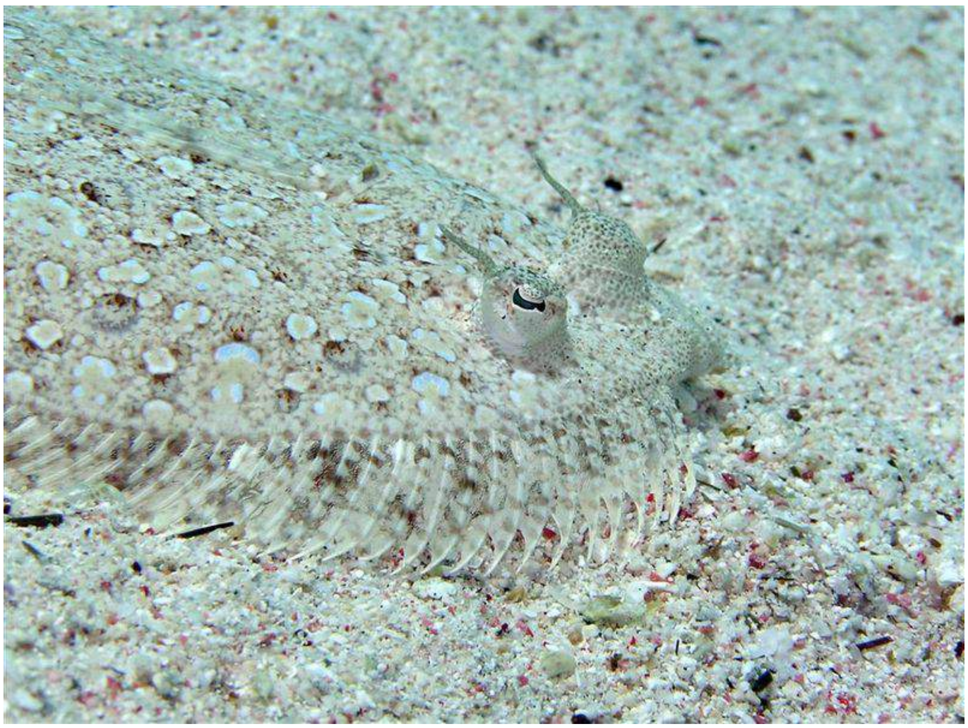
1. What is population growth?
2. What is the normal pattern of population growth?
3. What internal factors can limit population growth?
4. What external factors can limit population growth?
5. What are limiting factors? List examples.
6. What is carrying capacity?
7. What can cause carrying capacity to change?

Review

1. What happens if a population exceeds its carrying capacity?
2. What happens if a factor that has limited a population's size becomes more available?
3. How might a limiting factor lead to biological evolution?

8.4 Adaptation and Evolution of Populations

- Define adaptation.
- Explain the theory of evolution by natural selection.



Why would an organism match its background? Wouldn't it be better to stand out?

An organism that blends with its background is more likely to avoid predators. If it survives, it is more likely to have offspring. Those offspring are more likely to blend into their backgrounds.

Adaptation

The characteristics of an organism that help it to survive in a given environment are called **adaptations**. Adaptations are traits that an organism inherits from its parents. Within a population of organisms are genes coding for a certain number of traits. For example, a human population may have genes for eyes that are blue, green, hazel, or brown, but as far as we know, not purple or lime green.

Adaptations develop when certain **variations** or differences in a population help some members survive better than others (**Figure** 8.9). The variation may already exist within the population, but often the variation comes from a **mutation**, or a random change in an organism's genes. Some mutations are harmful and the organism dies; in that case, the variation will not remain in the population. Many mutations are neutral and remain in the population. If the environment changes, the mutation may be beneficial and it may help the organism adapt to the environment. The organisms that survive pass this favorable trait on to their offspring.

Biological Evolution

Many changes in the genetic makeup of a species may accumulate over time, especially if the environment is changing. Eventually the descendants will be very different from their ancestors and may become a whole new species. Changes in the genetic makeup of a species over time are known as biological **evolution**.

Natural Selection

The mechanism for evolution is **natural selection**. Traits become more or less common in a population depending on whether they are beneficial or harmful. An example of evolution by natural selection can be found in the deer mouse, species *Peromyscus maniculatus*. In Nebraska this mouse is typically brown, but after glaciers carried lighter sand over the darker soil in the Sand Hills, predators could more easily spot the dark mice. Natural selection favored the light mice, and over time, the population became light colored.

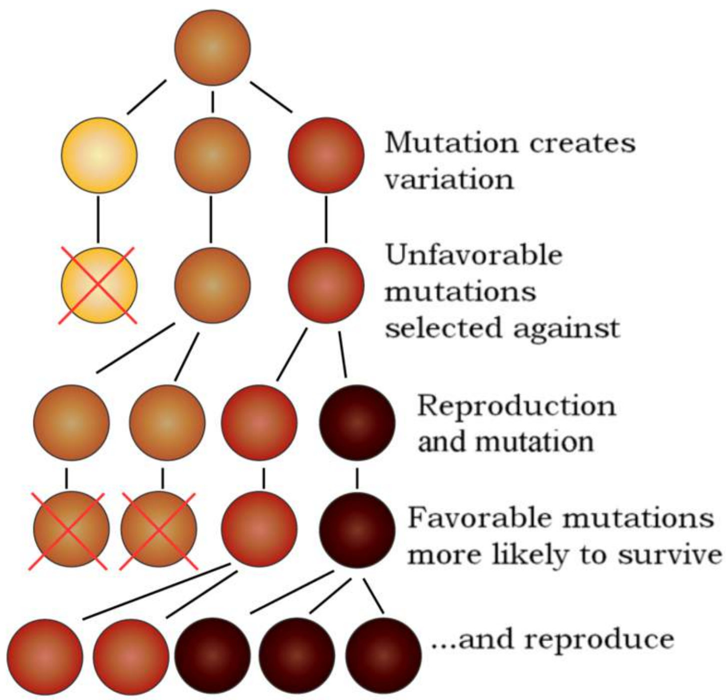


FIGURE 8.9
An explanation of how adaptations develop.

This story is covered in more detail here: http://news.harvard.edu/gazette/story/2009/08/mice-living-in-sand-hills-quickly-evolved-lighter-coloration/ .

Summary

- A population has genetic variations, possibly due to mutations. Favorable variations may allow an organism to be better adapted to its environment and survive to reproduce.
- Beneficial traits are favored in a population so that they may become better represented.
- Changes in the genetic makeup of a species may result in a new species; this is biological evolution.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use these resources to answer the questions that follow.

http://www.hippocampus.org/Biology → Non-Majors Biology→ Search: **Natural Selection and Evolution**

1. What is natural selection?
2. What are genes?
3. How does natural selection effect the individual?
4. What does natural selection cause in populations?

http://www.youtube.com/watch?v=-mPCqYxB4d4

MEDIA
Click image to the left for more content.

5. How does variety occur in an individual?
6. How are genomes diversified and passed on to offspring?

Review

1. The Grand Canyon was carved, separating what had once been a single population of squirrel into two separate populations. What do you think happened to those populations over time?
2. How does natural selection work?
3. How does biological evolution work?

8.5 Extinction and Radiation of Life

- Define extinction and explain why it occurs.
- Define adaptive radiation, and explain its relationship to extinction.

Should this pterodactyl be concerned? Should you?

When the dinosaurs were wiped out by an asteroid impact, the mammals were waiting to take over their niches. Could this happen again? Are there other ways species could go extinct and leave open niches for new organisms to fill?

Extinction

Most of the species that have lived have also gone extinct. There are two ways to go extinct: besides the obvious way of dying out completely, a species goes extinct if it evolves into a different species. Extinction is a normal part of Earth's history.

But sometimes large numbers of species go extinct in a short amount of time. This is a **mass extinction**. The causes of different mass extinctions are different: collisions with comets or asteroids, massive volcanic eruptions, or rapidly changing climate are all possible causes of some of these disasters (**Figure** 8.10).

Adaptive Radiation

After a mass extinction, many habitats are no longer inhabited by organisms because they have gone extinct. With new habitats available, some species will adapt to the new environments. Evolutionary processes act rapidly during

FIGURE 8.10
An extinct *Tyrannosaurus rex*. This fossil resembles a living organism.

these times and many new species evolve to fill those available habitats. The process in which many new species evolve in a short period of time to fill available niches is called **adaptive radiation**. At the end of this period of rapid evolution the life forms do not look much like the ones that were around before the mass extinction. For example, after the extinction of the dinosaurs, mammals underwent adaptive radiation and became the dominant life form.

Summary

- Species go extinct when all of the individuals die out or evolve into a different species.
- Many species go extinct at roughly the same time during a mass extinction.
- New habitats become available and species evolve to fill them so that biodiversity increases during adaptive radiation.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

http://news.discovery.com/videos/why-tell-me-why-mass-extinction.html

MEDIA
Click image to the left for more content.

1. What percentage of all species are now extinct?
2. What is a mass extinction?
3. Why do extinctions occur?
4. What allows species to survive?
5. What is the cause of the current mass extinction?
6. How may species face extinction in the next 100 years?

Review

1. Why is extinction considered a normal part of Earth's history?
2. What are some of the possible causes of mass extinctions?
3. Why do many new species evolve after a mass extinction?

8.6 Flow of Matter in Ecosystems

- Describe how matter flows through ecosystems.
- Compare and contrast the flow of matter with the flow of energy in ecosystems.

What killed millions of sailors in the 15th through 18th centuries?

Sailors at sea or explorers in polar regions, even Crusaders, who went without fresh food developed scurvy due to the lack of vitamin C in their diets. Without the right nutrients in the right amounts, you can't live —and humans need vitamin C. It wasn't until 1932 that the link between scurvy and a nutrient was made.

Flow of Matter in Ecosystems

The flow of matter in an ecosystem is not like energy flow. Matter enters an ecosystem at any level and leaves at any level. Matter cycles freely between trophic levels and between the ecosystem and the physical environment (**Figure** 8.11).

Nutrients

Nutrients are ions that are crucial to the growth of living organisms. Nutrients such as nitrogen and phosphorous are important for plant cell growth. Animals use silica and calcium to build shells and skeletons. Cells need nitrates and phosphates to create proteins and other biochemicals. From nutrients, organisms make tissues and complex molecules such as carbohydrates, lipids, proteins, and nucleic acids.

What are the sources of nutrients in an ecosystem? Rocks and minerals break down to release nutrients. Some enter the soil and are taken up by plants. Nutrients can be brought in from other regions, carried by wind or water. When one organism eats another organism, it receives all of its nutrients. Nutrients can also cycle out of an ecosystem.

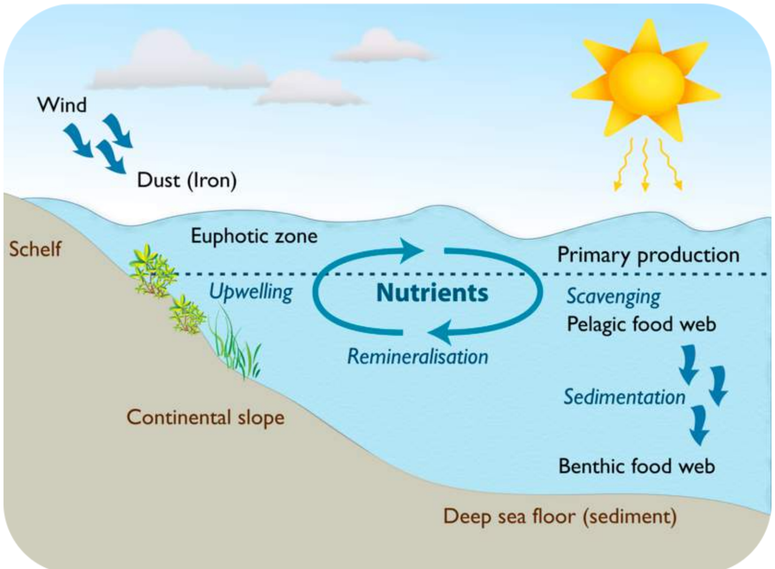


FIGURE 8.11
Nutrients cycle through ocean food webs.

Decaying leaves may be transported out of an ecosystem by a stream. Wind or water carries nutrients out of an ecosystem.

Decomposers play a key role in making nutrients available to organisms. Decomposers break down dead organisms into nutrients and carbon dioxide, which they respire into the air. If dead tissue would remain as it is, eventually nutrients would run out. Without decomposers, life on Earth would have died out long ago.

Summary

- Ions that are crucial to the growth of organisms are known as nutrients.
- Decomposers break down dead organisms into nutrients and gases so that they can be used by other organisms.
- Nutrients can enter or exit an ecosystem at any point and can cycle around the planet.

Practice

Use this resource to answer the questions that follow.

http://www.powerhouseanimation.com/gallery/projectArchive/publishers-resource-group/prg_flowOfEnergy.swf

1. What is carbon dioxide in the air a reservoir for?
2. What do producers do with carbon?
3. What do herbivores do with carbon?
4. Why is the biomass of carnivores less than herbivores?
5. What do decomposers do?
6. How is carbon returned to the atmosphere?

Review

1. How does the flow of matter differ from the flow of energy through an ecosystem?

2. How do nutrients enter and exit and ecosystem?
3. What would happen to life on Earth if there were no decomposers?

8.7 Nitrogen Cycle in Ecosystems

- Describe nitrogen's roles as a nutrient.
- Define nitrogen fixation and explain how it occurs.

Lentils, anyone?

Why are legumes important to biological cycles? Nitrogen gas, as found in the atmosphere, is not useful to organisms. Legumes have bacteria in their root nodules that fix nitrogen. Putting legumes into a crop rotation reduces fertilizer costs and makes the soil and the crops healthier.

Nitrogen as a Nutrient

Nitrogen (N_2) is vital for life on Earth as an essential component of organic materials, such as amino acids, chlorophyll, and nucleic acids such as DNA and RNA (**Figure** 8.12). Chlorophyll molecules, essential for photosynthesis, contain nitrogen.

Nitrogen Fixing

Although nitrogen is the most abundant gas in the atmosphere, it is not in a form that plants can use. To be useful, nitrogen must be "fixed," or converted into a more useful form. Although some nitrogen is fixed by lightning or blue-green algae, much is modified by bacteria in the soil. These bacteria combine the nitrogen with oxygen or hydrogen to create nitrates or ammonia (**Figure** 8.13).

Nitrogen-fixing bacteria either live free or in a symbiotic relationship with leguminous plants (peas, beans, peanuts). The symbiotic bacteria use carbohydrates from the plant to produce ammonia that is useful to the plant. Plants use

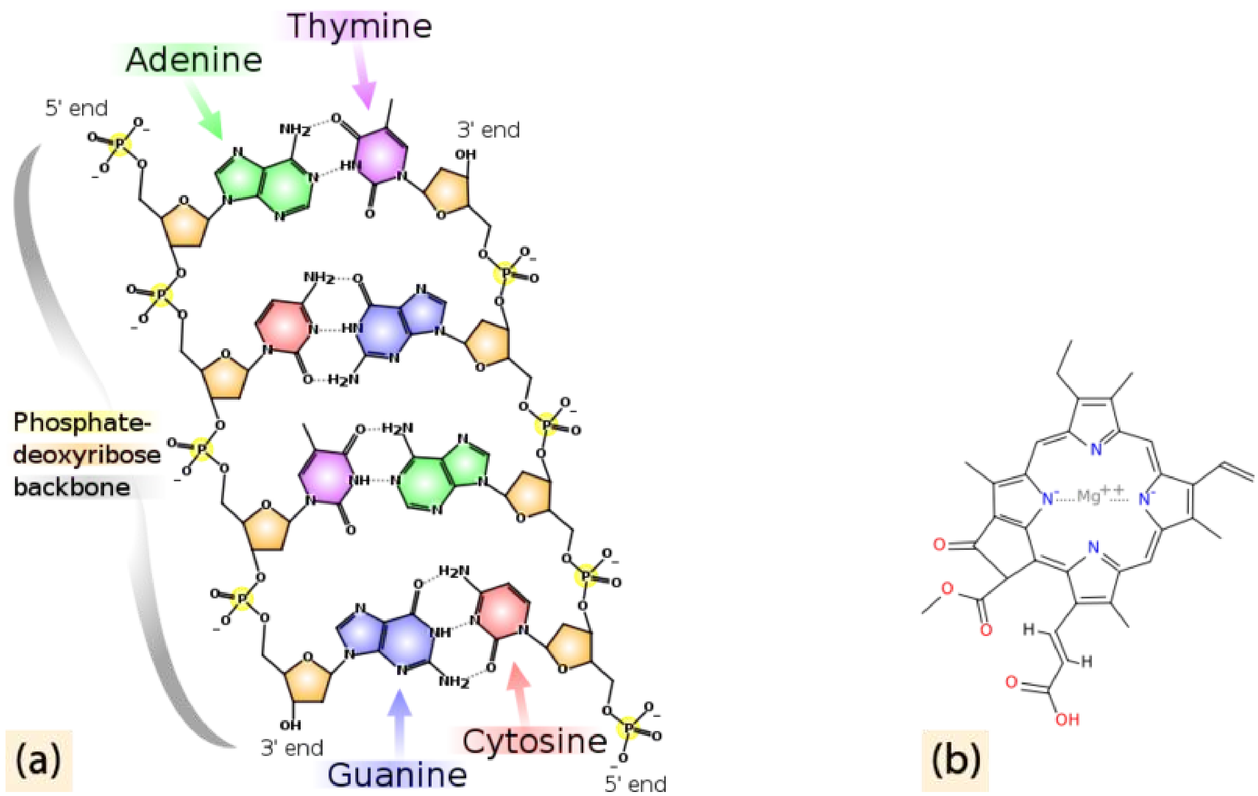


FIGURE 8.12

(a) Nucleic acids contain nitrogen (b) Chlorophyll molecules contain nitrogen

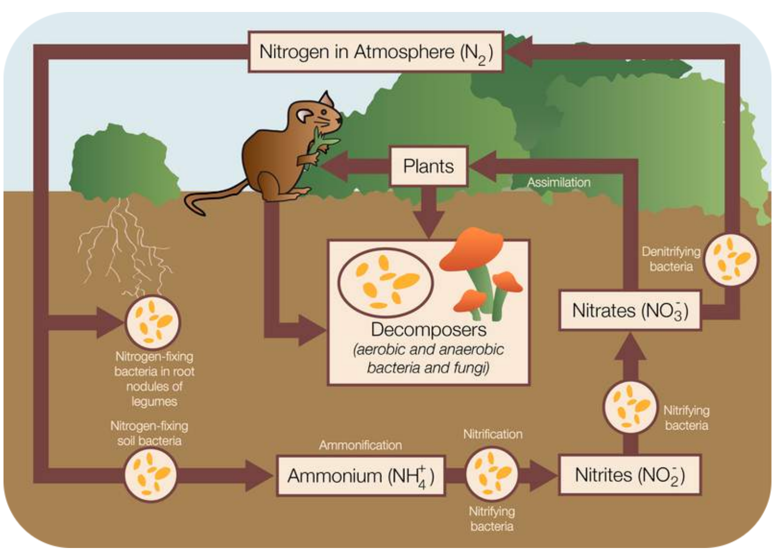


FIGURE 8.13

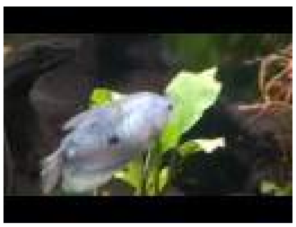
The nitrogen cycle.

this fixed nitrogen to build amino acids, nucleic acids (DNA, RNA), and chlorophyll. When these legumes die, the fixed nitrogen they contain fertilizes the soil.

Up the Food Chain

Animals eat plant tissue and create animal tissue. After a plant or animal dies or an animal excretes waste, bacteria and some fungi in the soil fix the organic nitrogen and return it to the soil as ammonia. Nitrifying bacteria oxidize the ammonia to nitrites, while other bacteria oxidize the nitrites to nitrates, which can be used by the next generation of plants. In this way, nitrogen does not need to return to a gas. Under conditions when there is no oxygen, some bacteria can reduce nitrates to molecular nitrogen.

This very thorough video on the nitrogen cycle with an aquatic perspective was created by high school students: http://www.youtube.com/watch?v=pdY4I-EaqJA (5:08).



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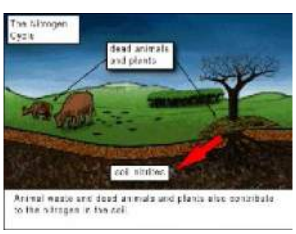
Summary

- Nitrogen is an essential component of many organic molecules.
- Nitrogen is fixed when it is changed into a form that organisms can use.
- Bacteria and some fungi fix organic nitrogen into ammonia and nitrifying bacteria oxidize it to nitrates.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=ZCogeBk92NA



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1. What percentage of the air is nitrogen?
2. How is nitrogen removed from the air?
3. What contributes nitrogen to the soil?
4. What happens to soil nitrates?
5. How is nitrogen released from the soil?

Review

1. Describe how nitrogen is fixed.
2. Why are legumes important as nitrogen fixers?
3. How is nitrogen fixed in an aquatic environment?

8.8 Carbon Cycle and Climate

- Explain the carbon cycle.

What is a diamond?

Carbon takes all sorts of forms as an element and as a compound. A diamond is just carbon, pure carbon. A diamond is good for cutting things, but it's not good for breathing or building proteins out of, yet other forms of carbon are. Carbon is essential for life on Earth and, as carbon dioxide, it is an important atmospheric gas.

The Carbon Cycle

Carbon is a very important element to living things. As the second most common element in the human body, we know that human life without carbon would not be possible. Protein, **carbohydrates**, and fats are all part of the body and all contain carbon. When your body breaks down food to produce energy, you break down protein, carbohydrates, and fat, and you breathe out carbon dioxide.

Carbon occurs in many forms on Earth. The element moves through organisms and then returns to the environment. When all this happens in balance, the ecosystem remains in balance too.

Short Term Cycling of Carbon

The short term cycling of carbon begins with carbon dioxide (CO_2) in the atmosphere.

Photosynthesis

Through photosynthesis, the inorganic carbon in carbon dioxide plus water and energy from sunlight is transformed into organic carbon (food) with oxygen given off as a waste product. The chemical equation for photosynthesis is:

$$\underset{\text{carbon dioxide}}{6\ CO_2} + \underset{\text{water}}{6\ H_2O} + \text{Energy from sunlight} \rightarrow \underset{\text{glucose (sugar)}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\ O_2}$$

Respiration

Plants and animals engage in the reverse of photosynthesis, which is respiration. In respiration, animals use oxygen to convert the organic carbon in sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

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

Photosynthesis and respiration are a gas exchange process. In photosynthesis, CO_2 is converted to O_2; in respiration, O_2 is converted to CO_2.

Remember that plants do not create energy. They change the energy from sunlight into chemical energy that plants and animals can use as food (**Figure** 8.14).

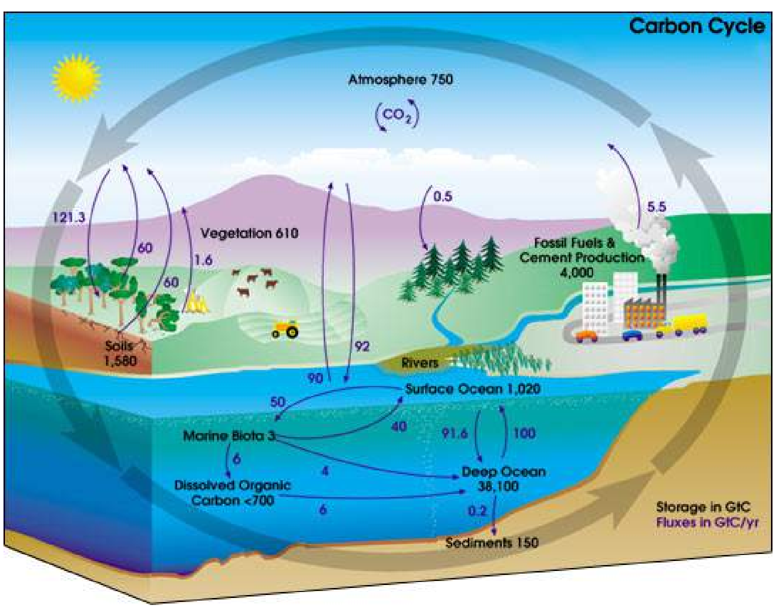

FIGURE 8.14
The carbon cycle shows where a carbon atom might be found. The black numbers indicate how much carbon is stored in various reservoirs, in billions of tons ("GtC" stands for gigatons of carbon). The purple numbers indicate how much carbon moves between reservoirs each year. The sediments, as defined in this diagram, do not include the ~70 million GtC of carbonate rock and kerogen.

Long-Term Carbon Cycling

Carbon Sinks and Carbon Sources

Places in the ecosystem that store carbon are reservoirs. Places that supply and remove carbon are **carbon sources** and **carbon sinks**, respectively. If more carbon is provided than stored, the place is a carbon source. If more carbon dioxide is absorbed than is emitted, the reservoir is a carbon sink. What are some examples of carbon sources and sinks?

- Carbon sinks are reservoirs where carbon is stored. Healthy living forests and the oceans act as carbon sinks.
- Carbon sources are reservoirs from which carbon can enter the environment. The mantle is a source of carbon from volcanic gases.

A reservoir can change from a sink to a source and vice versa. A forest is a sink, but when the forest burns it becomes a source.

The amount of time that carbon stays, on average, in a reservoir is the residence time of carbon in that reservoir.

The concept of residence times is explored using the undergraduate population at UGA as an example. In this example the reservoir is the university: http://www.youtube.com/watch?v=cIuaedcVvQg (2:44).

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Atmospheric Carbon Dioxide

Remember that the amount of CO_2 in the atmosphere is very low. This means that a small increase or decrease in the atmospheric CO_2 can have a large effect.

By measuring the composition of air bubbles trapped in glacial ice, scientists can learn the amount of atmospheric CO_2 at times in the past. Of particular interest is the time just before the Industrial Revolution, when society began to use fossil fuels. That value is thought to be the natural content of CO_2 for this time period; that number was 280 parts per million (ppm).

By 1958, when scientists began to directly measure CO_2 content from the atmosphere at Mauna Loa volcano in the Pacific Ocean, the amount was 316 ppm (**Figure** 8.15). In 2011, the atmospheric CO_2 content had risen to 390 ppm.

This is an increase in atmospheric CO_2 of 40% since the before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958.

Human Actions Impact the Carbon Cycle

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO_2 when they form, but they are a source for CO_2 when they are burned.

The equation for combustion of propane, which is a simple hydrocarbon looks like this:

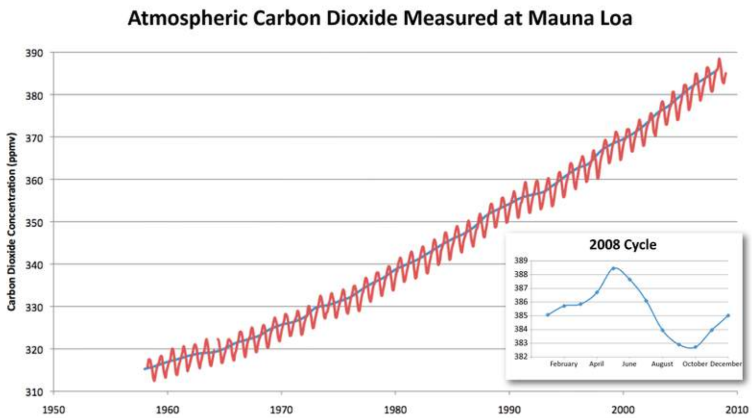


FIGURE 8.15
The amount of CO_2 in the atmosphere has been measured at Mauna Loa Observatory since 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2.

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\,O_2} \rightarrow \underset{\text{carbon dioxide}}{3\,CO_2} + \underset{\text{water}}{4\,H_2O}$$

The equation shows that when propane burns, it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas, the amount of CO_2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO_2, the result is the increase in atmospheric CO_2 seen in the **Figure** 8.15.

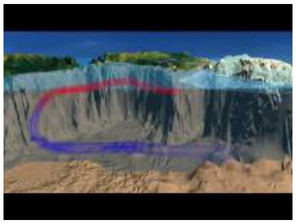
The second largest source of atmospheric CO_2 is **deforestation** (**Figure** 8.16). Trees naturally absorb CO_2 while they are alive. Trees that are cut down lose their ability to absorb CO_2. If the tree is burned or decomposes, it becomes a source of CO_2. A forest can go from being a carbon sink to being a carbon source.

FIGURE 8.16
This forest in Mexico has been cut down and burned to clear forested land for agriculture.

Why the Carbon Cycle is Important

Why is such a small amount of carbon dioxide in the atmosphere even important? Carbon dioxide is a greenhouse gas. Greenhouse gases trap heat energy that would otherwise radiate out into space, which warms Earth. These gases were discussed in the chapter Atmospheric Processes.

This video *Keeping up with Carbon* from NASA, focuses on the oceans. Topics include what will happen as temperature warms and the oceans can hold less carbon, and ocean acidification: http://www.youtube.com/watch?v=HrIr3xDhQ0E (5:39).



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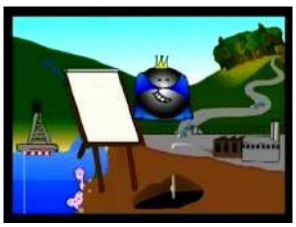
A very thorough but basic summary of the carbon cycle, including the effect of carbon dioxide in the atmosphere, is found in this video: http://www.youtube.com/watch?v=U3SZKJVKRxQ (4:37).



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Summary

- Carbon is essential for life as part of proteins, carbohydrates, and fats.
- The amount of carbon dioxide in the atmosphere is extremely low, but it is extremely important since carbon dioxide is a greenhouse gas, which helps to keep Earth's climate moderate.
- The amount of carbon dioxide in the atmosphere is rising, a fact that has been documented on Mauna Loa volcano since 1958.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Carbon Cycle**

1. How is carbon moved with photosynthesis?
2. How is carbon moved with respiration?
3. What process releases carbon dioxide to the atmosphere?
4. What gases does combustion produce?
5. What happens to sediment over time?
6. What occurs during weathering?

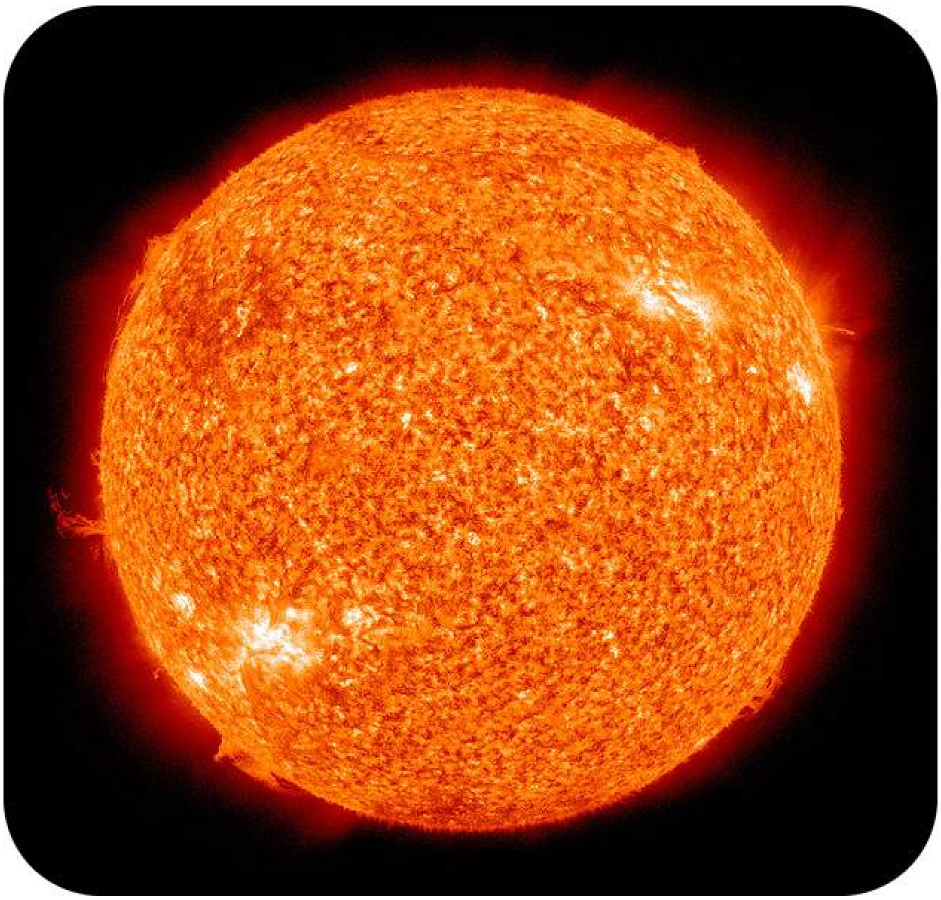
Review

1. What does it mean to say that photosynthesis and respiration are gas exchange processes?

2. How do scientists learn about carbon levels in the past?
3. How do human activities affect the carbon cycle?

8.9 Renewable vs Non-Renewable Energy Resources

- Define renewable resource and non-renewable resource.
- Compare and contrast renewable and non-renewable resources.
- Identify renewable and non-renewable resources.



What is the source of nearly all of Earth's energy?

The source of nearly all energy on Earth is our star, the Sun. Solar energy feeds almost all life on Earth, is trapped in fossil fuels, and is the reason wind blows and water flows. Earth's other big source of energy is the planet's internal heat.

Types of Energy Resources

Energy resources are either renewable or non-renewable. **Non-renewable resources** are used faster than they can be replaced, so the supply available to society is limited. **Renewable resources** will not run out because they are replaced as quickly as they are used (see example in **Figure** 8.17). Can you think of some renewable and non-renewable energy sources?

FIGURE 8.17
An old windmill in the Netherlands.

Non-Renewable Resources

Fossil fuels —coal, oil, and natural gas —are the most common example of non-renewable energy resources. Fossil fuels are formed from fossils, the partially decomposed remains of once living plants and animals. These fossils took millions of years to form. When fossil fuels are burned for energy, they release pollutants into the atmosphere. Fossil fuels also release carbon dioxide and other greenhouse gases, which are causing global temperatures to rise.

Renewable Resources

Renewable energy resources include solar, water, wind, biomass, and geothermal. These resources are either virtually limitless like the Sun, which will continue to shine for billions of years, or will be replaced faster than we can use them. Amounts of falling water or wind will change over the course of time, but they are quite abundant. Biomass energy, like wood for fire, can be replaced quickly.

The use of renewable resources may also cause problems. Some are expensive, while some, such as trees, have other uses. Some cause environmental problems. As the technology improves and more people use renewable energy, the prices may come down. At the same time, as we use up fossil fuels such as coal, oil, and natural gas, these non-renewable resources will become more expensive. At some point, even if renewable energy costs are high, non-renewable energy will be even more expensive. Ultimately, we will have to use renewable sources.

Important Things to Consider about Energy Resources

With both renewable and non-renewable resources, there are at least two important things to consider. One is that we have to have a practical way to turn the resource into a useful form of energy. The other is that we have to consider what happens when we turn the resource into energy.

For example, if we get much less energy from burning a fuel than we put into making it, then that fuel is probably not a practical energy resource. On the other hand, if another fuel gives us large amounts of energy but creates large amounts of pollution, that fuel also may not be the best choice for an energy resource.

Electrical Grids

No matter what the source, once it is generated electricity has go move from place to place. It does so by an electrical grid. Many communities have electrical grids that were built decades ago. These grids are inefficient and have high failure rates.

The electrical grids of the future are likely to be **smart grids**. Smart grids start with electricity production from one or more power generation sources. The electricity is streamed through multiple networks out to millions of consumers. Smart meters are placed with the consumers. They supply information on the state of the electrical system. Operators know within minutes if the power goes out, rather than having to wait for phone calls from consumers. Smart meters measure consumption and assist consumers in using power when it is more economical, even turning on or off appliances in homes or workplaces to smooth demand. Smart grids are essential for integrating renewable energy sources, such as solar and wind, into the network because they have highs and lows in their supply.

Today we rely on electricity more than ever, but the resources that currently supply our power are finite. The race is on to harness more renewable resources, but getting all that clean energy from production sites to homes and businesses is proving to be a major challenge.

Find out more at http://www.kqed.org/quest/television/climate-watch-unlocking-the-grid .

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Summary

- Non-renewable resources are used faster than they can be replaced. Once they're gone, they are, for all practical purposes, gone. Renewable resources are so abundant or are replaced so rapidly that, for all practical purposes, they can't run out.
- Fossil fuels are the most commonly used non-renewable resources. Renewable resources include solar, wind, hydro, and (possibly) biomass.
- A resource may take so much energy to harness that it doesn't provide much net energy.

Making Connections

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Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Renewable and Non-Renewable Energy**

1. What is non-renewable energy?
2. What are fossil fuels?
3. What are the forms of renewable energy?
4. How does hydroelectric energy work?
5. What is the concern with hydroelectric energy?
6. What problem has been cause by the use of fossil fuels?
7. What are oil companies expecting to occur by 2050?

Review

1. What does it mean that a form of energy might take more energy to harness than it provides?
2. Are renewable resources always renewable, or can they become non-renewable?
3. Why aren’t renewable resources used for everything that we use energy for?

8.10 Forms of Energy

Lesson Objectives

- Identify different forms of energy.
- Describe how energy changes form.

Lesson Vocabulary

- chemical energy
- electrical energy
- electromagnetic energy
- mechanical energy
- sound energy
- thermal energy

Introduction

The young man in **Figure** 8.18 is playing an electric guitar in a rock concert. He plucks the strings of the guitar with skill, and the sounds of the music thrill the crowd. The bright stage lights in the otherwise dark concert hall add to the excitement, although they make it hot on stage. This scene represents energy in several different forms. Do you know what they are? You'll find out in this lesson.

FIGURE 8.18
How many different forms of energy can you identify in this picture?

Comparing Forms of Energy

Energy, or the ability to do work, can exist in many different forms. The photo in **Figure** 8.18 represents six of the eight different forms of energy that are described in this lesson. The guitarist gets the energy he needs to perform from chemical energy in food. He uses mechanical energy to pluck the strings of the guitar. The stage lights use electrical energy and give off both light energy and thermal energy, commonly called heat. The guitar also uses electrical energy, and it produces sound energy when the guitarist plucks the strings. For an introduction to all these forms of energy, go to this URL: http://www.need.org/needpdf/FormsofEnergy.pdf .

For an interactive animation about the different forms of energy, visit this URL: http://www.explorelearning.com/index.cfm?method=cResource.dspView&ResourceID=651 .

After you read below about different forms of energy, you can check your knowledge by doing the drag and drop quiz at this URL: http://www.think-energy.co.uk/ThinkEnergy/11-14/activities/TypesEnergy.aspx .

Mechanical Energy

Mechanical energy is the energy of an object that is moving or has the potential to move. It is the sum of an object's kinetic and potential energy. In **Figure** 8.19, the basketball has mechanical energy because it is moving. The arrow in the same figure has mechanical energy because it has the potential to move due to the elasticity of the bow. What are some other examples of mechanical energy?

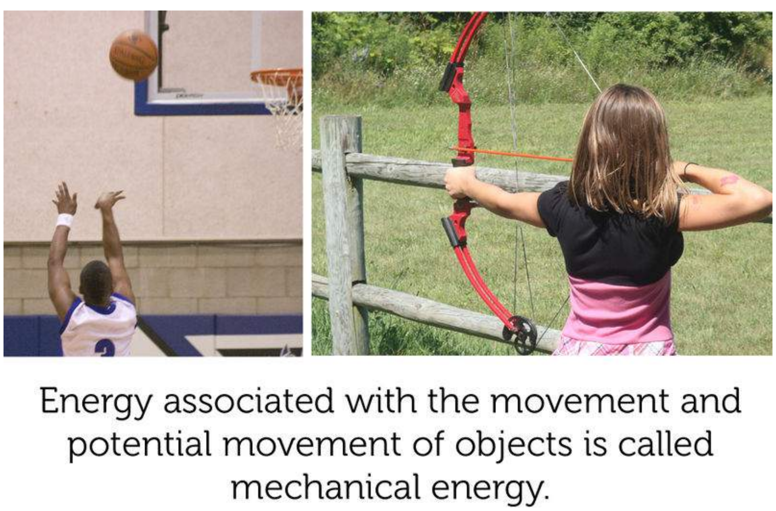


FIGURE 8.19

Kinetic and potential energy add up to mechanical energy.

Chemical Energy

Energy is stored in the bonds between atoms that make up compounds. This energy is called **chemical energy**, and it is a form of potential energy. If the bonds between atoms are broken, the energy is released and can do work. The wood in the fireplace in **Figure** 8.20 has chemical energy. The energy is released as thermal energy when the wood burns. People and many other living things meet their energy needs with chemical energy stored in food. When food molecules are broken down, the energy is released and may be used to do work.

FIGURE 8.20
Chemical energy is stored in wood and released when the wood burns.

Electrical Energy

Electrons are negatively charged particles in atoms. Moving electrons have a form of kinetic energy called **electrical energy**. If you've ever experienced an electric outage, then you know how hard it is to get by without electrical energy. Most of the electrical energy we use is produced by power plants and arrives in our homes through wires. Two other sources of electrical energy are pictured in **Figure** 8.21.

FIGURE 8.21
A lightning bolt is a powerful discharge of electrical energy. A battery contains stored chemical energy and converts it to electrical energy.

Nuclear Energy

The nuclei of atoms are held together by powerful forces. This gives them a tremendous amount of stored energy, called nuclear energy. The energy can be released and used to do work. This happens in nuclear power plants when nuclei fission, or split apart. It also happens in the sun and other stars when nuclei fuse, or join together. Some of the sun's energy travels to Earth, where it warms the planet and provides the energy for photosynthesis (see **Figure** 8.22).

Thermal Energy

The atoms that make up matter are in constant motion, so they have kinetic energy. All that motion gives matter thermal energy. **Thermal energy** is defined as the total kinetic energy of all the atoms that make up an object. It

FIGURE 8.22
In the sun, hydrogen nuclei fuse to form helium nuclei. This releases a huge amount of energy, some of which reaches Earth.

depends on how fast the atoms are moving and how many atoms the object has. Therefore, an object with more mass has greater thermal energy than an object with less mass, even if their individual atoms are moving at the same speed. You can see an example of this in **Figure** 8.23.

FIGURE 8.23
Atoms are moving at the same speed in the soup on the spoon as they are in the soup in the pot. However, there are more atoms of soup in the pot, so it has more thermal energy.

Electromagnetic Energy

Energy that the sun and other stars release into space is called **electromagnetic energy**. This form of energy travels through space as electrical and magnetic waves. Electromagnetic energy is commonly called light. It includes visible light, as well as radio waves, microwaves, and X rays (**Figure** 8.24).

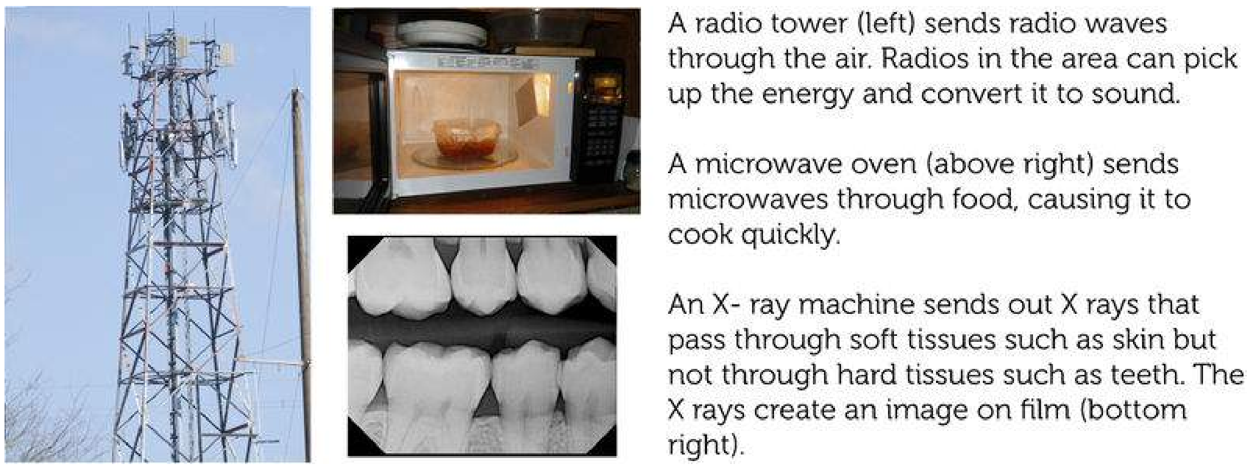


FIGURE 8.24
Radio waves, microwaves, and X rays are examples of electromagnetic energy.

Sound Energy

The drummer in **Figure** 8.25 is hitting the drumheads with drumsticks. This causes the drumheads to vibrate. The vibrations pass to surrounding air particles and then from one air particle to another in a wave of energy called **sound energy**. We hear sound when the sound waves reach our ears. Sound energy can travel through air, water, and other substances, but not through empty space. That's because the energy needs particles of matter to pass it on.

FIGURE 8.25
Vibrating objects such as drumheads produce sound energy.

How Energy Changes Form

Energy often changes from one form to another. For example, the mechanical energy of a moving drumstick changes to sound energy when it strikes the drumhead and causes it to vibrate. Any form of energy can change into any other form. Frequently, one form of energy changes into two or more different forms. For example, when wood burns, the wood's chemical energy changes to both thermal energy and light energy. Other examples of energy conversions are described in **Figure** 8.26. You can see still others at this URL: http://fi.edu/guide/hughes/energychangeex.html .

You can check your understanding of how energy changes form by doing the quizzes at these URLs:

- http://www.think-energy.co.uk/ThinkEnergy/11-14/activities/EnergyTrans2.aspx
- http://www.poweringourfuture.com/students/energy/2.html

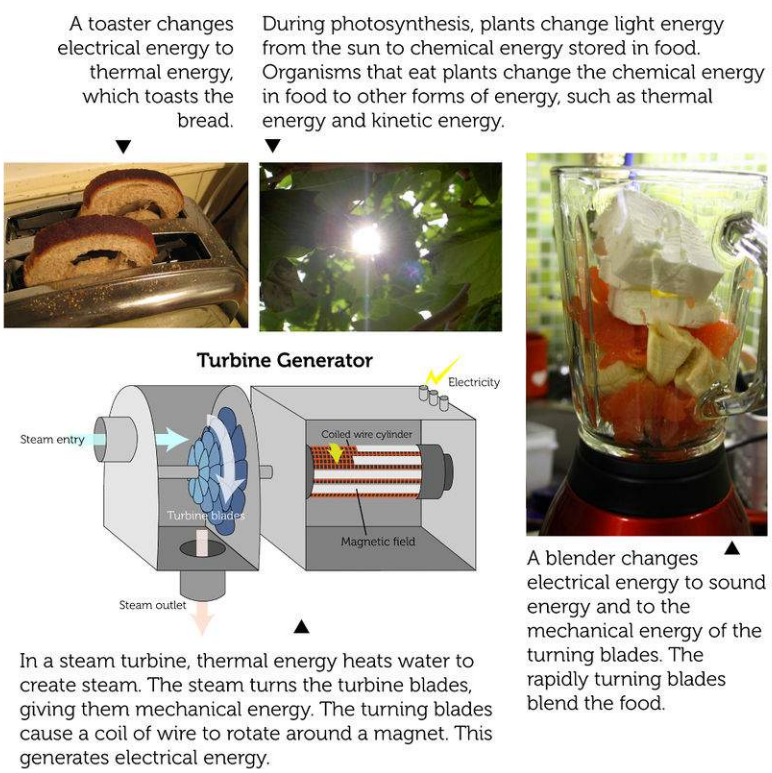


FIGURE 8.26
Energy is constantly changing form. Can you think of other examples of energy conversions?

Energy is conserved in energy conversions. No energy is lost when energy changes form, although some may be released as thermal energy due to friction. For example, not all of the energy put into a steam turbine in **Figure** 8.26 changes to electrical energy. Some changes to thermal energy because of friction of the turning blades and other moving parts. The more efficient a device is, the greater the percentage of usable energy it produces. Appliances with an "Energy Star" label like the one in **Figure** 8.27 use energy efficiently and thereby reduce energy use.

Lesson Summary

- Forms of energy include mechanical, chemical, electrical, nuclear, thermal, electromagnetic, and sound energy. These forms of energy can occur as either kinetic or potential energy.

FIGURE 8.27
The U.S. government's Energy Star program certifies the energy efficiency of appliances. Look for this label to identify those that are energy efficient.

- Energy often changes from one form to another. Any form of energy can change into any other, and one form may change into two or more different forms. Energy is always conserved when it changes form.

Lesson Review Questions

Recall

1. Define mechanical energy.
2. Give an example of chemical energy.
3. What is electrical energy?
4. Name two processes that release nuclear energy.
5. List three types of electromagnetic energy.

Apply Concepts

6. If you were on the moon, no sound energy would be able to reach your ears. Explain why. (*Hint:* The moon has no atmosphere.)
7. State how energy is converted by the following electrical devices: light bulb, alarm clock, hair dryer.

Think Critically

8. Relate the thermal energy of an object to the object's atoms.

Points to Consider

In this lesson, you read about electrical appliances that convert electrical energy to other forms of energy, such as thermal energy or sound energy.

- What form of energy is converted to electrical energy when electric current is generated?
- What natural resources might provide the energy needed to generate electricity?

8.11 Types of Energy

Lesson Objectives

- Relate energy to work.
- Describe kinetic energy.
- Identify two types of potential energy.
- Give examples of energy conversions between potential and kinetic energy.

Lesson Vocabulary

- energy conversion
- potential energy

Introduction

Did you ever babysit younger children, like the children in **Figure** 8.28? If you did, then you probably noticed that young children are often very active. They seem to be in constant motion. It may be hard to keep up with their boundless energy. What is energy, and where does it come from? Read on to find out.

FIGURE 8.28
Young children seem to be full of energy.

Defining Energy

The concept of energy was first introduced in the chapter "States of Matter," where it is defined as the ability to cause change in matter. Energy can also be defined as the ability to do work. Work is done whenever a force is used to move matter. When work is done, energy is transferred from one object to another. For example, when the batter in **Figure** 8.29 uses energy to swing the bat, she transfers energy to the bat. The moving bat, in turn, transfers energy to the ball. Like work, energy is measured in the joule (J), or newton·meter (N·m).

FIGURE 8.29
It takes energy to swing a bat. Where does the batter get her energy?

Energy exists in different forms, which you can read about in the lesson "Forms of Energy" later in the chapter. Some forms of energy are mechanical, electrical, and chemical energy. Most forms of energy can also be classified as kinetic or potential energy. Kinetic and potential forms of mechanical energy are the focus of this lesson. Mechanical energy is the energy of objects that are moving or have the potential to move.

Kinetic Energy

What do all the photos in **Figure** 8.30 have in common? All of them show things that are moving. Kinetic energy is the energy of moving matter. Anything that is moving has kinetic energy —from the atoms in matter to the planets in solar systems. Things with kinetic energy can do work. For example, the hammer in the photo is doing the work of pounding the nail into the board. You can see a cartoon introduction to kinetic energy and its relation to work at this URL: http://www.youtube.com/watch?v=zhX01toLjZs .

The amount of kinetic energy in a moving object depends on its mass and velocity. An object with greater mass or

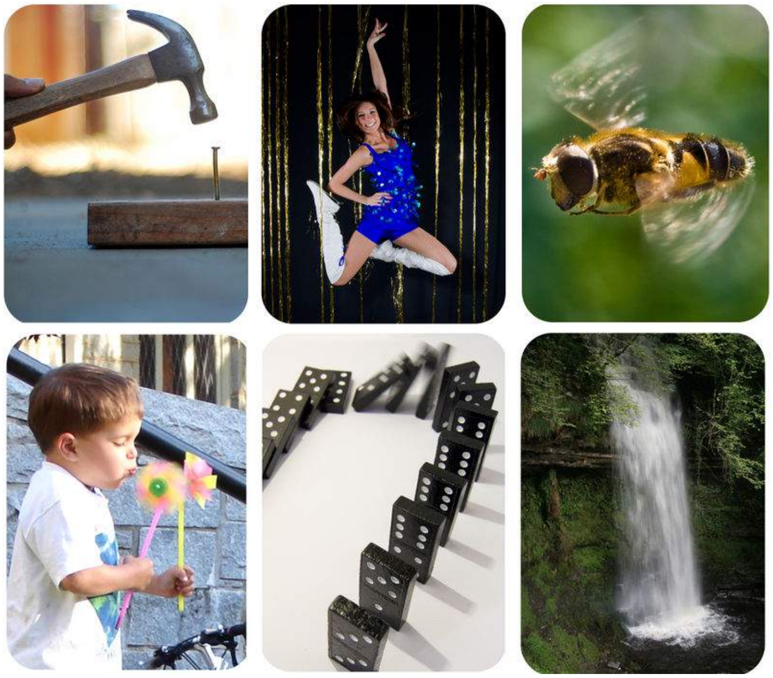


FIGURE 8.30
All of these photos show things that have kinetic energy because they are moving.

greater velocity has more kinetic energy. The kinetic energy of a moving object can be calculated with the equation:

$$\text{Kinetic Energy (KE)} = \frac{1}{2}\text{mass} \times \text{velocity}^2$$

This equation for kinetic energy shows that velocity affects kinetic energy more than mass does. For example, if mass doubles, kinetic energy also doubles. But if velocity doubles, kinetic energy increases by a factor of four. That's because velocity is squared in the equation. You can see for yourself how mass and velocity affect kinetic energy by working through the problems below.

Problem Solving

Problem: Juan has a mass of 50 kg. If he is running at a velocity of 2 m/s, how much kinetic energy does he have?

Solution: Use the formula: $\text{KE} = \frac{1}{2}\text{mass} \times \text{velocity}^2$

$$\begin{aligned}\text{KE} &= \frac{1}{2} \times 50 \text{ kg} \times (2 \text{ m/s}^2)\\ &= 100 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 100 \text{ N} \cdot \text{ m, or } 100 \text{ J}\end{aligned}$$

You Try It!

Problem: What is Juan's kinetic energy if he runs at a velocity of 4 m/s?

Problem: Juan's dad has a mass of 100 kg. How much kinetic energy does he have if he runs at a velocity of 2 m/s?

Potential Energy

Did you ever see a scene like the one in **Figure** 8.31? In many parts of the world, trees lose their leaves in autumn. The leaves turn color and then fall from the trees to the ground. As the leaves are falling, they have kinetic energy. While they are still attached to the trees they also have energy, but it's not because of motion. Instead, they have stored energy, called **potential energy**. An object has potential energy because of its position or shape. For example leaves on trees have potential energy because they could fall due to the pull of gravity.

FIGURE 8.31
Before leaves fall from trees in autumn, they have potential energy. Why do they have the potential to fall?

Gravitational Potential Energy

Potential energy due to the position of an object above Earth is called gravitational potential energy. Like the leaves on trees, anything that is raised up above Earth's surface has the potential to fall because of gravity. You can see examples of people with gravitational potential energy in **Figure** 8.32.

FIGURE 8.32
All three of these people have gravitational potential energy. Can you think of other examples?

Gravitational potential energy depends on an object's weight and its height above the ground. It can be calculated with the equation:

$$\text{Gravitational potential energy (GPE)} = \text{weight} \times \text{height}$$

Consider the diver in **Figure** 8.32. If he weighs 70 newtons and the diving board is 5 meters above Earth's surface, then his potential energy is:

$$\text{GPE} = 70\text{ N} \times 5\text{ m} = 350\text{ N}\cdot\text{ m, or } 350\text{ J}$$

You Try It!

Problem: Kris is holding a 2-kg book 1.5 m above the floor. What is the gravitational potential energy of the book?

Elastic Potential Energy

Potential energy due to an object's shape is called elastic potential energy. This energy results when elastic objects are stretched or compressed. Their elasticity gives them the potential to return to their original shape. For example, the rubber band in **Figure** 8.33 has been stretched, but it will spring back to its original shape when released. Springs like the handspring in the figure have elastic potential energy when they are compressed. What will happen when the handspring is released?

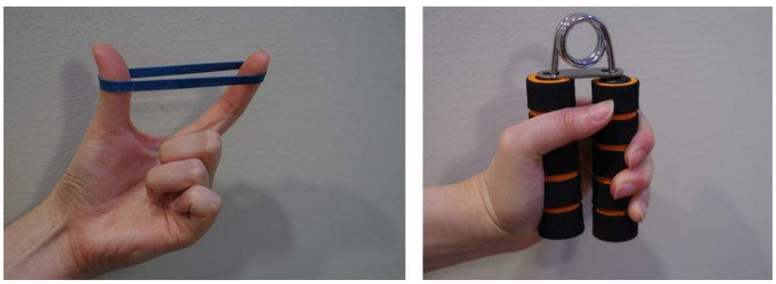


FIGURE 8.33
Changing the shape of an elastic material gives it potential energy.

Energy Conversion

Remember the diver in **Figure** 8.32? What happens when he jumps off the diving board? His gravitational potential energy changes to kinetic energy as he falls toward the water. However, he can regain his potential energy by getting out of the water and climbing back up to the diving board. This requires an input of kinetic energy. These changes in energy are examples of **energy conversion**, the process in which energy changes from one type or form to another.

Conservation of Energy

The law of conservation of energy applies to energy conversions. Energy is not used up when it changes form, although some energy may be used to overcome friction, and this energy is usually given off as heat. For example, the diver's kinetic energy at the bottom of his fall is the same as his potential energy when he was on the diving board, except for a small amount of heat resulting from friction with the air as he falls.

Examples of Energy Conversions

There are many other examples of energy conversions between potential and kinetic energy. **Figure** 8.34 describes how potential energy changes to kinetic energy and back again on swings and trampolines. You can see an animation of changes between potential and kinetic energy on a ramp at the URL below. Can you think of other examples?

http://www.physicsclassroom.com/mmedia/energy/ie.cfm

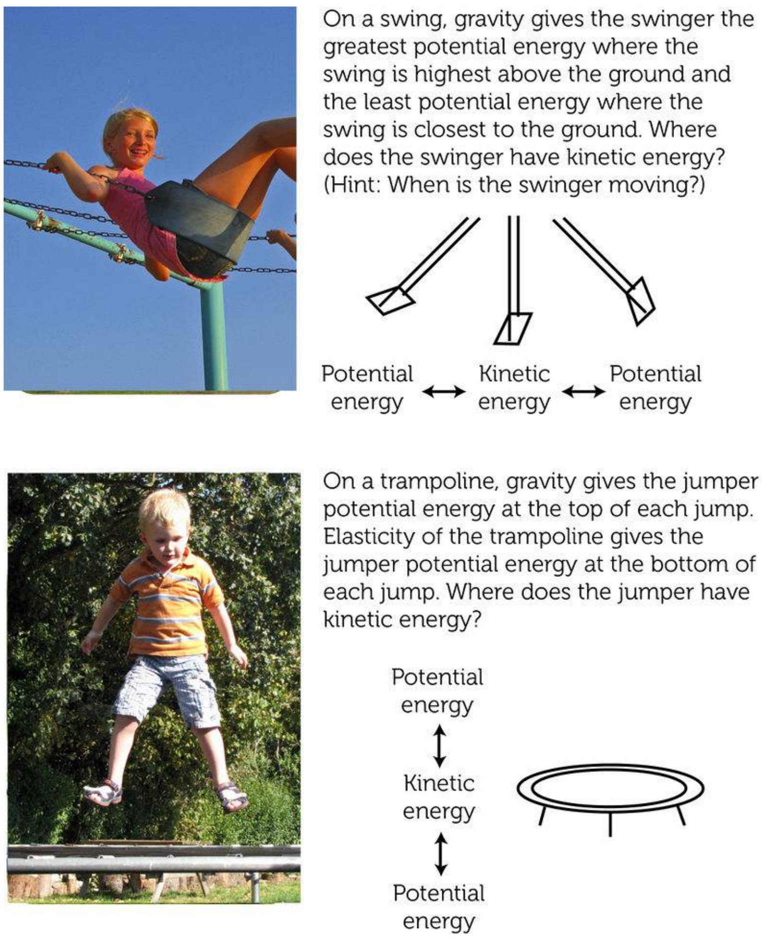


FIGURE 8.34

Energy continuously changes back and forth between potential and kinetic energy on a swing or trampoline.

Lesson Summary

- Energy is the ability to do work. When work is done, energy is transferred from one object to another. Energy can exist in different forms, such as electrical and chemical energy. Most forms of energy can also be classified as kinetic or potential energy.
- Kinetic energy is the energy of moving matter. Things with kinetic energy can do work. Kinetic energy depends on an object's mass and velocity.
- Potential energy is the energy stored in an object because of its position or shape. It includes gravitational potential energy and elastic potential energy. Gravitational potential energy depends on an object's weight and height above the ground.
- Energy conversion occurs when energy changes from one type or form of energy to another. Energy often changes between potential and kinetic energy. Energy is always conserved during energy conversions.

Lesson Review Questions

Recall

1. Define kinetic energy and give an example.

2. What is potential energy?
3. Describe how energy changes on a swing.

Apply Concepts

4. Explain how energy changes in the spring toy below when it goes down stairs.

Think Critically

5. How is energy related to work?
6. Compare and contrast gravitational potential energy and elastic potential energy.

Points to Consider

The examples of kinetic and potential energy you read about in this lesson are types of mechanical energy. Mechanical energy is one of several forms of energy you can read about in the next lesson, "Forms of Energy."

- Based on the examples in this lesson, how would you define mechanical energy?
- What might be other examples of mechanical energy?

8.12 Energy Resources

Lesson Objectives

- Describe nonrenewable energy resources.
- Identify several renewable energy resources.
- Outline world energy use and ways to conserve energy.

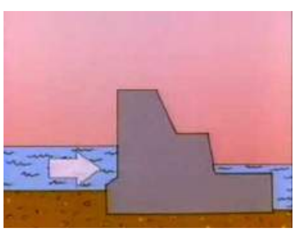
Lesson Vocabulary

- conservation
- fossil fuel
- natural resource
- nonrenewable resource
- renewable resource

Introduction

Did you ever go whitewater rafting, like the people in **Figure** 8.35? What an exciting ride! The churning water tosses the raft and drenches its riders with spray and foam. Water is a great place to have fun, whether you are rafting, swimming, snorkeling, jet skiing, or fishing. In fact, water is one of our most precious natural resources. A **natural resource** is anything people can use that comes from nature. In this lesson, you'll learn how we use water —and many other natural resources —for energy. For a brief overview of the energy resources you'll learn about in this lesson, go to this URL: http://www.think-energy.co.uk/ThinkEnergy/11-14/activities/EnergyTrans.aspx .

For a cartoon introduction to energy resources, go to this URL: http://www.youtube.com/watch?v=RD_54Cq_UMM (1:39).



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Click image to the left for more content.

Nonrenewable Energy Resources

Nonrenewable resources are natural resources that are limited in supply and cannot be replaced except over millions

FIGURE 8.35
Whitewater rafting is an exciting sport.

of years. Nonrenewable energy resources include fossil fuels and radioactive elements such as uranium.

Fossil Fuels

Fossil fuels are mixtures of hydrocarbons that formed over millions of years from the remains of dead organisms. They include petroleum (commonly called oil), natural gas, and coal. Fossil fuels provide most of the energy used in the world today. They are burned in power plants to produce electrical energy, and they also fuel cars, heat homes, and supply energy for many other purposes. You can see examples of their use in **Figure** 8.36.

Natural gas burns with a blue flame in this gas stove. Many homes also have natural gas water heaters and furnaces. Some motor vehicles burn natural gas as well.

Petroleum is used to make gasoline, which fuels most motor vehicles. It is also used to make heating oil for furnaces and kerosene for camp stoves.

The majority of electric power in the U.S. is generated by burning coal in power plants like this one.

FIGURE 8.36
Do you use any of these fossil fuels? How do you use them?

Fossil fuels contain stored chemical energy that came originally from the sun. Ancient plants changed energy in sunlight to stored chemical energy in food, which was eaten by other organisms. After the plants and other organisms died, their remains gradually changed to fossil fuels as they were pressed beneath layers of sediments. Petroleum and natural gas formed from marine organisms and are often found together. Coal formed from giant tree ferns and other swamp plants.

When fossil fuels burn, they release thermal energy, water vapor, and carbon dioxide. Carbon dioxide produced by fossil fuel use is a major cause of global warming. The burning of fossil fuels also releases many pollutants into the air. Pollutants such as sulfur dioxide form acid rain, which kills living things and damages metals, stonework, and other materials. Pollutants such as nitrogen oxides cause smog, which is harmful to human health. Tiny particles, or particulates, released when fossil fuels burn also harm human health. Natural gas releases the least pollution; coal releases the most (see **Figure** 8.37). Petroleum has the additional risk of oil spills, which may seriously damage ecosystems.

Fossil Fuel Pollution Levels

Pounds per Billion Units of Energy

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0	0.007	0.016

FIGURE 8.37
This table compares the levels of several air pollutants released by the burning of natural gas, oil, and coal.

Nuclear Energy

Like fossil fuels, the radioactive element uranium can be used to generate electrical energy in power plants. In a nuclear power plant, the nuclei of uranium atoms are split in the process of nuclear fission. This process releases a tremendous amount of energy from just a small amount of uranium. The total supply of uranium in the world is quite limited, however, and cannot be replaced once it is used up. This makes nuclear energy a nonrenewable resource. Although using nuclear energy does not release carbon dioxide or cause air pollution, it does produce dangerous radioactive wastes. Accidents at nuclear power plants also have the potential to release large amounts of radioactive material into the environment. **Figure** 8.38 describes the nuclear disaster caused by a Japanese tsunami in 2011. You can learn more about the disaster and its aftermath at the URLs below.

- http://www.bbc.co.uk/news/world-asia-pacific-12711226
- http://www.bbc.co.uk/news/world-asia-pacific-12731781
- http://www.bbc.co.uk/news/world-asia-pacific-12726591

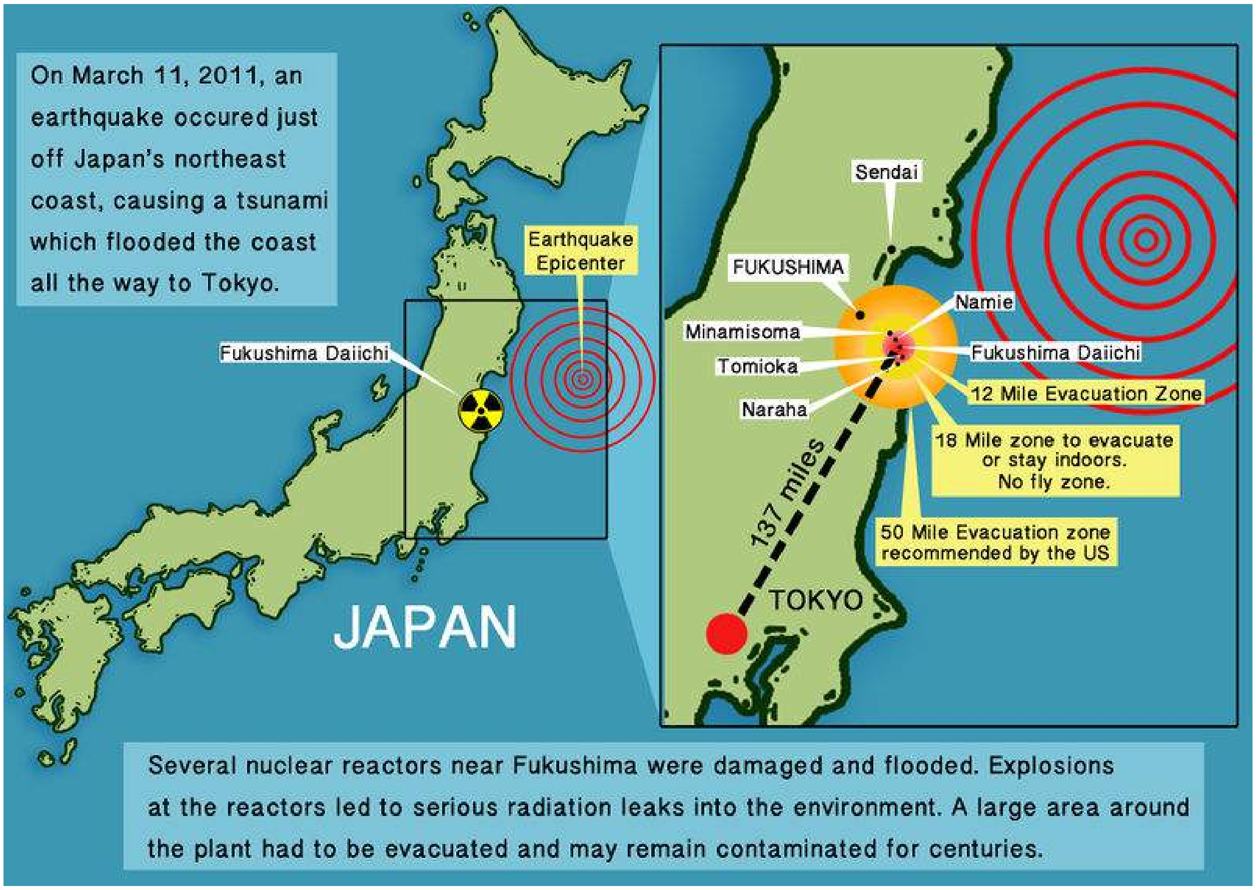


FIGURE 8.38

Do you remember Japan's 2011 nuclear disaster? (Note: the map on the right is not to scale.)

Renewable Energy Resources

Renewable resources are natural resources that can be replaced in a relatively short period of time or are virtually limitless in supply. Renewable energy resources include sunlight, moving water, wind, biomass, and geothermal energy. Each of these energy resources is described in **Table** 8.1. Resources such as sunlight and wind are limitless in supply, so they will never run out. Besides their availability, renewable energy resources also have the advantage of producing little if any pollution and not contributing to global warming. The technology needed to gather energy from renewable resources is currently expensive to install, but most of the resources themselves are free for the taking.

TABLE 8.1: What are the pros and cons of using each of the renewable energy resources described here?

Renewable Energy Resource	Example

TABLE 8.1: (continued)

Renewable Energy Resource	Example
Sunlight The energy in sunlight, or solar energy, can be used to heat homes. It can also be used to produce electricity in solar cells. However, solar energy may not be practical in areas that are often cloudy.	 Solar panels on the roof of this house generate enough electricity to supply a family's needs.
Moving Water When water falls downhill, its potential energy is converted to kinetic energy that can turn a turbine and generate electricity. The water may fall naturally over a waterfall or flow through a dam. A drawback of dams is that they flood land upstream and reduce water flow downstream. Either effect may harm ecosystems.	 Water flowing through Hoover dam between Arizona and Nevada generates electricity for both of these states and also by southern California. The dam spans the Colorado River.
Wind Wind is moving air, so it has kinetic energy that can do work. Remember the wind turbines that opened this chapter? Wind turbines change the kinetic energy of the wind to electrical energy. Only certain areas of the world get enough steady wind to produce much electricity. Many people also think that wind turbines are noisy and unattractive in the landscape.	 This old-fashioned windmill captures wind energy that is used for pumping water out of a well. Windmills like this one have been used for centuries.
Biomass The stored chemical energy of trees and other plants is called biomass energy. When plant materials are burned, they produce thermal energy that can be used for heating, cooking, or generating electricity. Biomass—especially wood—is an important energy source in countries where most people can't afford fossil fuels. Some plants can also be used to make ethanol, a fuel that is added to gasoline. Ethanol produces less pollution than gasoline, but large areas of land are needed to grow the plants needed to make it.	 This large machine is harvesting and grinding plants to be used for biomass energy.

TABLE 8.1: (continued)

Renewable Energy Resource	Example
Geothermal Heat below Earth's surface—called geothermal energy—can be used to produce electricity. A power plant pumps water underground where it is heated. Then it pumps the water back to the plant and uses its thermal energy to generate electricity. On a small scale, geothermal energy can be used to heat homes. Installing a geothermal system can be very costly, however, because of the need to drill through underground rocks.	 This geothermal power plant is located in Italy where hot magma is close to the surface.

Energy Use and Conservation

Figure 8.39 shows the mix of energy resources used worldwide in 2006. Fossil fuels still provide most of the world's energy, with oil being the single most commonly used energy resource. Natural gas is used less than the other two fossil fuels, but even natural gas is used more than all renewable energy resources combined. Wind, solar, and geothermal energy contribute the least to global energy use, despite the fact that they are virtually limitless in supply and nonpolluting.

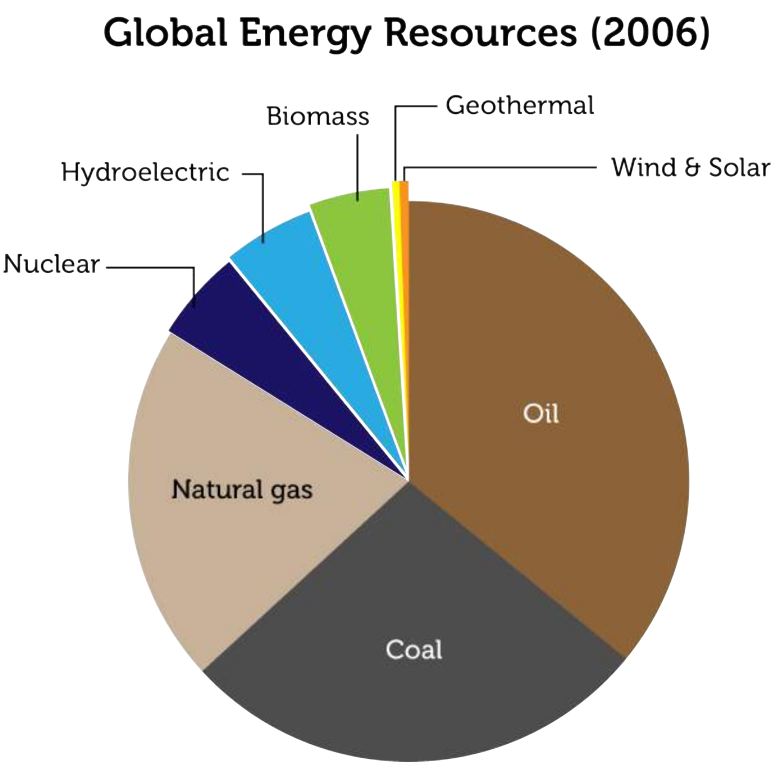


FIGURE 8.39
Which of the energy resources in this circle graph are renewable?

Energy Use by Nation

People in the richer nations of the world use far more energy, especially energy from fossil fuels, than people in the poorer nations do. **Figure** 8.40 compares the amounts of oil used by the top ten oil-consuming nations. The U.S. uses more oil than several other top-ten countries combined. If you also consider the population size in these countries, the differences are even more stunning. The average person in the U.S. uses a whopping 23 barrels of oil a year! In comparison, the average person in India or China uses just 1 or 2 barrels a year. Because richer nations use more fossil fuels, they also cause more air pollution and global warming than poorer nations do.

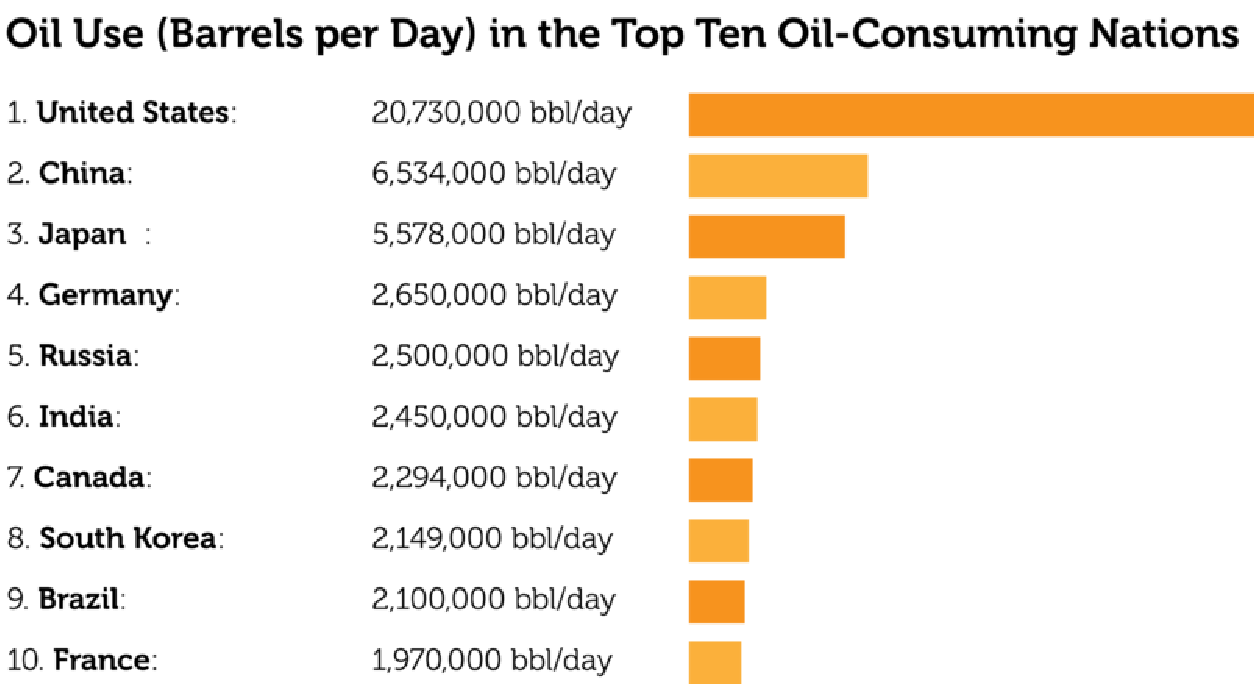


FIGURE 8.40
The U.S. uses far more oil than any other country in the world. It is even far ahead of the next largest oil user, which is China. The differences in use per person in these countries are even greater.

Conserving Energy

We can reduce our use of energy resources and the pollution they cause by conserving energy. **Conservation** means saving resources by using them more efficiently or not using them at all. **Figure** 8.41 shows several ways that people can conserve energy in their daily lives. You can find more energy-saving tips at the URL below. What do you do to save energy? What else could you do?

http://www.partselect.ca/resources/Home-Energy-Saving-Tips.aspx

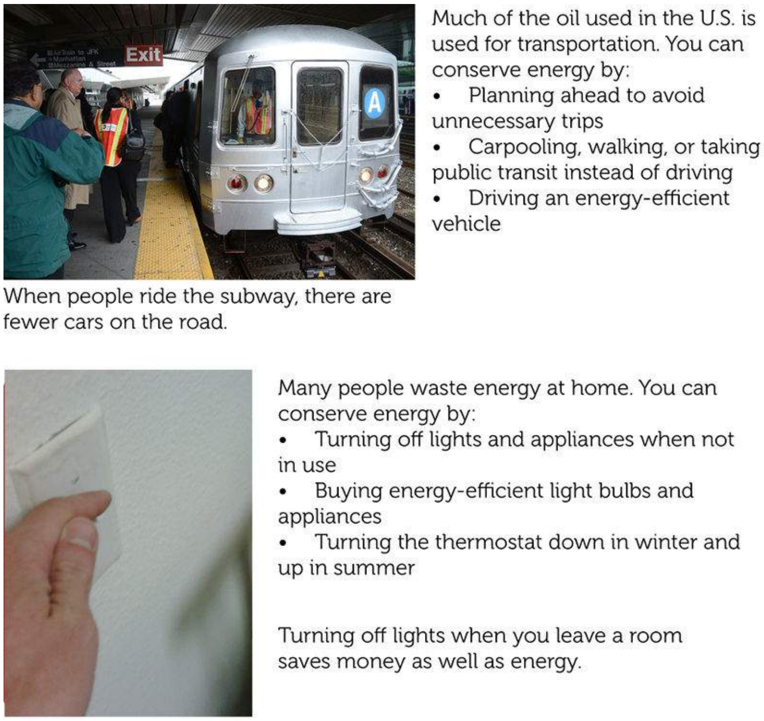


FIGURE 8.41

Small savings in energy really add up when everybody conserves energy.

Lesson Summary

- Nonrenewable resources are natural resources that are limited in supply and cannot be replaced except over millions of years. They also release pollutants and contribute to global climate change. Nonrenewable energy resources include fossil fuels, which are burned, and uranium, which is used for nuclear fission.
- Renewable resources are natural resources that can be replaced in a relatively short period of time or are virtually limitless in supply. They cause little if any pollution or global climate change. Renewable energy resources include sunlight, moving water, wind, biomass, and geothermal energy.
- Fossil fuels provide most of the energy used worldwide. Richer nations use far more energy resources, especially fossil fuels, than poorer nations do. There are several ways that people can conserve energy in their daily lives.

Lesson Review Questions

Recall

1. What is a natural resource?
2. Identify three fossil fuels.
3. Describe how fossil fuels form.
4. What are drawbacks of using fossil fuels?
5. State why nuclear energy is a nonrenewable resource.

Apply Concepts

6. Create a Web page or poster that encourages people to conserve energy and gives tips for how to do it.

Think Critically

7. Compare and contrast nonrenewable and renewable energy resources.
8. Argue for the use of any two renewable energy resources.

Points to Consider

In this chapter, you read that energy is transferred when work is done. You also read about thermal energy.

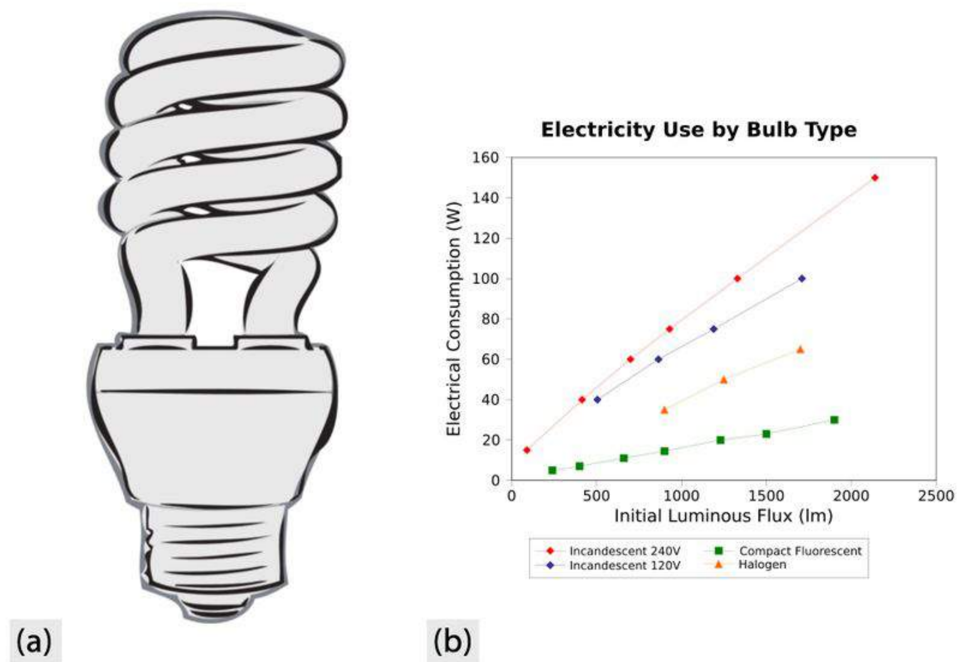
- You can use the thermal energy of a stove to cook food. How is thermal energy transferred from the hot stovetop to a pot on the stove?
- You can feel the thermal energy of a campfire, even when you are sitting a few feet away. How does thermal energy travel through the air from the fire to you?

For **Table** 8.1,

- Solar panel: Jon Callas. http://www.flickr.com/photos/joncallas/5586087273/ . CC BY 2.0.
- Dam: Flickr:NatureClip. http://www.flickr.com/photos/natureclip/9764092224/ . CC BY 2.0.
- Windmill: Fuzzy Gerdes. http://www.flickr.com/photos/fuzzy/3772169287/ . CC BY 2.0.
- Biomass: Image courtesy of Idaho National Laboratory (INL) Bioenergy Program (www.inl.gov/bioenergy). http://www.flickr.com/photos/inl/7896779532/ . CC BY 2.0.
- Geothermal plant: Birgit Juel Martinsen. http://www.flickr.com/photos/martinsen-jordenrundt/5437266214/ . CC BY 2.0.

8.13 Obtaining Energy Resources

- Describe how useable energy from an energy source is obtained and measured.



Have you converted to compact fluorescent light bulbs at your house?

Compact fluorescent light bulbs are more efficient than incandescent light bulbs. Look at the chart and try to see how much more efficient. The answer is that they could be as much as six times more efficient. So why aren't all people using compact fluorescent bulbs all the time? Early ones were large and expensive, and many people don't like the color of the light. But they are much more environmentally friendly.

Net Energy

Net energy is the amount of useable energy available from a resource after subtracting the amount of energy needed to make the energy from that resource available. For example, every 5 barrels of oil that are made available for use require 1 barrel for extracting and refining the petroleum. What is the net energy from this process? About 4 barrels (5 barrels minus 1 barrel).

What happens if the energy needed to extract and refine oil increases? Why might that happen? The energy cost of an energy resource increases when the easy deposits of that resource have already been consumed. For example, if all the nearshore petroleum in a region has been extracted, more costly drilling must take place further offshore (**Figure** 8.42). If the energy cost of obtaining energy increases, the resource will be used even faster.

Net-Energy Ratio

The **net-energy ratio** demonstrates the difference between the amount of energy available in a resource and the amount of energy used to get it. If it takes 8 units of energy to make available 10 units of energy, then the net-energy

FIGURE 8.42
Offshore drilling is taking place in deeper water than before. It takes a lot of energy to build a deep drilling platform and to run it.

ratio is 10/8 or 1.25. What does a net-energy ratio larger than 1 mean? What if the net-energy ratio is less than 1? A net-energy ratio larger than 1 means that there is a net gain in usable energy; a net-energy ratio smaller than one means there is an overall energy loss.

Table 8.2 shows the net-energy ratios for some common energy sources.

TABLE 8.2: Net-Energy Ratios for Common Energy Sources

Energy Source	Net-energy Ratio
Solar Energy	5.8
Natural Gas	4.9
Petroleum	4.5
Coal-fired Electricity	2.5-5.1

Notice from the table that solar energy yields much more net energy than other sources. This is because it takes very little energy to get usable solar energy. Sunshine is abundant and does not need to be found, extracted, or transported very far. The range for coal-fired electricity is because of the differing costs of transporting the coal. What does this suggest about using coal to generate electricity? The efficiency is greater in areas where the coal is locally mined and does not have to be transported great distances (**Figure** 8.43).

FIGURE 8.43
Obtaining coal for energy takes a lot of energy. The coal must be located, extracted, refined, and transported.

This is not to say that solar energy is less expensive than other types of energy. The cost of energy is dependent on lots of different factors, such as the cost of the equipment needed to harness the energy. If solar power cost less to use, it would be more widespread.

- The cost is kept lower.

Because so much of the energy we use is from fossil fuels, we need to be especially concerned about using them efficiently. Sometimes our choices affect energy efficiency. For example, transportation by cars and airplanes is less energy-efficient than transportation by boats and trains.

Summary

- Net energy is the amount of that is actually useable from an energy resource. Net-energy ratio is the ratio of the amount of useable energy from a resource and the amount it takes to make that energy useful.
- Many factors besides net-energy ratio go into determining if a type of energy will be used.
- An energy source with high energy efficiency provides a lot of work for the amount of energy used.

Practice

Use this resource to answer the questions that follow.

How to save money and energy: http://www.youtube.com/watch?v=VC3C_8eQgeE

MEDIA

Click image to the left for more content.

1. Besides energy, what is lost when energy drips away?
2. Why should you replace incandescent bulbs with CFLS?
3. Why is it good to plug electronics into a power strip?
4. Why should you use a programmable thermostat?
5. What is the purpose of insulation?
6. Why is an old appliance an energy sink?
7. If you did these things, how much money would you save in a decade on average (in Minnesota)?

Review

1. Compare and contrast net energy, the net-energy ratio, and energy efficiency.

2. Since the net-energy ratio for solar energy is higher than other types of energy, why don't we use solar for electricity almost exclusively?

3. Why would the energy needed to make a type of energy useful increase or decrease? In other words, why would the net-energy ratio change?

8.14 Mining Ores

- Describe how ore deposits are mined.

Can you be a miner too?

Yes! You can go to certain rivers or streams to mine for gold placers. You dip a large metal pan into the stream, and get some gravel and a little water. You swish the mix around. The gold is the heaviest material and it will sink to the bottom of the pan. You can then extract it. The placers in the U.S with a lot of ore have already been mined out. But you might make a little money!

Mining Ores

If an ore is found to be profitable, it will probably be mined. There are two major types of mining: surface mining and underground mining. There are different types of each of those two.

Surface Mining

Surface mining allows extraction of ores that are close to Earth's surface. Overlying rock is blasted, and the rock that contains the valuable minerals is placed in a truck. The truck takes the rock to a refinery. As pictured below (**Figure** 8.44), surface mining includes open-pit mining and mountaintop removal. As the name suggests, open-pit mining creates a big pit from which the ore is mined. The size of the pit grows as long as the miners can make a profit.

Other methods of surface mining include strip mining, placer mining, and dredging. Strip mining is like open pit mining but with material removed along a strip. A quarry is a type of open-pit mine that produces rocks and minerals that are used to make buildings and roads.

FIGURE 8.44
Open pit mining is a form of surface mining, extracting ores close to Earth's surface.

Placers are valuable minerals found in stream gravels. California's nickname, the Golden State, can be traced back to the discovery of placer deposits of gold in 1848. The gold weathered out of hard metamorphic rock in the western Sierra Nevada. The rock also contained deposits of copper, lead, zinc, silver, chromite, and other valuable minerals. The gold traveled down rivers and then settled in gravel deposits. Currently, California has active mines for gold and silver. Non-metal minerals such as sand and gravel, which are used for construction, are also mined in California and elsewhere.

Underground Mining

Underground mining is used to recover ores that are deeper into Earth's surface. Miners blast and tunnel into rock to gain access to the ores. An underground ore deposit can be approached from above, below, or sideways. The direction depends on the placement of the ore body, its depth, the concentration of ore, and the strength of the surrounding rock. An example of an underground mine can be seen below (**Figure** 8.45).

Underground mining is very expensive and dangerous. Fresh air and lights must also be brought into the tunnels for the miners. Accidents are far too common.

FIGURE 8.45
An underground mine.

Vocabulary

- **placer**: Valuable metal found in modern or ancient stream gravels.

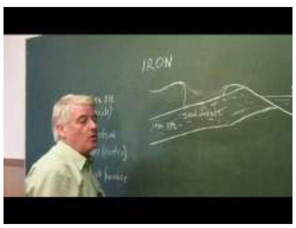
Summary

- Surface mines are created for mineral deposits that are near the surface.
- Underground mines are blasted into rock to get at deeper deposits.
- Underground mining is difficult; the safety and health of the miners is hard to maintain.

Practice

Use the resource below to answer the questions that follow.

- **How Things Work: How is Iron Mined?** at http://www.youtube.com/watch?v=jz_qlLKGwMM (2:20)



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Click image to the left for more content.

1. Where is iron usually found?
2. What is iron ore?
3. How do we get to the ore?
4. What is overburden?
5. What happens to the ore after it is dug up?
6. What steps does it go through from the blast furnace to the steel that creates your refrigerator?

Review

1. What separates surface from underground mining? Which technique do you think is more expensive? More dangerous?
2. How is a placer deposit mined?
3. Why are some ore deposits mined by mountaintop removal?

8.15 Finding and Mining Ores

- Describe how ore deposits are located, mined, and refined to become useful materials.

Why is the football team in San Francisco named the 49ers?

Football team names sometimes reflect the history of a region. The San Francisco 49ers are a reference to the California Gold Rush, when immigrants from around the United States came to what would become The Golden State to mine placer deposits. What that has to do with football is anyone's guess!

Ore Deposits

Some minerals are very useful. An **ore** is a rock that contains minerals with useful elements. Aluminum in bauxite ore (**Figure** 8.46) is extracted from the ground and refined to be used in aluminum foil and many other products. The cost of creating a product from a mineral depends on how abundant the mineral is and how much the extraction and refining processes cost. Environmental damage from these processes is often not figured into a product's cost. It is important to use mineral resources wisely.

Finding and Mining Minerals

Geologic processes create and concentrate minerals that are valuable natural resources. Geologists study geological formations and then test the physical and chemical properties of soil and rocks to locate possible ores and determine their size and concentration.

FIGURE 8.46
Aluminum is made from the aluminum-bearing minerals in bauxite.

A mineral deposit will only be mined if it is profitable. A concentration of minerals is only called an **ore deposit** if it is profitable to mine. There are many ways to mine ores.

Surface Mining

Surface mining allows extraction of ores that are close to Earth's surface. Overlying rock is blasted and the rock that contains the valuable minerals is placed in a truck and taken to a refinery. As pictured in **Figure** 8.47, surface mining includes open-pit mining and mountaintop removal. Other methods of surface mining include strip mining, placer mining, and dredging. Strip mining is like open pit mining but with material removed along a strip.

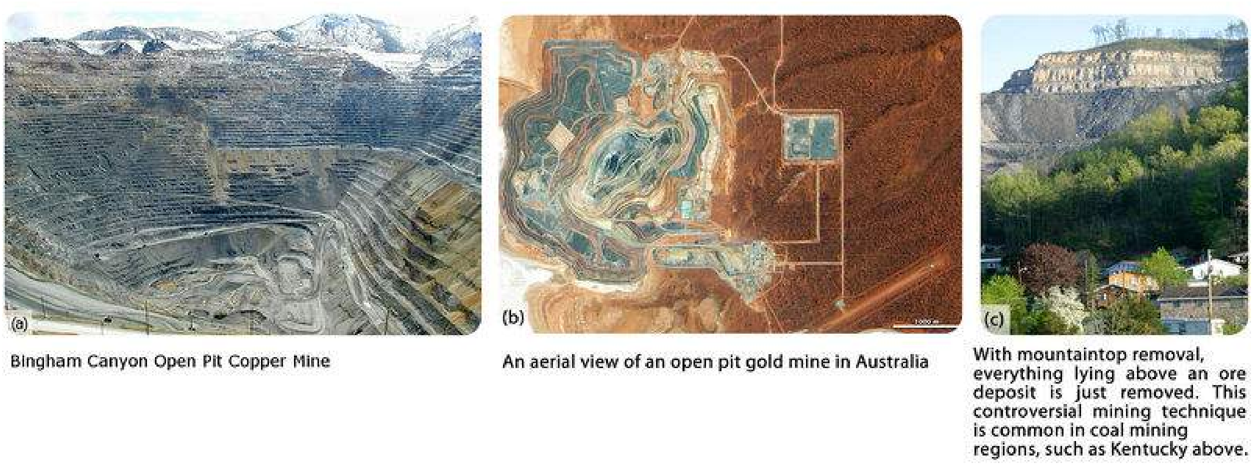


FIGURE 8.47
These different forms of surface mining are methods of extracting ores close to Earth's surface.

Placers are valuable minerals found in stream gravels. California's nickname, the Golden State, can be traced back to the discovery of placer deposits of gold in 1848. The gold weathered out of hard metamorphic rock in the western Sierra Nevada, which also contains deposits of copper, lead, zinc, silver, chromite, and other valuable minerals. The gold traveled down rivers and then settled in gravel deposits. Currently, California has active mines for gold and silver and for non-metal minerals such as sand and gravel, which are used for construction.

Underground Mining

Underground mining is used to recover ores that are deeper into Earth's surface. Miners blast and tunnel into rock to gain access to the ores. How underground mining is approached —from above, below, or sideways —depends on the placement of the ore body, its depth, the concentration of ore, and the strength of the surrounding rock.

Underground mining is very expensive and dangerous. Fresh air and lights must also be brought into the tunnels for the miners, and accidents are far too common.

FIGURE 8.48
Underground mine.

Ore Extraction

The ore's journey to becoming a useable material is only just beginning when the ore leaves the mine (**Figure** 8.49). Rocks are crushed so that the valuable minerals can be separated from the waste rock. Then the minerals are separated out of the ore. A few methods for extracting ore are:

- heap leaching: the addition of chemicals, such as cyanide or acid, to remove ore.
- flotation: the addition of a compound that attaches to the valuable mineral and floats.
- smelting: roasting rock, causing it to segregate into layers so the mineral can be extracted.

To extract the metal from the ore, the rock is melted at a temperature greater than 900^{o}C, which requires a lot of energy. Extracting metal from rock is so energy-intensive that if you recycle just 40 aluminum cans, you will save the energy equivalent of one gallon of gasoline.

FIGURE 8.49
Enormous trucks haul rock containing ore from a mine site to where the rock is processed.

FIGURE 8.50
A steel mill.

Summary

- An ore deposit must be profitable to mine by definition. If it is no longer profitable, it is no longer an ore deposit.
- Surface mines are created for mineral deposits that are near the surface; underground mines are blasted into rock to get at deeper deposits.
- Ore is extracted from rock by heap leaching, flotation or smelting.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What is the Superpit?
2. How large is the Superpit?
3. How is gold extracted from this mine?
4. What is Australia's rank in gold mining?
5. What minerals is Australia the leading country for?

Review

1. What sorts of changes can transform a deposit that is an ore into a deposit that is not an ore?
2. Why is the production of the metal to create your aluminum soda can energy-intensive?
3. How is ore taken from a rock and made into a metal like a copper wire?

8.16 Flow of Energy in Ecosystems

- Define trophic levels.
- Compare and contrast food chains and webs.
- Explain how energy flows through ecosystems.

What is the source of energy for almost all ecosystems?

The Sun supports most of Earth's ecosystems. Plants create chemical energy from abiotic factors that include solar energy. Chemosynthesizing bacteria create usable chemical energy from unusable chemical energy. The food energy created by producers is passed to consumers, scavengers, and decomposers.

Trophic Levels

Energy flows through an ecosystem in only one direction. Energy is passed from organisms at one **trophic level** or energy level to organisms in the next trophic level. Which organisms do you think are at the first trophic level (**Figure** 8.51)?

Most of the energy at a trophic level –about 90% –is used at that trophic level. Organisms need it for locomotion, heating themselves, and reproduction. So animals at the second trophic level have only about 10% as much energy available to them as do organisms at the first trophic level. Animals at the third level have only 10% as much available to them as those at the second level.

Food Chains

The set of organisms that pass energy from one trophic level to the next is described as the **food chain** (**Figure** 8.52). In this simple depiction, all organisms eat at only one trophic level (**Figure** 8.53).

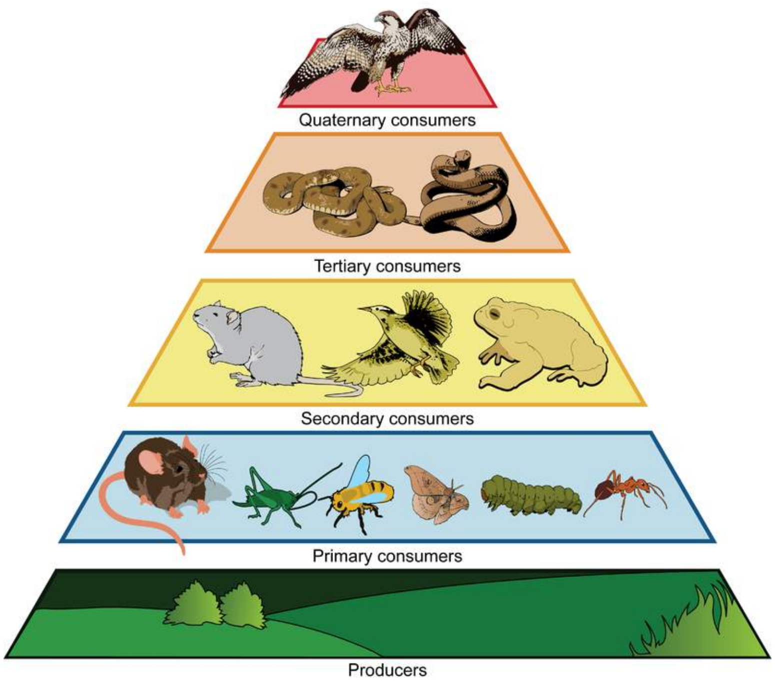


FIGURE 8.51

Producers are always the first trophic level, herbivores the second, the carnivores that eat herbivores the third, and so on.

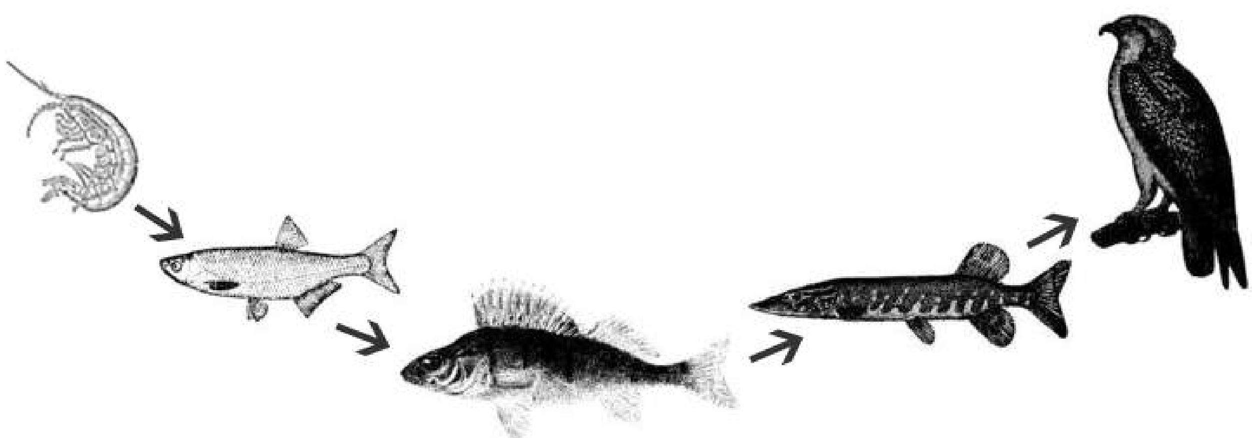


FIGURE 8.52

A simple food chain in a lake. The producers, algae, are not shown. For the predatory bird at the top, how much of the original energy is left?

What are the consequences of the loss of energy at each trophic level? Each trophic level can support fewer organisms.

What does this mean for the range of the osprey (or lion, or other top predator)? A top predator must have a very large range in which to hunt so that it can get enough energy to live.

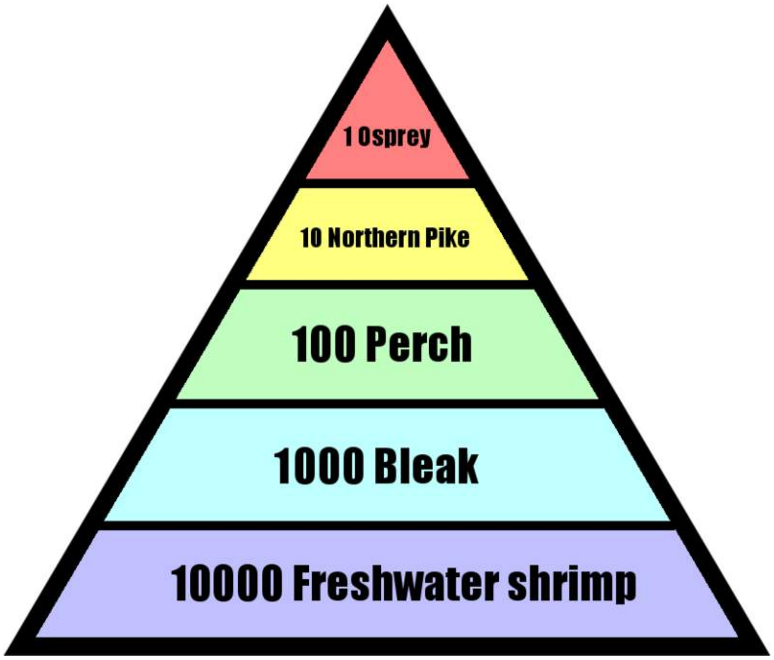


FIGURE 8.53
How many osprey are there relative to the number of shrimp?

Why do most food chains have only four or five trophic levels? There is not enough energy to support organisms in a sixth trophic level. Food chains of ocean animals are longer than those of land-based animals because ocean conditions are more stable.

Why do organisms at higher trophic levels tend to be larger than those at lower levels? The reason for this is simple: a large fish must be able to eat a small fish, but the small fish does not have to be able to eat the large fish (**Figure** 8.54).

FIGURE 8.54
In this image the predators (wolves) are smaller than the prey (bison), which goes against the rule placed above. How does this relationship work? Many wolves are acting together to take down the bison.

Food Webs

What is a more accurate way to depict the passage of energy in an ecosystem? A **food web** (**Figure** 8.55) recognizes that many organisms eat at multiple trophic levels.

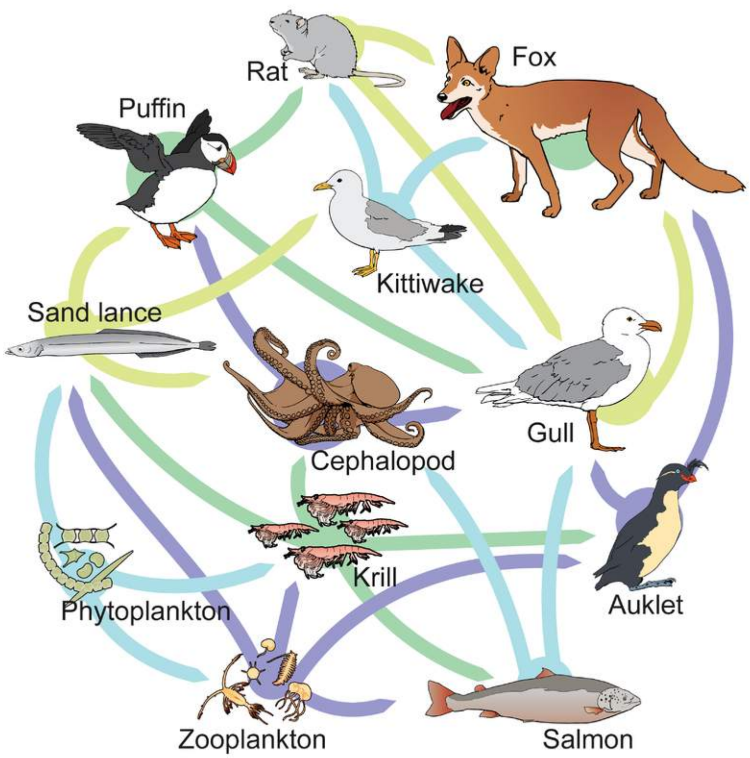


FIGURE 8.55
A food web includes the relationships between producers, consumers, and decomposers.

Even food webs are interconnected. All organisms depend on two global food webs. The base of one is phytoplankton and the other is land plants. How are these two webs interconnected? Birds or bears that live on land may eat fish, which connects the two food webs.

Humans are an important part of both of these food webs; we are at the top of a food web, since nothing eats us. That means that we are top predators.

Summary

- A food chain describes the passage of energy between trophic levels.
- A food web is a set of interconnected and overlapping food chains.
- Food webs are interconnected, such as nearby land and a marine food webs.

Making Connections

MEDIA
Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

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

MEDIA

Click image to the left for more content.

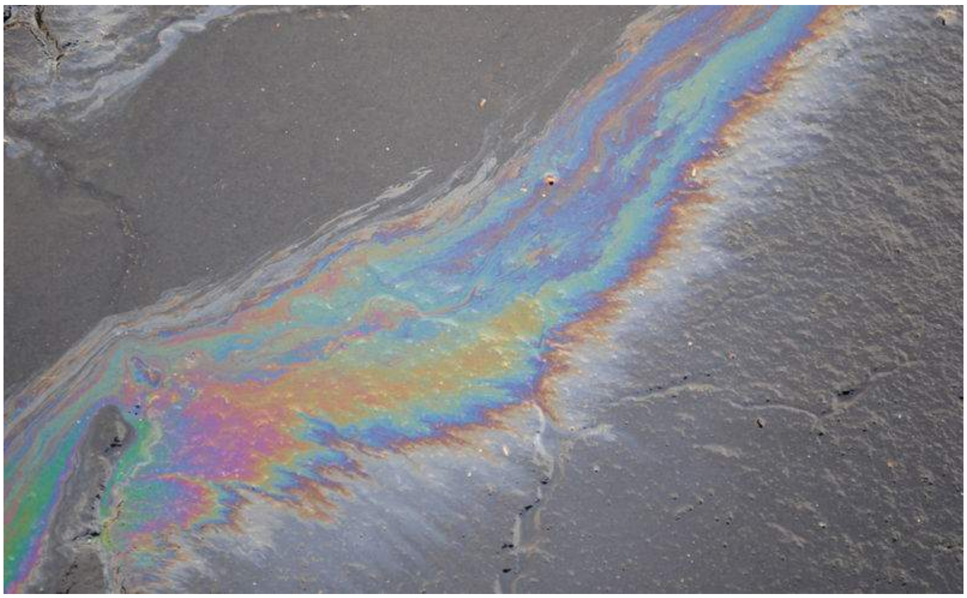
1. What do all organisms require?
2. What provides the energy required by the ecosystem?
3. How is energy transferred from one organism to another?
4. How is some of the energy lost?
5. How do nutrients move through and ecosystem?

Review

1. What does a food chain depict? Why do scientists usually use a food web instead of a food chain?
2. Start with the Sun and describe what happens to energy through the trophic levels. Why does this not go on forever (with many more trophic levels)?
3. What trophic level do you inhabit? Do all humans inhabit the same trophic level?

8.17 Non-Renewable Energy Resources

- Define nonrenewable resource.
- Identify nonrenewable energy resources.
- State drawbacks of using nonrenewable energy resources.



It may look beautiful, but this oil slick threatens the environment and living things. Unfortunately, oil spills are common because we rely heavily on oil as an energy resource. Oil is an example of a nonrenewable resource.

What Are Nonrenewable Resources?

Nonrenewable resources are natural resources that are limited in supply and cannot be replaced as quickly as they are used up. A natural resource is anything people can use that comes from nature. Energy resources are some of the most important natural resources because everything we do requires energy. Nonrenewable energy resources include fossil fuels such as oil and the radioactive element uranium.

Types of Fossil Fuels

Oil, or petroleum, is one of several **fossil fuels**. Fossil fuels are mixtures of hydrocarbons (compounds containing only hydrogen and carbon) that formed over millions of years from the remains of dead organisms. In addition to oil, they include coal and natural gas. Fossil fuels provide most of the energy used in the world today. They are burned in power plants to produce electrical energy, and they also fuel cars, heat homes, and supply energy for many other purposes. You can see some ways they are used in the **Figure** 8.56. For a more detailed introduction to fossil fuels, go to this URL: http://www.ecokids.ca/pub/eco_info/topics/energy/ecostats/index.cfm

Q: Why do fossil fuels have energy?

A: Fossil fuels contain stored chemical energy that came originally from the sun.

Natural gas burns with a blue flame on this gas range. Many homes also have natural gas water heaters and furnaces.

Gasoline, which is made from oil, is one of the most readily seen fossil fuels. Combustion engines in cars, planes, and boats use gasoline as fuel.

The majority of electric power in the U.S. is generated by burning coal in power plants like this one.

FIGURE 8.56

How Fossil Fuels Formed

When ancient plants underwent photosynthesis, they changed energy in sunlight to stored chemical energy in food. The plants used the food and so did the organisms that ate the plants. After the plants and other organisms died, their remains gradually changed to fossil fuels as they were covered and compressed by layers of sediments. Petroleum and natural gas formed from ocean organisms and are found together. Coal formed from giant tree ferns and other swamp plants.

Fossil Fuels and the Environment

When fossil fuels burn, they release thermal energy, water vapor, and carbon dioxide. The thermal energy can be used to generate electricity or do other work. The carbon dioxide is released into the atmosphere and is a major cause of global climate change. The burning of fossil fuels also releases many pollutants into the air. Pollutants such as sulfur dioxide form acid rain, which kills living things and damages metals, stonework, and other materials. Pollutants such as nitrogen oxides cause smog, which is harmful to human health. Tiny particles, or particulates, released when fossil fuels burn also harm human health.

The **Figure** 8.57 shows the amounts of pollutants released by different fossil fuels. Natural gas releases the least pollution; coal releases the most. Petroleum has the additional risk of oil spills, which may seriously damage ecosystems. To learn about other ways that our dependence on fossil fuels damages the environment and threatens human life, watch the video at this URL: http://coal.wiki.lovett.org/Home

Q: Some newer models of cars and other motor vehicles can run on natural gas. Why would a natural gas vehicle be better for the environment than a vehicle that burns gasoline, which is made from oil?

A: Natural gas produces much less pollution and carbon dioxide when it burns than gasoline does. So a natural gas vehicle would contribute less to global climate change, acid rain, and air pollution that harms health. Besides being better for the environment, burning natural gas instead of gasoline results in less engine wear and provides more energy for a given amount of fuel.

Nuclear Energy

Like fossil fuels, the radioactive element uranium can be used to generate electrical energy in power plants. This source of energy is known as **nuclear energy**. In a nuclear power plant, the nuclei of uranium atoms are split apart into smaller nuclei in the process of nuclear fission. This process releases a tremendous amount of energy from just a small amount of uranium. The total supply of uranium in the world is quite limited, however, and cannot be replaced once it is used up. That's why nuclear energy is a nonrenewable resource. The use of nuclear energy also produces dangerous radioactive wastes. In addition, accidents at nuclear power plants have the potential to release large amounts of harmful radiation into the environment.

Fossil Fuel Pollution Levels

Pounds per Billion Units of Energy

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0	0.007	0.016

FIGURE 8.57

Q: Why is nuclear energy often considered to be "greener" than energy from fossil fuels?

A: Unlike energy from fossil fuels, nuclear energy doesn't produce air pollution or carbon dioxide that contributes to global climate change.

Summary

- Nonrenewable resources are natural resources that are limited in supply and cannot be replaced as quickly as they are used up. Nonrenewable energy resources include fossil fuels and uranium.
- Fossil fuels—including oil, natural gas, and coal—provide most of the energy used in the world today. Burning fossil fuels produces air pollution as well as carbon dioxide that causes global climate change.
- Nuclear energy is produced by splitting the nuclei of radioactive uranium. This doesn't release air pollution or carbon dioxide, but it does produce dangerous radioactive wastes.

Vocabulary

- **fossil fuel**: Mixture of hydrocarbons that formed over millions of years from the remains of dead organisms (petroleum, natural gas, or coal).
- **natural resource**: Anything people can use that comes from nature.
- **nonrenewable resource**: Natural resource that is limited in supply and cannot be replaced except over millions of years.
- **nuclear energy**: Energy released in a nuclear reaction (nuclear fission or nuclear fusion).

Practice

At the following URL, do the word search puzzle for nonrenewable energy resources. http://www.softschools.com/science/words/games/word_search888.html

Review

1. Define natural resource. What are nonrenewable natural resources?
2. List four commonly used nonrenewable energy resources.
3. Explain how fossil fuels formed.
4. Compare and contrast the three types of fossil fuels in terms of the pollution they produce.
5. Present the pros and cons of nuclear energy use.

8.18 Coal Power

- Explain how coal forms and is used.
- Describe the environmental consequences of burning coal.

What was the foundation of the Industrial Revolution?

The Industrial Revolution was the change in society that resulted from people learning to use fossil fuels. By harnessing fossil fuels, work could be done more rapidly and more cheaply, allowing people to manufacture goods cheaply and efficiently.

Coal

Coal, a solid fossil fuel formed from the partially decomposed remains of ancient forests, is burned primarily to produce electricity. Coal use is undergoing enormous growth as the availability of oil and natural gas decreases and cost increases. This increase in coal use is happening particularly in developing nations, such as China, where coal is cheap and plentiful.

Coal is black or brownish-black. The most common form of coal is bituminous, a sedimentary rock that contains impurities such as sulfur (**Figure** 8.58). Anthracite coal has been metamorphosed and is nearly all carbon. For this reason, anthracite coal burns more cleanly than bituminous coal.

FIGURE 8.58
Bituminous coal is a sedimentary rock.

Coal Formation

Coal forms from dead plants that settled at the bottom of ancient swamps. Lush coal swamps were common in the tropics during the Carboniferous period, which took place more than 300 million years ago (**Figure** 8.59). The climate was warmer then.

Mud and other dead plants buried the organic material in the swamp, and burial kept oxygen away. When plants are buried without oxygen, the organic material can be preserved or fossilized. Sand and clay settling on top of the decaying plants squeezed out the water and other substances. Millions of years later, what remains is a carbon-containing rock that we know as coal.

Coal Use

Around the world, coal is the largest source of energy for electricity. The United States is rich in coal (**Figure** 8.60). California once had a number of small coal mines, but the state no longer produces coal. To turn coal into electricity, the rock is crushed into powder, which is then burned in a furnace that has a boiler. Like other fuels, coal releases its energy as heat when it burns. Heat from the burning coal boils the water in the boiler to make steam. The steam spins turbines, which turn generators to create electricity. In this way, the energy stored in the coal is converted to useful energy like electricity.

Consequences of Coal Use

For coal to be used as an energy source, it must first be mined. Coal mining occurs at the surface or underground by methods that are described in the the chapter Materials of Earth's Crust (**Figure** 8.61). Mining, especially

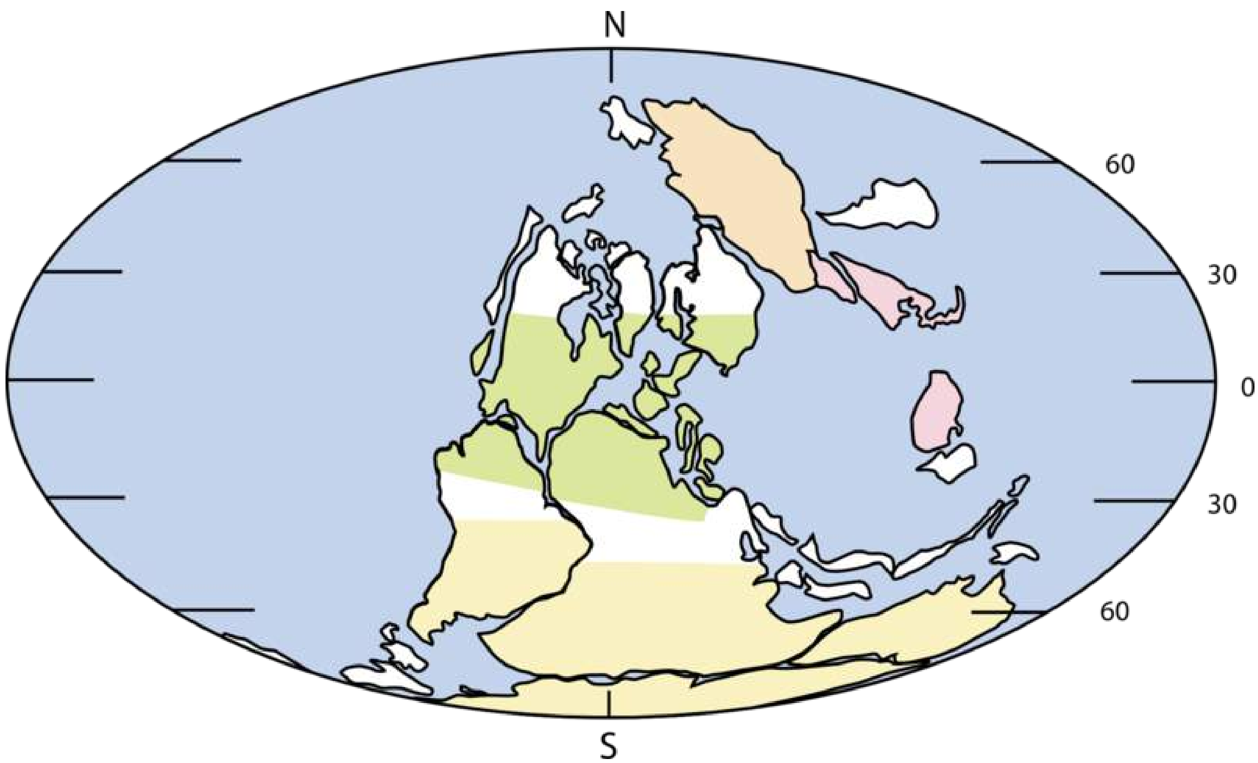


FIGURE 8.59

The location of the continents during the Carboniferous period. Notice that quite a lot of land area is in the region of the tropics.

underground mining, can be dangerous. In April 2010, 29 miners were killed at a West Virginia coal mine when gas that had accumulated in the mine tunnels exploded and started a fire.

Coal mining exposes minerals and rocks from underground to air and water at the surface. Many of these minerals contain the element sulfur, which mixes with air and water to make sulfuric acid, a highly corrosive chemical. If the sulfuric acid gets into streams, it can kill fish, plants, and animals that live in or near the water.

Summary

- Coal is solid fossil fuels formed primarily from ancient swamp plants, especially during the Carboniferous.
- Coal is the source of most electricity.
- Coal mining may bring dangerous materials into the air and coal burning is sometimes quite dirty.

Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/how-do-they-do-it-coal-mining.html

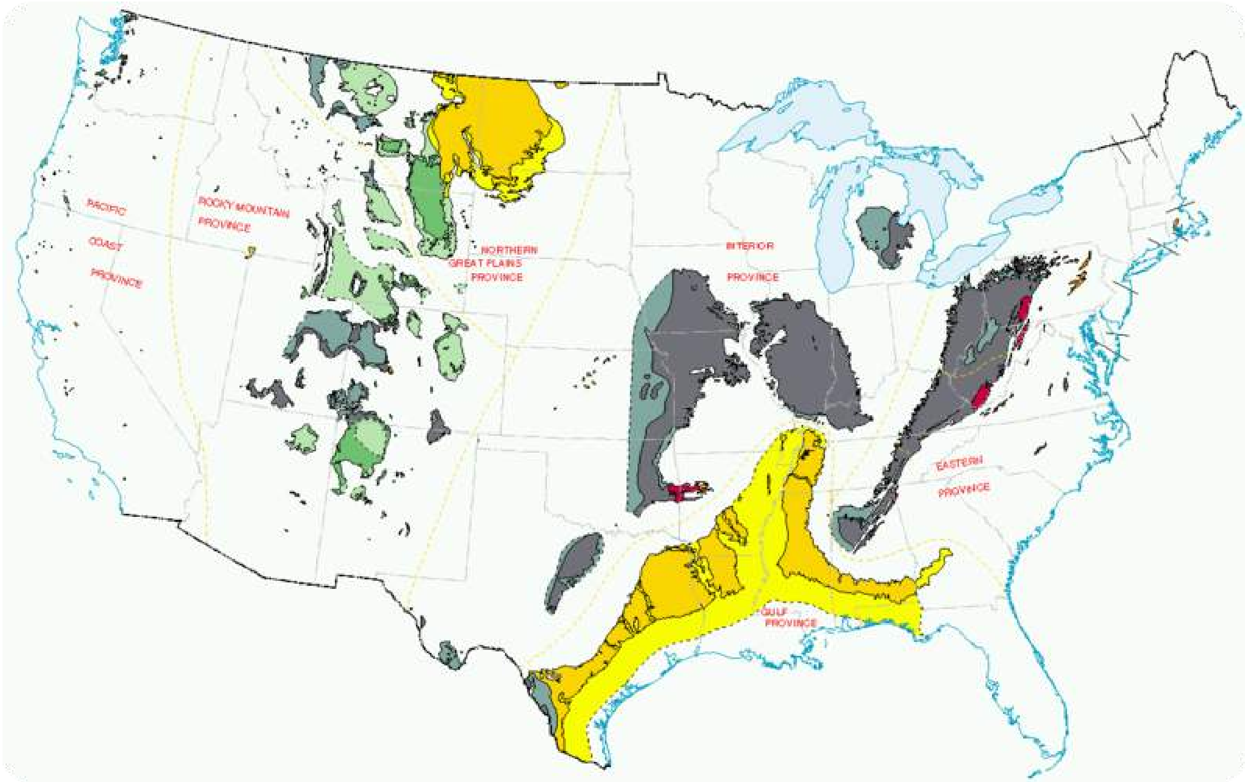


FIGURE 8.60

United States coal-producing regions in 1996. Orange is highest grade anthracite; red is low volatile bituminous; gray and gray-green is medium to high-volatile bituminous; green is subbituminous; and yellow is the lowest grade lignite.

MEDIA

Click image to the left for more content.

1. How much electricity is produced from coal?
2. Where is the largest underground coal mining complex?
3. How much coal does it produce?
4. How long have they been mining at this site?
5. What is a continuous miner?
6. How is the coal processed?
7. What waste is produced?
8. How quickly is the coal processed?

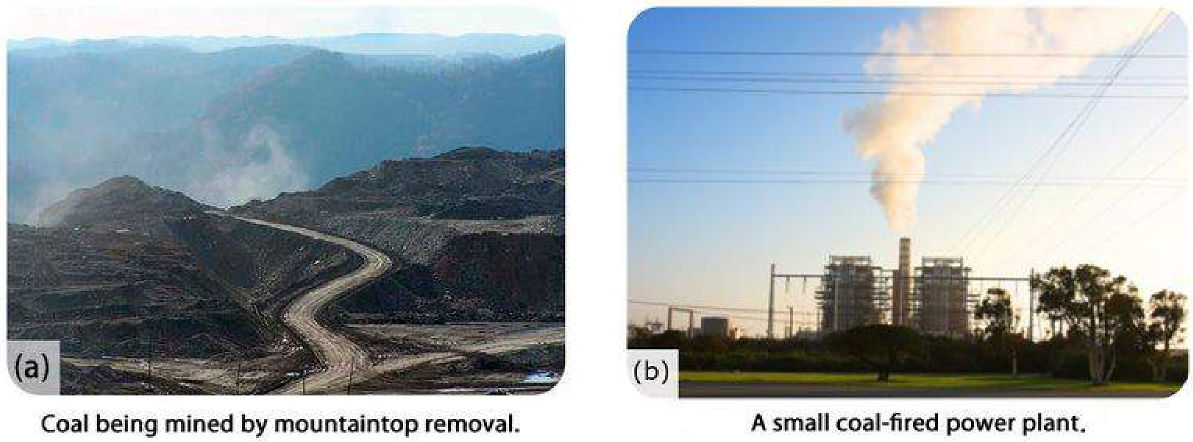


FIGURE 8.61
The coal used in power plants must be mined. One method to mine coal is by mountaintop removal.

Review

1. How does coal form?
2. There are swamps today. Why is coal not a renewable resource?
3. What are some of the environmental consequences of coal use?

8.19 Petroleum Power

- Explain how petroleum forms and is used.
- Describe the environmental consequences of petroleum use.

What is the connection between ancient organisms and the Indy 500?

Many forms of fun and transportation are made possible by liquid petroleum. Petroleum is the result of ancient plankton or plants dying in a sea.

Oil

Oil is a liquid fossil fuel that is extremely useful because it can be transported easily and can be used in cars and other vehicles. Oil is currently the single largest source of energy in the world.

Oil Formation

Oil from the ground is called **crude oil**, which is a mixture of many different hydrocarbons. Crude oil is a thick dark brown or black liquid hydrocarbon. Oil also forms from buried dead organisms, but these are tiny organisms that live on the sea surface and then sink to the seafloor when they die. The dead organisms are kept away from oxygen by layers of other dead creatures and sediments. As the layers pile up, heat and pressure increase. Over millions of years, the dead organisms turn into liquid oil.

Oil Production

In order to be collected, the oil must be located between a porous rock layer and an impermeable layer (**Figure** 8.62). Trapped above the porous rock layer and beneath the impermeable layer, the oil will remain between these layers until it is extracted from the rock.

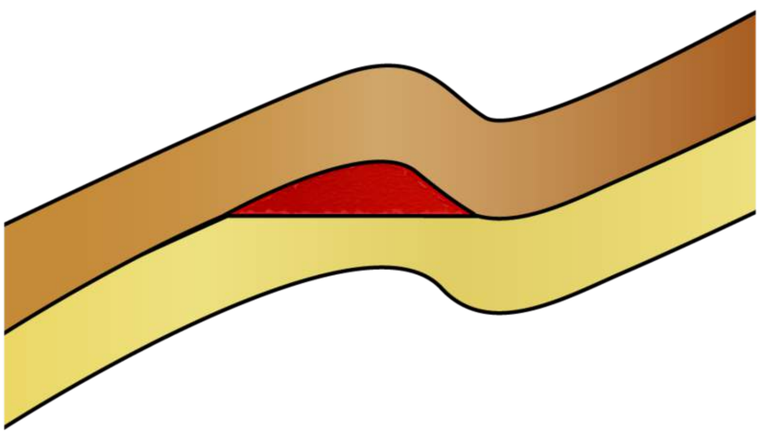


FIGURE 8.62
Oil (red) is found in the porous rock layer (yellow) and trapped by the impermeable layer (brown). The folded structure has allowed the oil to pool so a well can be drilled into the reservoir.

- An animation of an oil deposit forming is shown here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/ENTRAP_3.MPG .
- The oil pocket is then drilled into from the surface. An animation of an oil deposit being drilled is shown here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/DRILL_3.MPG .
- Sideways drilling allows a deposit that lies beneath land that cannot be drilled to be mined for oil: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/HORDRI_3.MPG .

To separate the different types of hydrocarbons in crude oil for different uses, the crude oil must be refined in refineries like the one shown in **Figure** 8.63. Refining is possible because each hydrocarbon in crude oil boils at a different temperature. When the oil is boiled in the refinery, separate equipment collects the different compounds.

Oil Use

Most of the compounds that come out of the refining process are fuels, such as gasoline, diesel, and heating oil. Because these fuels are rich sources of energy and can be easily transported, oil provides about 90% of the energy used for transportation around the world. The rest of the compounds from crude oil are used for waxes, plastics, fertilizers, and other products.

Gasoline is in a convenient form for use in cars and other transportation vehicles. In a car engine, the burned gasoline mostly turns into carbon dioxide and water vapor. The fuel releases most of its energy as heat, which causes the gases to expand. This creates enough force to move the pistons inside the engine and to power the car.

FIGURE 8.63
Refineries like this one separate crude oil into many useful fuels and other chemicals.

Consequences of Oil Use

The United States does produce oil, but the amount produced is only about one-quarter as much as the nation uses. The United States has only about 1.5% of the world's proven oil reserves, so most of the oil used by Americans must be imported from other nations.

The main oil-producing regions in the United States are the Gulf of Mexico, Texas, Alaska, and California (**Figure** 8.64). An animation of the location of petroleum basins in the contiguous United States can be seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/BASINS_3.MPG .

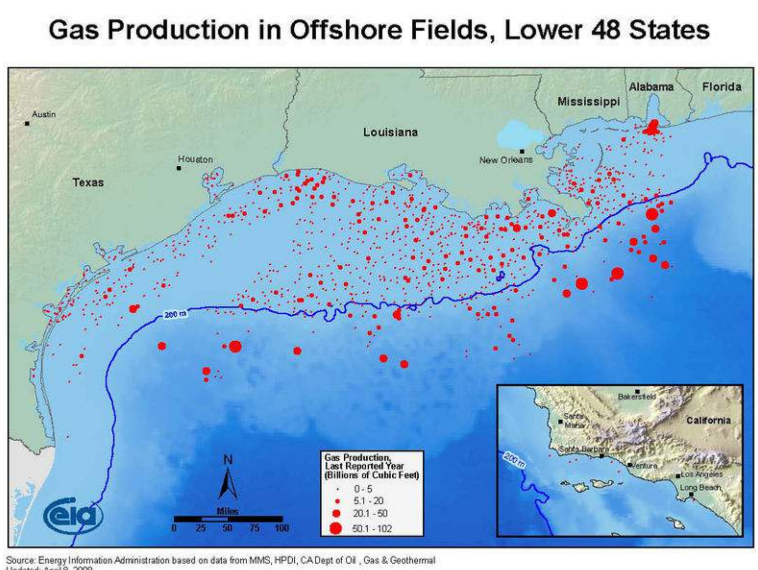


FIGURE 8.64
Offshore well locations in the Gulf of Mexico. Note that some wells are located in very deep water.

As in every type of mining, mining for oil has environmental consequences. Oil rigs are unsightly (**Figure** 8.65), and spills are too common (**Figure** 8.66).

FIGURE 8.65
Drill rigs at the San Ardo Oil Field in Monterey, California.

FIGURE 8.66
A deadly explosion on an oil rig in the Gulf of Mexico in April 2010 led to a massive oil spill. When this picture was taken in July 2010, oil was still spewing into the Gulf. The long-term consequences of the spill are being studied and are as yet unknown.

Summary

- Liquid fossil fuels include petroleum, which is useful for vehicles because it is easily stored and transported.
- Petroleum is also extremely important for materials like waxes, plastics, fertilizers, and other products.
- Extracting petroleum from the ground and transporting it can be damaging to the environment.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=rgrUwPWjj2Q

MEDIA
Click image to the left for more content.

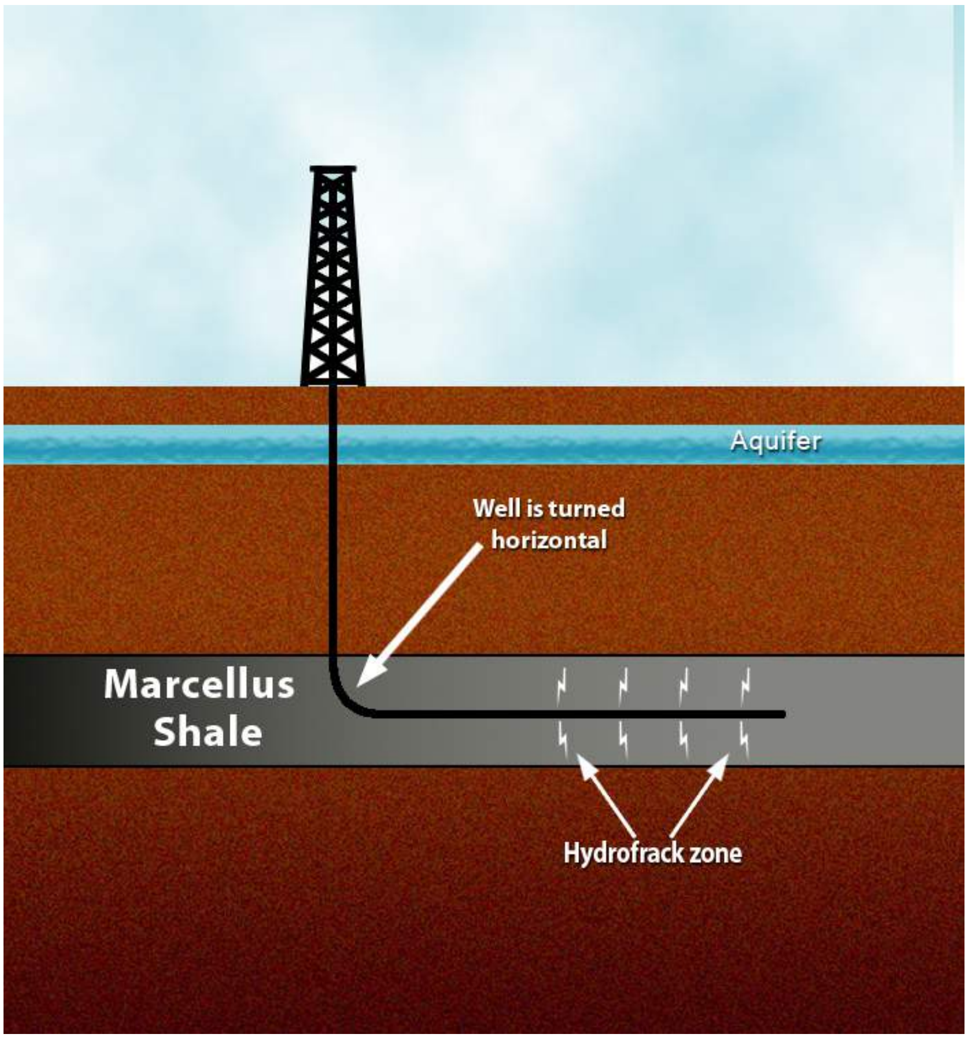
1. What produced the fossil fuels?
2. What is sediment?
3. What is kerogen? How is it produced?
4. How do we find oil?
5. How do we get the oil out of the ground?
6. Why is drilling mud pumped down the pipe?
7. What are cuttings?
8. What does the pumping unit do?
9. What happens at the refinery?
10. What does fractional distillation produce?
11. What are petrochemicals used for?
12. What other products are made from oil?

Review

1. Why is it harder to find a substitute for petroleum than it is for coal? Think about what these fuels are used for.
2. Why are there more likely to be hazardous consequences for deep oil drilling than for the shallow drilling that's been taking place for centuries?
3. How is crude oil formed?

8.20 Natural Gas Power

- Explain how natural gas forms and is used.
- Describe the consequences of natural gas extraction.



What caused the recent earthquakes in Ohio and Oklahoma?

The process of extracting natural gas, known as fracking, injects liquid waste into deep wells. Coincidentally, locations where seismic activity is virtually unknown have begun to experience earthquakes. Is fracking related to earthquake activity? Many geologists think the link is undeniable.

Natural Gas

Natural gas, often known simply as gas, is composed mostly of the hydrocarbon methane. The amount of natural gas being extracted and used in the Untied States is increasing rapidly.

Natural Gas Formation

Natural gas forms under the same conditions that create oil. Organic material buried in the sediments harden to become a shale formation that is the source of the gas. Although natural gas forms at higher temperatures than crude oil, the two are often found together.

The formation of an oil and gas deposit that can be mined is seen in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/PETSYS_3.MPG .

The largest natural gas reserves in the United States are in the Appalachian Basin, North Dakota and Montana, Texas, and the Gulf of Mexico region (**Figure** 8.67). California also has natural gas, found mostly in the Central Valley. In the northern Sacramento Valley and the Sacramento Delta, a sediment-filled trough formed along a location where crust was pushed together (an ancient convergent margin).

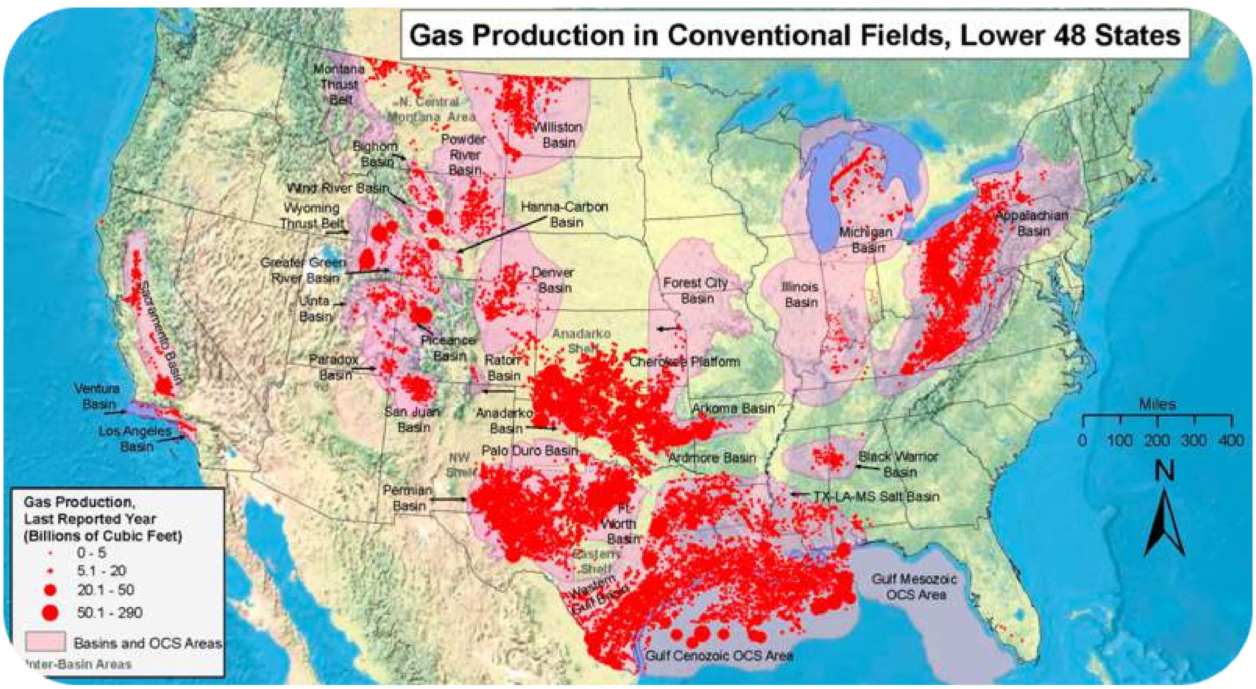


FIGURE 8.67
Gas production in the lower 48 United States.

- An animation of global natural gas reserves is seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/GLOBE_3.MPG .

Natural Gas Use

Like crude oil, natural gas must be processed before it can be used as a fuel. Some of the chemicals in unprocessed natural gas are poisonous to humans. Other chemicals, such as water, make the gas less useful as a fuel. Processing natural gas removes almost everything except the methane. Once the gas is processed, it is ready to be delivered and used. Natural gas is delivered to homes for uses such as cooking and heating. Like coal and oil, natural gas is also burned to generate heat for powering turbines. The spinning turbines turn generators, and the generators create electricity.

Consequences of Natural Gas Use

Natural gas burns much cleaner than other fossil fuels, meaning that it causes less air pollution. Natural gas also produces less carbon dioxide than other fossil fuels do for the same amount of energy, so its global warming effects are less (**Figure** 8.68).

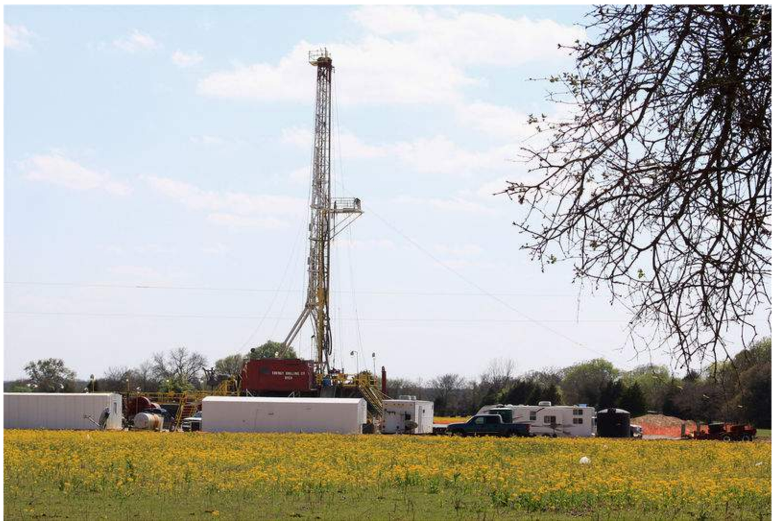


FIGURE 8.68
A natural gas drill rig in Texas.

- See the pollution created by a car burning gasoline and a car burning natural gas in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/GASPOL_3.MPG .

Unfortunately, drilling for natural gas can be environmentally destructive. One technique used is hydraulic fracturing, also called **fracking**, which increases the rate of recovery of natural gas. Fluids are pumped through a borehole to create fractures in the reservoir rock that contains the natural gas. Material is added to the fluid to prevent the fractures from closing. The damage comes primarily from chemicals in the fracturing fluids. Chemicals that have been found in the fluids may be carcinogens (cancer-causing), radioactive materials, or endocrine disruptors, which interrupt hormones in the bodies of humans and animals. The fluids may get into groundwater or may runoff into streams and other surface waters. As noted above, fracking may cause earthquakes.

Summary

- Natural gas forms with crude oil but at higher temperatures.
- Natural gas burns more cleanly than petroleum and produces fewer greenhouse gases.
- Hydraulic fracturing, known as fracking, is a relatively new method for extracting natural gas, which may be linked to groundwater contamination and the generation of small earthquakes in non-seismic regions.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=zmAwkYLEV80

MEDIA
Click image to the left for more content.

1. What is fracking?
2. Explain how natural gas is extracted.
3. What used to cause additional fracking?
4. What is the concern with fracking?
5. What law is the gas company exempted from?

Review

1. You'll be hearing a lot about fracking in the coming years. What is it and how does it work?
2. How is natural gas different from crude oil and how does it form differently?
3. Why is natural gas considered more environmentally sound than other fossil fuels?

8.21 Fossil Fuel Reserves

- Describe the limitations of traditional and alternative fossil fuels.

How much is left?

The answer to that question depends on what we as a society are willing to do to get fossil fuels. How much are we willing to damage the environment to extract and transport fossil fuels? How much are we willing to raise atmospheric greenhouse gas levels and further alter climate? The Keystone Pipeline would bring crude oil from tar sands to the U.S., but for the time being, that project is on hold.

Fossil Fuel Reserves

Fossil fuels provide about 85% of the world's energy at this time. Worldwide fossil fuel usage has increased many times over in the past half century (coal –2.6x, oil –8x, natural gas –14x) because of population increases, because of increases in the number of cars, televisions, and other fuel-consuming uses in the developed world, and because of lifestyle improvements in the developing world.

- Past and predicted use of different types of energy in the United States can be seen in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/MAXGAS_3.MPG .

The amount of fossil fuels that remain untapped is unknown, but can likely be measured in decades for oil and natural gas and in a few centuries for coal (**Figure** 8.69).

Alternative Fossil Fuels

As the easy-to-reach fossil fuel sources are depleted, alternative sources of fossil fuels are increasingly being exploited (**Figure** 8.70). These include oil shale and tar sands. **Oil shale** is rock that contains dispersed oil that has not collected in reservoirs. To extract the oil from the shale requires enormous amounts of hot water. **Tar sands** are rocky materials mixed with very thick oil. The tar is too thick to pump and so tar sands are strip-mined. Hot water and caustic soda are used to separate the oil from the rock.

The environmental consequences of mining these fuels, and of fossil fuel use in general, along with the fact that these fuels do not have a limitless supply, are prompting the development of alternative energy sources in some regions.

Summary

- Easy to get at fossil fuels are running out, but there are other sources that are harder to get at that are still available.

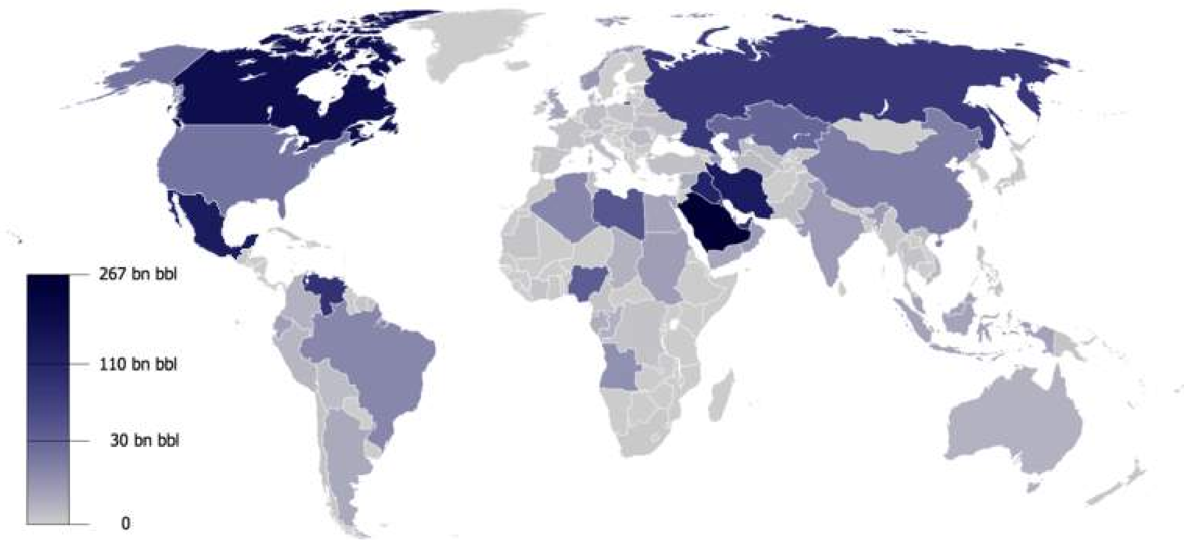


FIGURE 8.69
Worldwide oil reserves.

FIGURE 8.70
A satellite image of an oil-sands mine in Canada.

- Oil shales and tar sands are two of the alternative sources of fossil fuels that are much in the news.
- The need for fossil fuels continues to grow as people in the developed work use more and more people in the developing world want them.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=6MJQOyeRvBc

MEDIA

Click image to the left for more content.

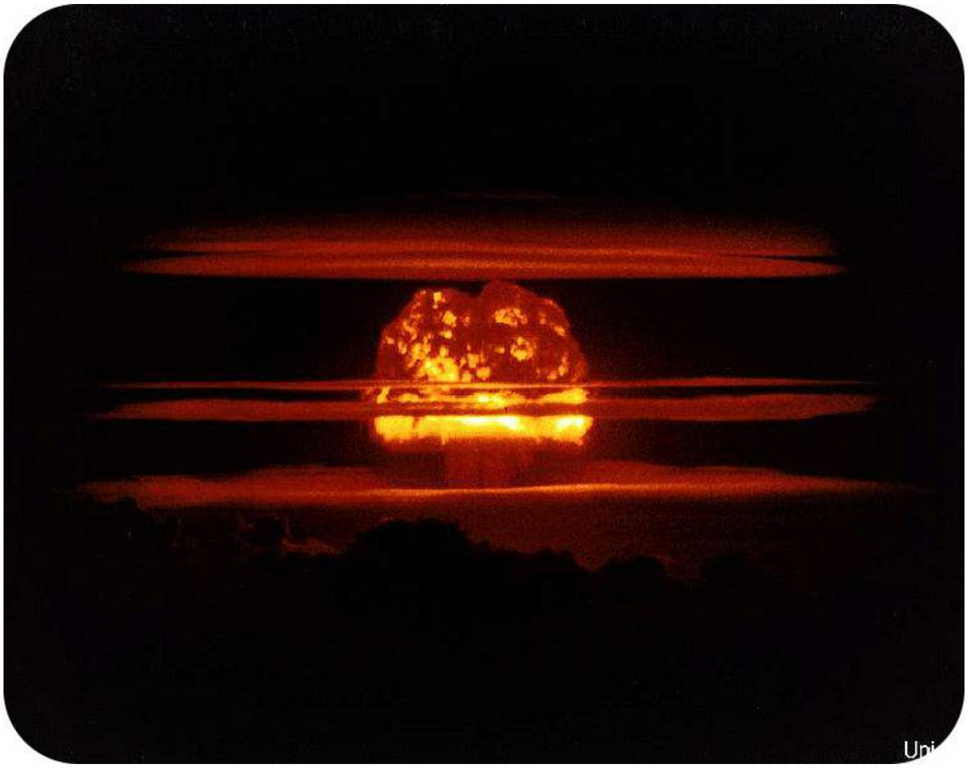
1. How much oil shale is there in the United States?
2. Hoe much oil can be produced from oil shale?
3. Where is the Green River Formation?
4. What is oil shale?
5. How many barrels does OSEC plan to produce each day?

Review

1. What are oil shales and tar sands?
2. How do scientists and politicians determine how much fossil fuel is left? Why is this number undoubtedly inaccurate?
3. Why is the need for fossil fuels increasing?

8.22 Nuclear Power

- Explain how nuclear energy is harnessed and used, and describe its consequences.



What does an atomic bomb have to do with energy generation?

Splitting atoms releases enormous amounts of energy. To be useful rather than destructive, nuclear power plants must be safeguarded, but this attempt is not always successful.

Nuclear Energy

When the nucleus of an atom is split, it releases a huge amount of energy called **nuclear energy**. For nuclear energy to be used as a power source, scientists and engineers have learned to split nuclei and to control the release of energy (**Figure** 8.71).

Nuclear Energy Use

Nuclear power plants, such as the one seen in **Figure** 8.72, use uranium, which is mined, processed, and then concentrated into fuel rods. When the uranium atoms in the fuel rods are hit by other extremely tiny particles, they split apart. The number of tiny particles allowed to hit the fuel rods needs to be controlled, or they would cause a dangerous explosion. The energy from a nuclear power plant heats water, which creates steam and causes a turbine to spin. The spinning turbine turns a generator, which in turn produces electricity.

Many countries around the world use nuclear energy as a source of electricity. In the United States, a little less than 20% of electricity comes from nuclear energy.

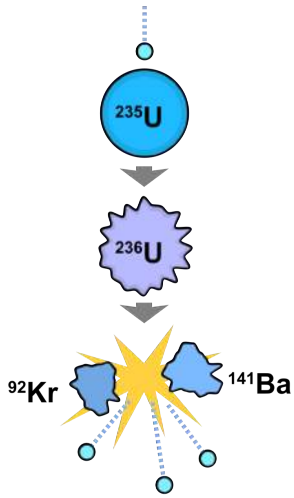


FIGURE 8.71
When struck by a tiny particle, Uranium-235 breaks apart and releases energy.

FIGURE 8.72
Nuclear power plants like this one provide France with almost 80% of its electricity.

Consequences of Nuclear Power

Nuclear power is clean. It does not pollute the air. However, the use of nuclear energy does create other environmental problems. Uranium must be mined (**Figure** 8.73). The process of splitting atoms creates radioactive waste, which remains dangerous for thousands or hundreds of thousands of years. As yet, there is no long-term solution for storing this waste.

The development of nuclear power plants has been on hold for three decades. Accidents at Three Mile Island and Chernobyl, Ukraine verified people's worst fears about the dangers of harnessing nuclear power (**Figure** 8.74).

Recently, nuclear power appeared to be making a comeback as society looked for alternatives to fossil fuels. After all, nuclear power emits no pollutants, including no greenhouse gases. But the 2011 disaster at the Fukushima Daiichi Nuclear Power Plant in Japan may have resulted in a new fear of nuclear power. The cause of the disaster was a 9.0 magnitude earthquake and subsequent tsunami, which compromised the plant. Although a total meltdown was averted, the plant experienced multiple partial meltdowns, core breaches, radiation releases, and cooling failures. The plant is scheduled for a complete cold shutdown before the end of 2011.

FIGURE 8.73
Uranium mine in Kakadu National Park, Australia.

FIGURE 8.74
Damaged building near the site of the Chernobyl disaster.

Nuclear power is a controversial subject in California and most other places. Nuclear power has no pollutants including carbon emissions, but power plants are not always safe and the long-term disposal of wastes is a problem that has not yet been solved. The future of nuclear power is murky.

Find out more at http://science.kqed.org/quest/audio/new-nuclear/.

MEDIA
Click image to the left for more content.

Summary

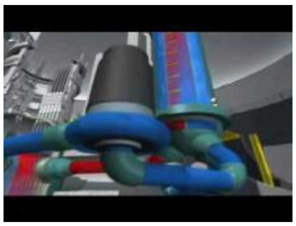
- Nuclear energy is released when the nucleus of an atom is split.
- Nuclear power plants use uranium in fuel rods, which later become nuclear waste. Nuclear waste can be dangerous for hundreds of thousands of years.

- Periodic accidents involving nuclear power plants seem to slow down the development of nuclear power in many countries.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=VJfIbBDR3e8



MEDIA

Click image to the left for more content.

1. How many countries use nuclear power?
2. What is used to produce the electricity in the power plant?
3. What releases the heat in nuclear plants?
4. What is used as the fuel?
5. What are the two types of reactors?
6. What is the function of the control rods?

Review

1. How is nuclear energy generated?
2. Since the waste from nuclear power plants is dangerous for up to hundreds of thousands of years, how do you think it should be safeguarded?
3. Do you think that the nuclear disaster in Japan in 2011 should affect how nations develop or choose not to develop their nuclear resources? What about nations that are not near a subduction zone?

8.23 Renewable Energy Resources

- Define renewable resource.
- Describe several renewable energy resources.

Acre upon acre of wind turbines stretch over the landscape in this photo. The blades of the turbines spin in the wind like giant pinwheels. The energy of the moving blades is used to generate useful electrical energy. Wind is one of several renewable energy resources.

Q: What are some other renewable energy resources?

A: You can read about the major renewable energy resources in this article. But here's a hint in advance. Renewable energy resources include mechanical, electromagnetic, chemical, and thermal forms of energy.

What Are Renewable Resources?

Renewable resources are natural resources that can be replaced in a relatively short period of time or are virtually limitless in supply. In addition to wind, renewable energy resources include sunlight, moving water, biomass, and geothermal energy. All of these resources are freely available and won't run out. Most of them also have the advantage of producing little if any pollution or carbon dioxide, which contributes to global climate change. Nonetheless, these energy resources are used far less than nonrenewable energy resources, especially fossil fuels. You can see where renewable energy resources are used in the U.S., as well as learn more about them, at this URL: http://www.nationalatlas.gov/articles/people/a_energy.html

Wind

Wind is moving air, so it has mechanical energy that can do work. People have been using wind for energy for thousands of years. The old-fashioned windmill in the **Figure** 8.75 is one way that wind energy can be used. The wind turbines in the opening photo above are a much newer way of using wind energy. They change the kinetic energy of the wind to electrical energy. However, only certain areas of the world get enough steady wind to produce much electricity. Many people also think that wind turbines are noisy, dangerous to birds, and unattractive in the landscape. At the URL below, you can watch a video about the development of wind energy in China, which aims to become a world leader in renewable energy production.

http://www.guardian.co.uk/world/2012/mar/19/china-windfarms-renewable-energy

FIGURE 8.75
This old windmill uses wind energy to operate a mechanical pump that lifts water out of a well. Windmills like this one have been used for centuries.

Q: Where does the energy of the wind come from? Why does air move in the atmosphere?

A: Wind is caused by unequal heating of the atmosphere by the sun. In other words, differences in thermal energy cause air to move in the atmosphere.

Sunlight

The sunlight that reaches Earth is the planet's most important source of energy. The energy in sunlight, called solar energy, is electromagnetic energy. This is a form of energy that travels through space in electric and magnetic waves. Solar energy can be used to heat homes and produce electricity in solar cells like those on the roof seen in the **Figure** 8.76. Sunny areas receive plenty of sunlight to generate electricity, but solar energy may not be practical in areas that are often cloudy.

Q: In addition to the roofs of homes and other buildings, where else can you find solar cells?

A: Calculators often have solar cells. Solar-powered outdoor lights are very common as well.

Moving Water

The mechanical energy of rapidly flowing water can turn a turbine and generate electricity. Electricity produced in this way is called hydroelectric power. The water may flow over a waterfall or through a dam. You can see a picture of a dam in the **Figure** 8.77. A drawback of dams is that they flood land upstream from the dam and reduce water flow downstream from the dam, and this can destroy ecosystems. At the following URL, you can learn more about

FIGURE 8.76
Solar panels on the roof of this family home generate enough electricity to supply the family's needs.

hydroelectric power and see an animation of a hydroelectric power plant.

http://ga.water.usgs.gov/edu/hyhowworks.html

FIGURE 8.77
This is Hoover dam on the Colorado River between Arizona and Nevada. Water flowing through the dam generates electricity for both of these states and southern California.

Q: Does a hydroelectric power plant release air pollution or carbon dioxide? Why or why not.

A: No, it is doesn't. A hydroelectric plant doesn't burn fuel, which is what produces air pollution in power plants that generate electricity from fossil fuels or biomass.

Biomass

The stored chemical energy in organic matter or wastes is called biomass energy. The organic matter may be trees or other plants, or it may be wastes from homes and industries. When biomass is burned, it produces thermal energy that can be used for heating homes, cooking, or generating electricity. Biomass—especially wood—is an important energy source in the poorer nations where most people can't afford fossil fuels. However, burning biomass releases air pollution and contributes to global climate change. Biomass can be used to make ethanol, a fuel that is added to gasoline. Although ethanol releases less pollution than gasoline, large areas of land are needed to grow the plants needed to make it (see **Figure** 8.78). This reduces the amount of land available for food production.

FIGURE 8.78
This large machine is harvesting and grinding plants to make ethanol.

Geothermal Energy

Geothermal energy is thermal ("heat") energy from below Earth's surface. It can be used to heat homes or generate electricity. A geothermal system pumps water underground where it is heated and then pumps the warm water back to the home or power plant (see **Figure** 8.79). The thermal energy of the water can be used directly to heat the home. Or it can be used to produce steam and generate electricity. Installing a geothermal system can be expensive because of the need to drill through underground rocks, but the energy it uses is free.

FIGURE 8.79
This power plant uses geothermal energy.

Summary

- Renewable resources are natural resources that can be replaced in a relatively short period of time or are virtually limitless in supply.
- Renewable energy resources include wind, sunlight, moving water, biomass, and geothermal energy. Except for biomass, which is burned, these renewable energy resources produce little if any pollution, although each has other drawbacks.

Vocabulary

- **renewable resource**: Natural resource that can be replaced in a relatively short period of time or is virtually limitless in supply.

Practice

At the following URL, play the renewable energy resources vocabulary game. Be sure to read the definition of each renewable energy resource.

http://www.neok12.com/vocabulary/Energy-Sources-02.htm

Review

1. What is a renewable resource?
2. List five renewable energy sources. What form of energy does each resource supply?
3. Choose one of the five renewable energy resources described in this article, and do a Web quest to learn more about it. Start you search at the URL below. Based on your research, make a list of main points about the energy source you chose. http://www.aresearchguide.com/energy.html

8.24 Solar Power

- Explain how solar energy is collected and used.

Since so much of the energy we use came ultimately from the Sun, why don't we just get our power directly from the Sun?

That's a good question. Can you answer it?

Solar Energy

Energy from the Sun comes from the lightest element, hydrogen, fusing together to create the second lightest element, helium. Nuclear fusion on the Sun releases tremendous amounts of solar energy. The energy travels to the Earth, mostly as visible light. The light carries the energy through the empty space between the Sun and the Earth as **radiation**.

Solar Power Use

Solar energy has been used for power on a small scale for hundreds of years, and plants have used it for billions of years. Unlike energy from fossil fuels, which almost always come from a central power plant or refinery, solar power can be harnessed locally (**Figure** 8.80). A set of solar panels on a home's rooftop can be used to heat water for a swimming pool or can provide electricity to the house.

Society's use of solar power on a larger scale is just starting to increase. Scientists and engineers have very active, ongoing research into new ways to harness energy from the Sun more efficiently. Because of the tremendous amount of incoming sunlight, solar power is being developed in the United States in southeastern California, Nevada, and Arizona.

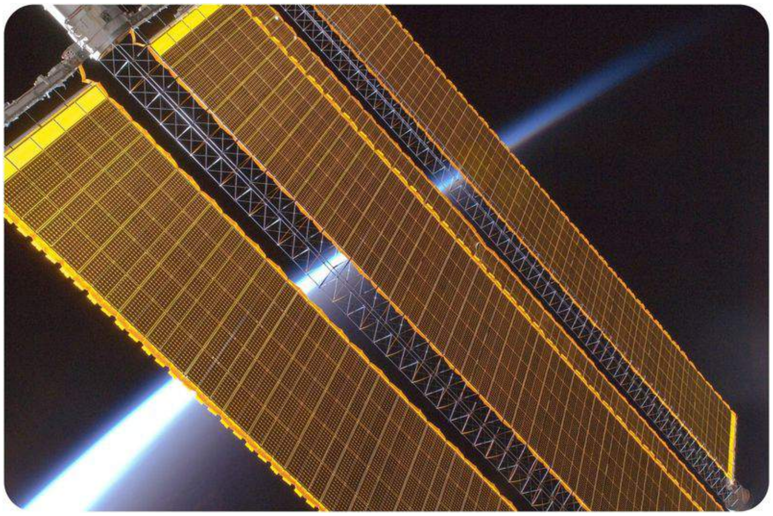


FIGURE 8.80
Solar panels supply power to the International Space Station.

Solar power plants turn sunlight into electricity using a large group of mirrors to focus sunlight on one place, called a receiver (**Figure** 8.81). A liquid, such as oil or water, flows through this receiver and is heated to a high temperature by the focused sunlight. The heated liquid transfers its heat to a nearby object that is at a lower temperature through a process called **conduction**. The energy conducted by the heated liquid is used to make electricity.

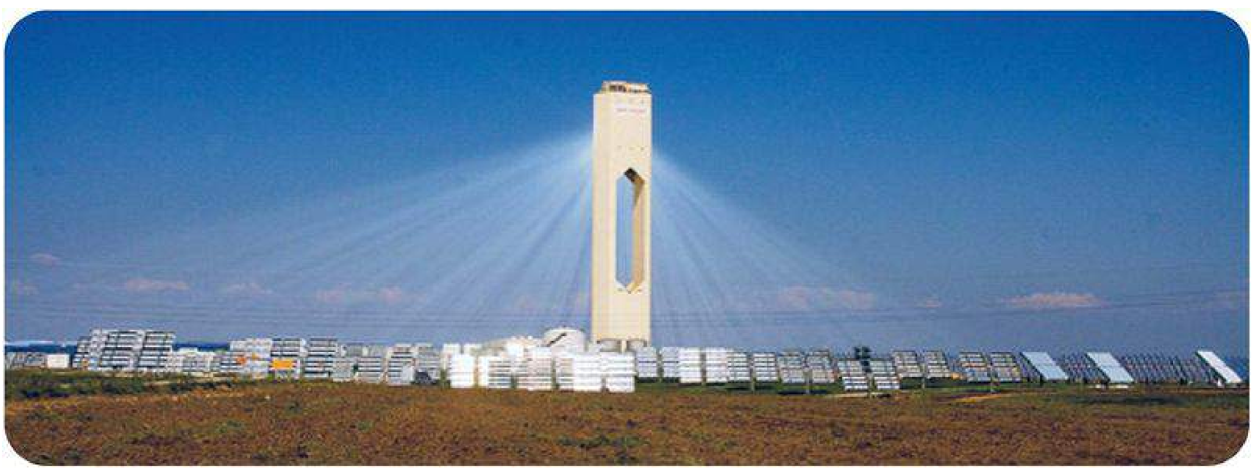


FIGURE 8.81
This solar power plant uses mirrors to focus sunlight on the tower in the center. The sunlight heats a liquid inside the tower to a very high temperature, producing energy to make electricity.

A video of how solar energy can be concentrated so that it can be used for power: http://www1.eere.energy.gov/multimedia/video_csp.html .

Consequences of Solar Power Use

Solar energy has many benefits. It is extremely abundant, widespread, and will never run out. But there are problems with the widespread use of solar power.

- Sunlight must be present. Solar power is not useful in locations that are often cloudy or dark. However, storage technology is being developed.
- The technology needed for solar power is still expensive. An increase in interested customers will provide incentive for companies to research and develop new technologies and to figure out how to mass-produce existing technologies (**Figure** 8.82).
- Solar panels require a lot of space. Fortunately, solar panels can be placed on any rooftop to supply at least some of the power required for a home or business.

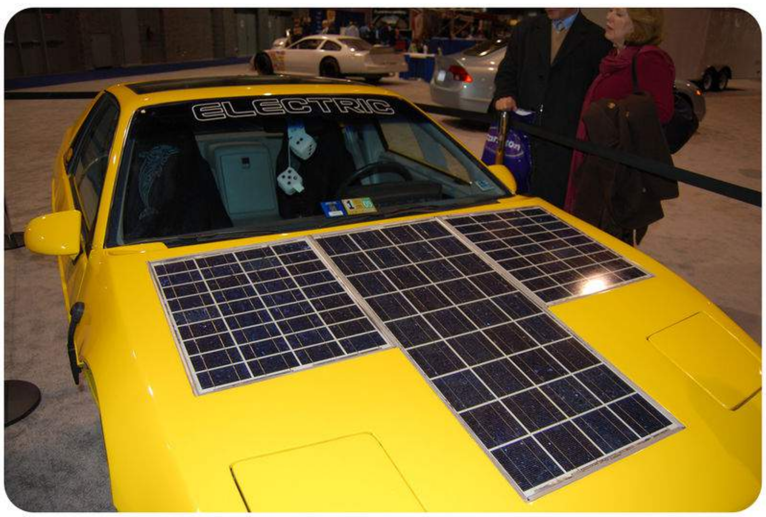


FIGURE 8.82
This experimental car is one example of the many uses that engineers have found for solar energy.

Summary

- Solar energy is the result of nuclear fusion in our nearest star.
- A liquid is heated and moves that energy by conduction.
- Solar power is expensive, but as demand increases technology improves and costs decrease.

Practice

Use this resource to answer the questions that follow.

https://www.eeremultimedia.energy.gov/solar/videos/solar_power_basics

1. What does solar power do for the planet?

2. What is diffuse light?

3. Explain passive solar heating.

4. What is solar thermal energy used for?

5. Explain how concentrating solar power works.

6. How do photovoltaic panels work?

7. What are the advantages of photovoltaic panels?
8. List the advantages to using solar power.

Review

1. How is solar power collected on a large scale?
2. What are some of the downsides of depending on solar energy?
3. What are some of the positive sides of using solar energy?

8.25 Wind Power

- Explain how wind energy is harnessed and used, and describe its consequences.

What does "NIMBY" stand for?

Not in my backyard. As much as any type of power source, wind power pits people who are concerned about the environment against, well, people who are concerned about the environment. Some people want the benefits of clean wind power but don't want the turbines in their vicinity.

Wind Energy

Energy from the Sun also creates wind, which can be used as wind power. The Sun heats different locations on Earth by different amounts. Air that becomes warm rises and then sucks cooler air into that spot. The movement of air from one spot to another along the ground creates wind. Since wind is moving, it has kinetic energy.

Wind power is the fastest growing renewable energy source in the world. Windmills are now seen in many locations, either individually or, more commonly, in large fields.

"Wind Powering America" follows the development of wind power in the United States over the past several years: http://www.windpoweringamerica.gov/wind_installed_capacity.asp .

Wind Power Use

Wind is the source of energy for wind power. Wind has been used for power for centuries. For example, windmills were used to grind grain and pump water. Sailing ships traveled by wind power long before ships were powered by fossil fuels. Wind can be used to generate electricity, as the moving air spins a turbine to create electricity (**Figure** 8.83).

FIGURE 8.83
Wind turbines like the ones shown here turn wind into electricity without creating pollution.

This animation shows how wind power works: http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10501 .

Consequences of Wind Power

Wind power has many advantages. It does not burn, so it does not release pollution or carbon dioxide. Also, wind is plentiful in many places. Wind, however, does not blow all of the time, even though power is needed all of the time. Just as with solar power, engineers are working on technologies that can store wind power for later use.

Windmills are expensive and wear out quickly. A lot of windmills are needed to power a region, so nearby residents may complain about the loss of a nice view if a wind farm is built. Coastlines typically receive a lot of wind, but wind farms built near beaches may cause unhappiness for local residents and tourists.

The Cape Wind project off of Cape Cod, Massachusetts has been approved but is generating much controversy. Opponents are in favor of green power but not at that location. Proponents say that clean energy is needed and the project would supply 75% of the electricity needed for Cape Cod and nearby islands (**Figure** 8.84).

California was an early adopter of wind power. Windmills are found in mountain passes, where the cooler Pacific Ocean air is sucked through on its way to warmer inland valleys. Large fields of windmills can be seen at Altamont Pass in the eastern San Francisco Bay Area, San Gorgonio Pass east of Los Angeles, and Tehachapi Pass at the southern end of the San Joaquin Valley.

Summary

- Wind contains energy, which can move a turbine and generate electricity.
- Wind power is clean and does not release greenhouse gases, but some people complain about the spread of windmills across certain locations.
- Wind has been used as a local energy source for centuries and is now being scaled up for use regionally.

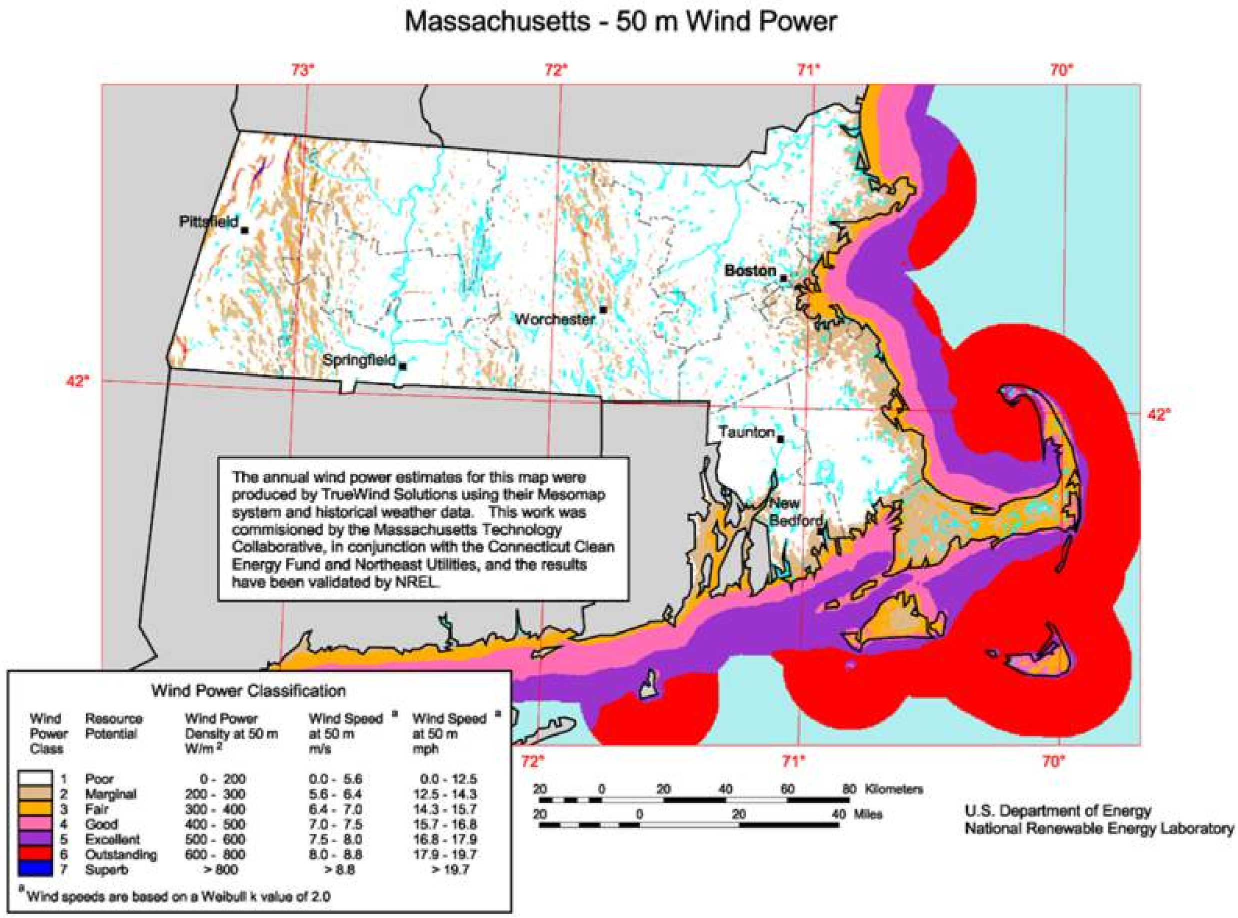


FIGURE 8.84

Cape Wind off of Cape Cod in Massachusetts receives a great deal of wind (red color) but is also popular with tourists for its beauty.

Practice

Use this resource to answer the questions that follow.

http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10501

1. How much has wind power production increased in the United States?
2. How do wind turbines work?
3. What is the wind vane for?
4. What does an anemometer measure?
5. What is the yaw drive for?
6. What is the wind potential in your state?
7. What are the advantages of an off grid system?
8. What are the advantages of wind farms?

Review

1. Describe what causes wind and how wind energy can be harnessed.
2. What are some of the downsides of using wind power?
3. Why do you think that wind is the fastest growing non-renewable energy source?

8.26 Hydroelectric Power

- Explain how energy from falling water is harnessed for hydroelectric power.
- Describe the consequences of hydroelectric power use.

Did the idea for the first dam come from beavers?

Beavers have been building dams for a long time, for food, for a home, and for protection from predators. They probably haven't realized that they can use a dam for hydroelectric power, although are we sure there aren't little TVs in those lodges?

Water Power

Water covers 70% of the planet's surface, and water power (hydroelectric power) is the most widely used form of renewable energy in the world. Hydroelectric power from streams provides almost one fifth of the world's electricity.

Hydroelectric Power

Remember that potential energy is the energy of an object waiting to fall. Water held behind a dam has a lot of potential energy.

In a hydroelectric plant, a dam across a riverbed holds a stream to create a reservoir. Instead of flowing down its normal channel, the water is allowed to flow into a large turbine. As the water moves, it has kinetic energy, which makes the turbine spin. The turbine is connected to a generator, which makes electricity (**Figure** 8.85).

Most of the streams in the United States and elsewhere in the developed world that are suitable for hydroelectric power have already been dammed. In California, about 14.5% of the total electricity comes from hydropower. The

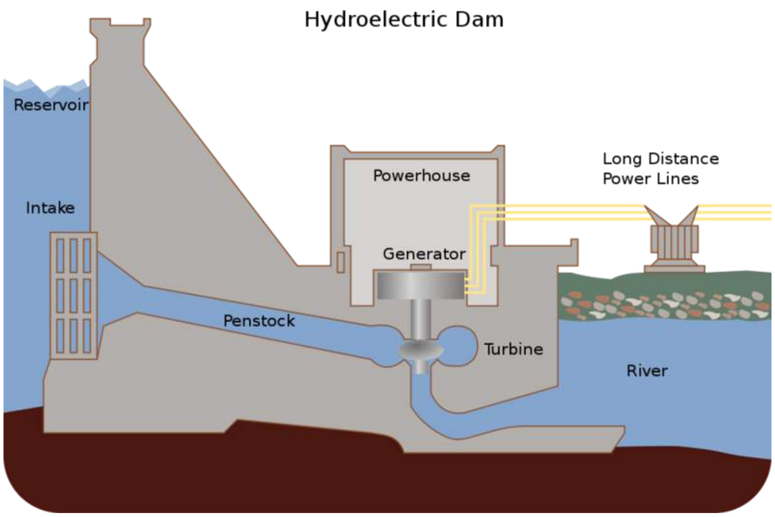


FIGURE 8.85
A cross-section of a hydroelectric plant.

state's nearly 400 hydropower plants are mostly located in the eastern mountain ranges, where large streams descend down a steep grade.

Consequences of Water Power Use

The major benefit of hydropower is that it generates power without releasing any pollution. Hydropower is also a renewable resource since the stream will keep on flowing. However, there are a limited number of suitable dam sites. Hydropower also has environmental problems. When a large dam disrupts a river's flow, it changes the ecosystem upstream. As the land is flooded by rising water, plants and animals are displaced or killed. Many beautiful landscapes, villages, and archeological sites have been drowned by the water in a reservoir (**Figure** 8.86).

FIGURE 8.86
Glen Canyon Dam in Arizona created Lake Powell. The dam was controversial because it flooded Glen Canyon, a beautiful desert canyon.

The dam and turbines also change the downstream environment for fish and other living things. Dams slow the release of silt so that downstream deltas retreat and seaside cities become dangerously exposed to storms and rising sea levels.

Ocean Water Power

The energy of waves and tides can be used to produce water power. Tidal power stations may need to close off a narrow bay or estuary. Wave power applications have to be able to withstand coastal storms and the corrosion of seawater. Because of the many problems with them, tide and wave power plants are not very common.

Although not yet widely used, many believe tidal power has more potential than wind or solar power for meeting alternative energy needs. Quest radio looks at plans for harnessing power from the sea by San Francisco and along the northern California coast.

Find out more at http://science.kqed.org/quest/audio/harnessing-power-from-the-sea/.

Adobe Flash

MEDIA

Click image to the left for more content.

Summary

- Hydroelectric power is clean and is important in many regions of the world.
- Hydropower has downsides like the changes dams make to a river's ecosystem.
- Hydropower utilizes the energy of falling water.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Hydroelectric Power**

1. How is hydroelectric power generated?

2. What does the height of the water determine?

3. How is the turbine rotated?

4. What are the advantages of hydroelectric power?

5. What are the disadvantages of hydroelectric power?

Review

1. How does energy transition from one form to another as water moves from behind a dam to downstream of a dam?

2. Describe how hydroelectric energy is harnessed.

3. What are some of the downsides of using hydroelectric power?

8.27 Geothermal Power

- Explain how geothermal energy is harnessed and used.

How could geothermal energy be used just about anywhere?

Geothermal energy comes from heat deep below the surface of the Earth. That heat may come to the surface naturally or it may be available through drilling. Nothing must be done to the geothermal energy. It is a resource that can be used without processing.

Geothermal Energy

The heat that is used for geothermal power may come to the surface naturally as hot springs or geysers, like The Geysers in northern California. Where water does not naturally come to the surface, engineers may pump cool water into the ground. The water is heated by the hot rock and then pumped back to the surface for use. The hot water or steam from a geothermal well spins a turbine to make electricity.

Geothermal energy is clean and safe. The energy source is renewable since hot rock is found everywhere in the

Earth, although in many parts of the world the hot rock is not close enough to the surface for building geothermal power plants. In some areas, geothermal power is common (**Figure** 8.87).

FIGURE 8.87
A geothermal energy plant in Iceland. Iceland gets about one fourth of its electricity from geothermal sources.

In the United States, California is a leader in producing geothermal energy. The largest geothermal power plant in the state is in the Geysers Geothermal Resource Area in Napa and Sonoma Counties. The source of heat is thought to be a large magma chamber lying beneath the area.

Where Earth's internal heat gets close to the surface, geothermal power is a clean source of energy. In California, The Geysers supplies energy for many nearby homes and businesses.

Find out more at http://www.kqed.org/quest/television/geothermal-heats-up .

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Summary

- Most geothermal energy being used now is in regions where hot material comes to the surface.
- Hot rocks are everywhere below Earth's surface so geothermal energy could be used anywhere with drilling.
- Geothermal energy is clean and does not release greenhouse gases.

Practice

Use this resource to answer the questions that follow.

http://www1.eere.energy.gov/geothermal/egs_animation.html

1. What is an enhanced geothermal system?

2. How is an appropriate site found?

3. What can occur where the fractures are created in the rock?

4. How is the heat extracted?

5. How can the system be expanded?
6. What is the future of geothermal energy?

Review

1. How is geothermal energy harnessed?
2. How would it be possible for a geothermal plant to gather energy if the hot material was not located at the surface?
3. Why is geothermal energy becoming more popular?

8.28 Energy from Biomass

- Explain how biomass energy is harnessed and used, and describe its consequences.

Why is algae better than corn for biofuel?

Algae is a better alternative for producing biofuel than traditional crops because crops could be used for other things, like feeding people.

Biomass

Biomass is the material that comes from plants and animals that were recently living. Biomass can be burned directly, such as setting fire to wood. For as long as humans have had fire, people have used biomass for heating and cooking. People can also process biomass to make fuel, called **biofuel**. Biofuel can be created from crops, such as corn or algae, and processed for use in a car (**Figure** 8.88). The advantage to biofuels is that they burn more cleanly than fossil fuels. As a result, they create less pollution and less carbon dioxide.

FIGURE 8.88
Biofuels, such as ethanol, are added to gasoline to cut down the amount of fossil fuels that are used.

Organic material, like almond shells, can be made into electricity. Biomass power is a great use of wastes and is more reliable than other renewable energy sources, but harvesting biomass energy uses energy and biomass plants produce pollutants including greenhouse gases.

Find out more at http://science.kqed.org/quest/audio/how-green-is-biomass-energy/.

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Cow manure can have a second life as a source of methane gas, which can be converted to electricity. Not only that food scraps can also be converted into green energy.

Find out more at http://science.kqed.org/quest/video/from-waste-to-watts-biofuel-bonanza/.

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Food that is tossed out produces methane, a potent greenhouse gas. But that methane from leftovers can be harnessed and used as fuel. Sounds like a win-win situation.

Find out more at http://science.kqed.org/quest/audio/power-up-with-leftovers/.

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Consequences of Biomass Use

In many instances, the amount of energy, fertilizer, and land needed to produce the crops used make biofuels mean that they often produce very little more energy than they consume. The fertilizers and pesticides used to grow the crops run off and become damaging pollutants in nearby water bodies or in the oceans.

To generate biomass energy, break down the cell walls of plants to release the sugars and then ferment those sugars to create fuel. Corn is a very inefficient source; scientists are looking for much better sources of biomass energy.

See more at http://www.kqed.org/quest/television/biofuels-beyond-ethanol.

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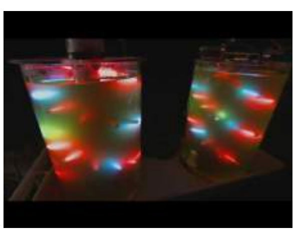
Algae Biofuels

Research is being done into alternative crops for biofuels. A very promising alternative is algae. Growing algae requires much less land and energy than crops. Algae can be grown in locations that are not used for other things, like in desert areas where other crops are not often grown. Algae can be fed agricultural and other waste so valuable resources are not used. Much research is being done to bring these alternative fuels to market. Many groups are researching the use of algae for fuel.

Many people think that the best source of biomass energy for the future is algae. Compared to corn, algae is not a food crop, it can grow in many places, it's much easier to convert to a usable fuel, and it's carbon neutral.

Find out more at http://science.kqed.org/quest/video/algae-power/ .



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Summary

- Biofuels are useful because they are liquid and can go into a gas tank unlike many other types of alternative energy.
- Algae is the focus of much research because it is a very promising alternative to traditional crops for biofuels.
- Biofuels have been used for as long as people have been burning wood for warmth or to cook their food.

Practice

Use this resource to answer the questions that follow.

MEDIA

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1. How much gas is produced from corn?
2. What was the Model T designed to run on?
3. Why are cell phones forbidden in the factory?
4. How much ethanol does the factory produce?
5. Is corn an efficient energy source? Explain your answer.

Review

1. What are the advantages of algae over other sources of biofuels?
2. Why are some crops, like corn, not necessarily a good source of biofuels?
3. How can an energy source produce very little energy more than the energy it takes to produce it?

8.29 Energy Conservation

- Describe forms of energy conservation.
- Explain why energy conservation is important

How much energy can you save?

By turning off the lights, keeping rooms at a reasonable temperature in summer and winter, driving a fuel-efficient car or taking the bus, and many other things, society can save a lot of energy. By saving energy we reduce the financial and environmental costs of collecting that energy, and the pollution and greenhouse gases that come from using that energy. In all, it's a win-win situation!

Energy Conservation

What benefits are there from energy conservation? Conserving energy means that less energy is needed, which reduces costs, ensures that non-renewable energy sources will last longer, and reduces political and environmental impacts.

What are the two ways that energy can be conserved? (1) Use less energy, and (2) use energy more efficiently.

The pie chart (**Figure** 8.89) shows how energy is used in the United States.

Table 8.3 shows some ways that people can decrease energy use and use energy more efficiently in transportation, residences, industries, and office settings.

TABLE 8.3: **Ways to Use Energy More Efficiently**

Where Energy is Used	How We Can Use Less Energy	How We Can Use Energy More Efficiently

TABLE 8.3: (continued)

Where Energy is Used	How We Can Use Less Energy	How We Can Use Energy More Efficiently
Transportation	Ride a bike or walk instead of taking a car. Reduce the number of trips you make. Use public transportation.	Increase fuel efficiency in cars. Buy and drive smaller cars. Build cars from lighter and stronger materials. Drive at speeds at or below 90 kilometers per hour (55 miles per hour).
Residential	Turn off lights when not in a room. Only run appliances when necessary. Unplug appliances when not in use. Wear a sweater instead of turning up heat. Use fans instead of turning down air conditioner. Engage in activities that do not involve electronics. Rely on sunlight instead of artificial light.	Replace old appliances with newer more efficient models. Insulate your home. Make sure windows and doors are well sealed. Use LED bulbs if available, or compact fluorescent light bulbs (and dispose of properly!).
Industrial	Recycle materials like soda cans and steel. Reduce use of plastic, paper, and metal materials.	Practice conservation in factories. Reuse materials. Design equipment to be more efficient.
Commercial (businesses, shopping areas, etc.)	Turn off appliances and equipment when not in use.	Use fluorescent lighting. Set thermostats to automatically turn off heat or air conditioning when buildings are closed.

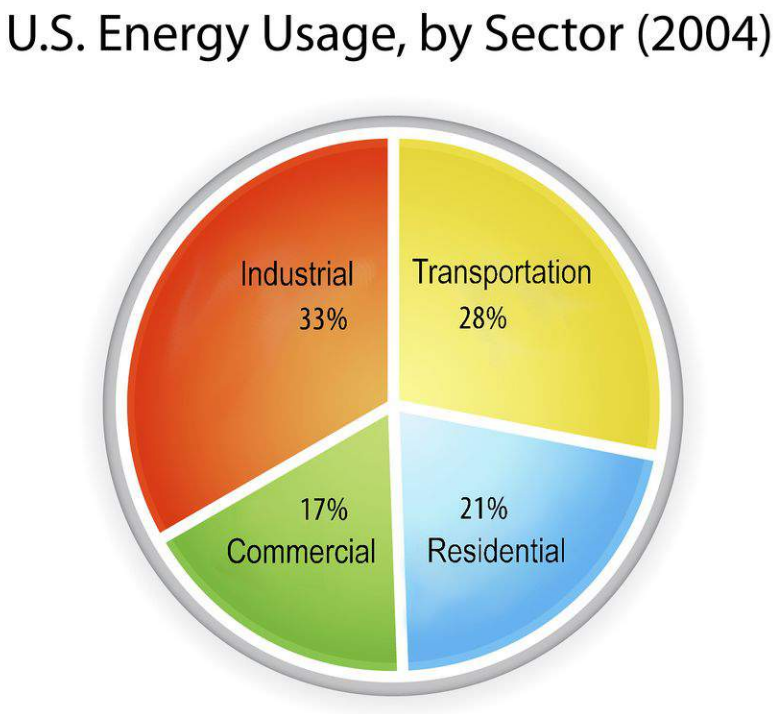

FIGURE 8.89
Almost one-half of the energy used in the United States is for transportation and home use. This means individual choices can make a big impact on energy conservation.

Using less energy, or using energy more efficiently, will help conserve our energy resources. Since many of the energy resources we depend upon are non-renewable, we need to make sure that we waste them as little as possible.

Energy saving tips from the U.S. Department of Energy: http://www.energy.gov/energytips.htm .

The U.S. Department of Energy has a video to let you know how a home energy audit will help you to make your home more energy efficient. Be sure to follow links to the "Do it yourself" page. http://www.energysavers.gov/your_home/energy_audits/index.cfm/mytopic=11160

Summary

- Conserving energy is is cleaner and cheaper than finding new energy.
- To conserve energy, use less energy and be more efficient about the energy you use.
- There are many ways to conserve energy in your own life, such as walking or taking the bus, wearing a sweater instead of turning up the heat, etc.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=QG3HNQiEaTM

MEDIA

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1. What will the population be in 2030?
2. How much will our energy demands increase by 2030?
3. What is energy efficiency?
4. How can industries optimize their energy efficiency?
5. What can be done to make vehicles more efficient?
6. How effective can using energy efficiently be?

Review

1. Why is conservation the best way to stretch our energy resources?
2. List some ways that society can conserve energy.
3. List some ways that you and the other members of your household can conserve energy.

8.30 Availability of Natural Resources

- Explain how factors such as abundance, price, and politics influence the availability and cost of resources.

What is electronic waste?

We obtain resources of developing nations. We also dump waste on these nations. Many of our electronic wastes, which we think are being recycled, end up in developing countries. These are known as electronic waste or **e-waste**. People pick through the wastes looking for valuable materials that they can sell, but this exposes them to many toxic compounds that are hazardous to them and the environment.

Resource Availability

Supply

From the table in the concept "Materials Humans Use," you can see that many of the resources we depend on are non-renewable. Non-renewable resources vary in their availability; some are very abundant and others are rare. Materials, such as gravel or sand, are technically non-renewable, but they are so abundant that running out is no issue. Some resources are truly limited in quantity: when they are gone, they are gone, and something must be found that will replace them. There are even resources, such as diamonds and rubies, that are valuable in part because they are so rare.

Price

Besides abundance, a resource's value is determined by how easy it is to locate and extract. If a resource is difficult to use, it will not be used until the price for that resource becomes so great that it is worth paying for. For example, the oceans are filled with an abundant supply of water, but desalination is costly, so it is used only where water is really limited (**Figure** 8.90). As the cost of desalination plants comes down, more will likely be built.

FIGURE 8.90
Tampa Bay, Florida, has one of the few desalination plants in the United States.

Politics

Politics is also part of determining resource availability and cost. Nations that have a desired resource in abundance will often **export** that resource to other countries, while countries that need that resource must **import** it from one of the countries that produces it. This situation is a potential source of economic and political trouble.

Of course the greatest example of this is oil. Twelve countries have approximately 80% of all of the world's oil (**Figure** 8.91). However, the biggest users of oil, the United States, China, and Japan, are all located outside this oil-rich region. This leads to a situation in which the availability and price of the oil is determined largely by one set of countries that have their own interests to look out for. The result has sometimes been war, which may have been attributed to all sorts of reasons, but at the bottom, the reason is oil.

Waste

The topic of overconsumption was touched on in the chapter Life on Earth. Many people in developed countries, such as the United States and most of Europe, use many more natural resources than people in many other countries. We have many luxury and recreational items, and it is often cheaper for us to throw something away than to fix it or just hang on to it for a while longer. This consumerism leads to greater resource use, but it also leads to more waste. Pollution from discarded materials degrades the land, air, and water (**Figure** 8.92).

Natural resource use is generally lower in developing countries because people cannot afford many products. Some of these nations export natural resources to the developed world since their deposits may be richer and the cost of labor lower. Environmental regulations are often more lax, further lowering the cost of resource extraction.

Summary

- The availability of a resource depends on how much of it there is and how hard it is to extract, refine, and transport to where it is needed.
- Politics plays an important role in resource availability since an unfavorable political situation can make a resource unavailable to a nation.
- Increased resource use generally means more waste; electronic waste from developed nations is a growing problem in the developing world.

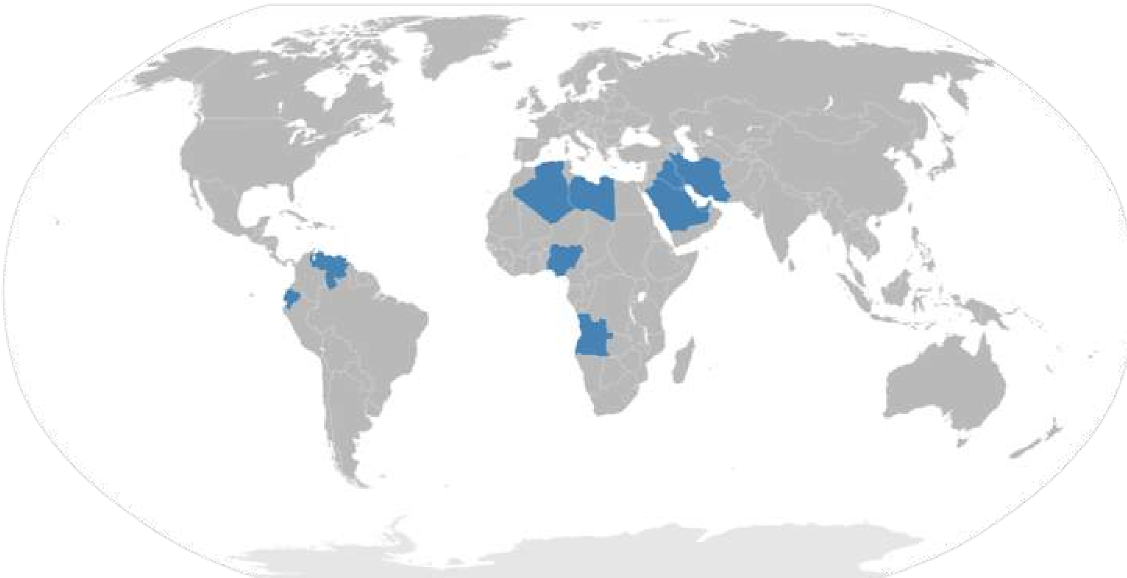

FIGURE 8.91
The nations in blue are the 12 biggest producers of oil; they are Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.

FIGURE 8.92
Pollution from discarded materials degrades the environment and reduces the availability of natural resources.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=0JZey9GJQP0

MEDIA
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1. Why are they melting computer circuit boards?
2. What toxic gases are given off?
3. What metals are they extracting from these computers?
4. What do CRTs contain?
5. What do computer batteries contain?
6. How can these chemicals harm people?
7. How much does recycling a computer cost in India?
8. What companies have committed to reducing the toxic chemicals in their products?

Review

1. Why does electronic waste that is generated in developed nations get dumped in developing nations?
2. Why is politics important in the availability of resources?
3. Why do some nations consume more goods and generate more waste than others?

8.31 Natural Resource Conservation

- Describe forms of natural resource conservation.
- Explain why natural resource conservation is important.

Can you make a difference?

Yes! You can conserve natural resources every day with every decision you make. Should you recycle that can? Yes! Should you buy a bottle of water or drink from the water fountain? Fountain! Should you walk or ride your bike to school or ask for a ride? Walk - it's good exercise too!

Conserving Natural Resources

So that people in developed nations maintain a good lifestyle and people in developing nations have the ability to improve their lifestyles, natural resources must be conserved and protected (**Figure** 8.93). People are researching ways to find renewable alternatives to non-renewable resources. Here is a checklist of ways to conserve resources:

- Buy less stuff (use items as long as you can, and ask yourself if you really need something new).
- Reduce excess packaging (drink tap water instead of water from plastic bottles).
- Recycle materials such as metal cans, old cell phones, and plastic bottles.

FIGURE 8.93
Recycling can help conserve natural resources.

- Purchase products made from recycled materials.
- Reduce pollution so that resources are maintained.
- Prevent soil erosion.
- Plant new trees to replace those that are cut down.
- Drive cars less, take public transportation, bicycle, or walk.
- Conserve energy at home (turn out lights when they are not needed).

Conserving natural resources are explored in a set of National Geographic videos found at http://video.nationalgeographic.com/video/environment/habitats-environment/rainforests . Search for these videos:

- "Mamirarua" is a sustainable development reserve that is protecting the Amazon
- "Vancouver Rain Forest" explores an alliance between conservationists and logging companies

Or find ways to go green from National Geographic Conservation in Action series: http://video.nationalgeographic.com/video/environment/going-green-environment/conservation-in-action

- "Sustainable Logging"
- The problem with plastic bags is discussed in "Edward Norton: Bag the Bag"
- Trying to mitigate problems caused by intensive logging in Ecuador while helping the people who live there improve their standards of living is in "Ecuador Conservation"

Summary

- To conserve natural resources it is important to use less resources or even eliminate the use of some resources.
- It is important to watch unintended consumption; e.g. with packaging.
- To reduce resource use, work on making some renewable: plant trees or use recycled products.

Making Connections

MEDIA

Click image to the left for more content.

Practice

Use this resource to answer the questions that follow.

http://www.energyhog.org/childrens.htm

Play the game to answer these questions.

1. What are energy hogs?
2. List 3 ways to save energy in the living room.
3. List 3 ways you can conserve energy in the kitchen.
4. List 2 ways to save water in the bathroom.
5. List 2 ways to conserve energy in the bedroom.
6. How can energy be conserved in the attic?

Review

1. Why should you use renewable resources rather than non-renewable resources when possible?
2. Why should you recycle materials when possible?
3. Why should you drink tap water or install a filter on your tap for filtered water?

8.32 References

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71. User:Fastfission/Wikimedia Commons. Illustration of nuclear fission. Public Domain
72. Gretchen Mahan. Picture of a nuclear power plant in France. CC BY 2.0
73. Alberto Otero García. Uranium mine in Kakadu National Park, Australia. CC BY 2.0
74. Image copyright Sergey Kamshylin, 2014. Abandoned building near the site of the Chernobyl disaster. Used under license from Shutterstock.com
75. Boyd Norton. Windmills have been used for centuries. Public Domain
76. Mike Spasoff. Solar panels can generate enough electricity to power homes. CC BY 2.0
77. L. Richard Martin Jr.. Hoover Dam. CC BY 2.0
78. Dan Davison (Flickr: Mostly Dans). Combine harvester grinding plants to produce ethanol. CC BY 2.0
79. ThinkGeoEnergy. Geothermal plant producing electricity. CC BY 2.0
80. Courtesy of NASA. Solar array panels on International Space Station. Public Domain
81. Flickr:afloresm. A solar power tower is used to concentrate the solar energy collected by many solar panels. CC BY 2.0
82. Daniel Borman (Flickr:borman818). Picture of a solar car. CC BY 2.0
83. Andre Engels. Wind turbines provide electricity. CC BY 2.0
84. Courtesy of National Renewable Energy Laboratory/US Department of Energy. Cape Wind off of Cape Cod in Massachusetts. Public Domain
85. User:Tomia/Wikimedia Commons. A cross-section of a hydroelectric plant. CC BY 2.5
86. Image copyright Manamana, 2014. Glen Canyon Dam in Arizona created Lake Powell. Used under license from Shutterstock.com
87. Gretar Ívarsson. A geothermal energy plant in Iceland. Public Domain
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89. Hana Zavadska. Graph of energy use in the United States. CC BY-NC 3.0
90. Image copyright Anthony Jay D. Villalon, 2014. Desalination plant in Tampa Bay, Florida. Used under license from Shutterstock.com
91. User:Bourgeois/Wikimedia Commons. Map of the 12 biggest producers of oil. Public Domain
92. Courtesy of the US Environmental Protection Agency. Garbage and trash alongside a road. Public Domain
93. Terence Ong. Recycling bins. CC BY 2.5

CHAPTER 9

Appendix I: Standards Alignements

Chapter Outline

9.1 About the Standards

Every effort has been made to align this content with the National Next Generation Science Standards for High School Earth and Space Science and the North Carolina Essential Standards for Earth/Environmental Science. However, due to the disconnect in the creation of these two sets of standards, the National Middle School Next Generation Science Standards are referenced as needed.

9.2 Links to the Standards

The Next Generation Science Standards

http://www.nextgenscience.org/

North Carolina Essential Standards Earth/Environmental Science

http://www.ncpublicschools.org/docs/acre/standards/support-tools/unpacking/science/earth.pdf

9.3 Chapter Alignments

Astronomy

TABLE 9.1:

Chapter Section	HS ESS Alignment	NCES EES Alignment
3.1	1-2	1.1.1
3.2	1-2	1.1.1
3.3	1-2	1.1.1
3.4	1-2	1.1.1
3.5	1-2	1.1.1
3.6	1-1 / 1-3	1.1.1 / 1.1.3
3.7	1-1 / 1-3	1.1.1 / 1.1.3
3.8	1-1 / 1-3	1.1.1 / 1.1.3
3.9	1-1	1.1.1
3.10	1-4	1.1.1
3.11	1-4	1.1.1
3.12	1-4	1.1.2
3.13	1-4	1.1.2
3.14	1-4	1.1.1
3.15	2-2 / MS EES 1-2	1.1.2
3.16	1-4	1.1.2
3.17	1-4 / 2-2	1.1.4
3.18	1-6	1.1.1
3.19	1-6	1.1.1
3.20	1-4 / MS EES 1-2	1.1.1
3.21	2-2	1.1.2
3.22	1-2	1.1.1

Structure of the Planet

TABLE 9.2:

Chapter Section	HS ESS Alignment	NCES EES Alignment
4.1	1-5 / 1-6	2.1.1
4.2	1-5 / 1-6	2.1.1
4.3	1-5 / 1-6	2.1.1
4.4	1-5 / 1-6	2.1.1
4.5	1-5 / 1-6	2.1.1
4.6	1-5 / 1-6	2.1.1
4.7	2-1 / 2-3	2.1.1
4.8	2-1 / 2-3	2.1.1
4.9	2-1 / 2-3	2.1.1
4.10	2-1 / 2-3	2.1.1
4.11	2-1 / 2-3	2.1.1 / 1.1.4
4.12	2-1 / 2-3	2.1.1

TABLE 9.2: (continued)

4.13	2-1 / 2-3	2.1.1
4.14	2-1 / 2-3	2.1.1
4.15	2-1 / 2-3	2.1.1
4.16	2-1 / 2-3	2.1.1
4.17	2-1 / 2-3	2.1.1
4.18	2-1 / 2-3	2.1.1
4.19	2-1 / 2-3	2.1.1
4.20	2-1 / 2-3	2.1.1
4.21	2-1 / 2-3	2.1.1 / 2.1.4
4.22	2-1 / 2-3	2.1.1 / 2.1.4
4.23	2-1 / 2-3	2.1.1 / 2.1.4
4.24	2-1 / 2-3	2.1.1 / 2.1.4
4.25	2-1	2.1.1
4.26	2-1	2.1.1
4.27	2-1	2.1.1
4.28	2-1	2.1.1
4.29	2-1	2.1.2 / 2.1.4
4.30	2-1	2.1.2 / 2.1.4
4.31	2-3 / MS ESS 2-1	2.1.1
4.32	2-3 / MS ESS 2-1	2.1.1
4.33	2-3 / MS ESS 2-1	2.1.1
4.34	2-3 / MS ESS 2-1	2.1.1
4.35	2-3 / MS ESS 2-1	2.1.1
4.36	2-3 / MS ESS 2-1	2.1.1
4.37	2-3 / MS ESS 2-1	2.1.1
4.38	2-3 / MS ESS 2-1	2.1.1
4.39	2-3 / MS ESS 2-1	2.1.1

Hydrology Weathering

TABLE 9.3:

Chapter Section	HS ESS Alignment	NCES EES Alignment
5.1	2-5	2.3.1 / 2.3.2
5.2	2-5	2.3.2
5.3	2-5	2.3.2 / 2.4.2
5.4	2-5	2.3.2 / 2.4.2
5.5	2-5	2.3.2 /2.4.2
5.6	2-2 / 2-5	2.1.4 / 2.3.2 / 2.4.2
5.7	2-2 / 2-4 / 2-5	2.3.2 / 2.6.4
5.8	2-5	2.3.2 / 2.4.2
5.9	2-5	2.3.2 / 2.4.2 / 2.7.3
5.10	2-2	2.4.1/2.4.2/2.7.3/2.8.3
5.11	3-1	2.4.1/2.4.2/2.7.3/2.8.3
5.12	3-1	2.4.1/2.4.2/2.7.3/2.8.3
5.13	2-2 / 2-5	2.1.3
5.14	2-2 / 2-5	2.1.3
5.15	2-5	2.1.3

TABLE 9.3: (continued)

5.16	2-5	2.1.3
5.17	2-2 / 2-5	2.1.3
5.18	2-2 / 2-5	2.1.3
5.19	2-2 / 2-5	2.1.3
5.20	2-5 / 2-6	2.1.3
5.21	2-5 / 2-6	2.1.3
5.22	2-5 / 2-6	2.1.3
5.23	2-5 / 2-6	2.1.3
5.24	2-2 / 2-5	2.1.3 / 2.1.4
5.25	2-2	2.2.1/2.6.4/2.7.3/2.8.2
5.26	2-7 / 3-3 / 3-6	2.2.1/2.6.4/2.7.3/2.8.2/2.8.3
5.27	2-7 / 3-3 / 3-6	2.2.1/2.6.4/2.7.3/2.8.2/2.8.3
5.28	2-7 / 3-3 / 3-6	2.2.1/2.6.4/2.7.3/2.8.2
5.29	2-2 / 2-7 / 3-3 / 3-6	2.2.1/2.6.4/2.7.3/2.8.2/2.8.3
5.30	2-7 / 3-3 / 3-6	2.2.1/2.6.4/2.7.3/2.8.2/2.8.3

Oceanography

TABLE 9.4:

Chapter Section	HS ESS Alignment	NCES EES Alignment
6.1	2-2	2.1.3 / 2.2.1
6.2	2-2 / 3-6	2.6.4
6.3	2-1	2.1.2 / 2.1.1
6.4	2-2	2.3.1
6.5	2-4	2.3.1
6.6	2-4	2.3.1
6.7	2-4	2.3.1
6.8	1-4	1.1.1
6.9	2-2 / 2-4	2.3.1
6.10	3-6	2.6.4
6.11	3-6	2.8.4
6.12	2-7	2.6.4 / 2.7.2
6.13	2-7	2.7.1 / 2.7.2
6.14	2-7	2.7.1 / 2.7.2
6.15	3-3	2.6.4 / 2.8.3

The Atmosphere

TABLE 9.5:

Chapter Section	HS ESS Alignment	NCES EES Alignment
7.1	2-3	2.5.1
7.2	2-3	2.5.1
7.3	2-3	2.5.1
7.4	2-3	2.5.1
7.5	2-3	2.5.1
7.6	2-3	2.5.1
7.7	2-3	2.5.1

TABLE 9.5: (continued)

7.8	2-3	2.5.1
7.9	2-3	2.5.1
7.10	2-4	1.1.3
7.11	MS ESS 2-5 / 2-6	2.1.3
7.12	MS ESS 2-5 / 2-6	2.5.3
7.13	MS ESS 2-5 / 2-6	2.5.2
7.14	MS ESS 2-5 / 2-6	2.5.2
7.15	MS ESS 2-5 / 2-6	2.5.2
7.16	MS ESS 2-5 / 2-6	2.5.2
7.17	MS ESS 2-5 / 2-6	2.5.2
7.18	MS ESS 2-5 / 2-6	2.5.4
7.19	MS ESS 2-5 / 2-6	2.5.4
7.20	MS ESS 2-5 / 2-6	2.5.4
7.21	3-1 / MS ESS 2-5 / 2-6	2.5.2 / 2.5.3 / 2.6.4
7.22	3-1 / MS ESS 2-5 / 2-6	2.5.3
7.23	3-1 / MS ESS 2-5 / 2-6	2.5.3
7.24	3-1 / MS ESS 2-5 / 2-6	2.5.3
7.25	2-4	2.6.1 / 2.6.4
7.26	2-2 / 2-4	2.3.1 / 2.6.4
7.27	2-2 / 2-4	2.3.1
7.28	2-4	2.3.1
7.29	2-2	2.6.2
7.30	2-2	2.6.2
7.31	2-4	2.6.2 / 2.6.4
7.32	2-2	2.6.2 / 2.7.3
7.33	2-2	2.6.2 / 2.7.3
7.34	2-2	2.6.2 / 2.7.3
7.35	3-5 / 3-6	2.6.2 / 2.7.3
7.36	3-5 / 3-6	2.6.3 / 2.7.3
7.37	3-5 / 3-6	2.6.3 / 2.6.4
7.38	3-5 / 3-6	2.6.3 / 2.7.4
7.39	3-5 / 3-6	2.5.5/2.6.3/2.7.3/2.8.3
7.40	3-5 / 3-6	2.5.5/2.6.3/2.7.3/2.8.3
7.41	3-5 / 3-6	2.5.5/2.6.3/2.6.4/2.7.3/2.8.3
7.42	3-5 / 3-6	2.5.5/2.6.3/2.7.3/2.8.3
7.43	3-5 / 3-6	2.5.5/2.6.3/2.7.3/2.8.3

Natural Resource Management

TABLE 9.6:

Chapter Section	HS ESS Alignment	NCES EES Alignment
8.1	2-7	2.7.1 / 2.7.2
8.2	2-2	2.7.1 / 2.7.2
8.3	2-2	2.7.1 / 2.7.2
8.4	2-7	2.7.2
8.5	2-7	2.7.2 / 2.7.3
8.6	2-2	1.1.4 / 2.7.1

TABLE 9.6: (continued)

8.7	2-2	2.6.4 / 2.7.1
8.8	2-6	2.6.2 / 2.6.3 / 2.6.4 / 2.7.1
8.9	3-2	2.2.2 / 2.6.3 / 2.8.4
8.10	3-2 / 3-3 / 3-4	2.2.2 / 2.8.4
8.11	3-2 / 3-3 / 3-4	2.2.2 / 2.8.4
8.12	3-2 / 3-3 / 3-4	2.2.2 / 2.8.4
8.13	3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.14	3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.15	3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.16	2-2 /3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.17	3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.18	3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.19	3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.20	3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.21	3-2 / 3-3 / 3-4	2.2.1 / 2.2.2 / 2.8.4
8.22	3-2 / 3-3 / 3-4	2.2.2 / 2.8.4
8.23	3-2 / 3-3 / 3-4	2.2.2 / 2.8.1 / 2.8.4
8.24	3-2 / 3-3 / 3-4	2.2.2 / 2.8.1 / 2.8.4
8.25	3-2 / 3-3 / 3-4	2.2.2 / 2.8.1 / 2.8.4
8.26	3-2 / 3-3 / 3-4	2.2.2 / 2.8.1 / 2.8.4
8.27	3-2 / 3-3 / 3-4	2.2.2 / 2.8.1 / 2.8.4
8.28	3-3	2.2.2 / 2.8.1 / 2.8.4
8.29	3-3	2.2.1 / 2.2.2 / 2.8.3 / 2.8.4
8.30	3-3	2.2.1/2.2.2/2.6.3/2.8.1/2.8.3/2.8.4
8.31	3-3	2.2.1/2.2.2/2.6.3/2.8.1/2.8.3/2.8.4

CHAPTER 10 Appendix II: Physical Science Suplemental Information

Chapter Outline

10.1 Gravity

Lesson Objectives

- Define gravity.
- State Newton's law of universal gravitation.
- Explain how gravity affects the motion of objects.

Lesson Vocabulary

- gravity
- law of universal gravitation
- orbit
- projectile motion

Introduction

Long, long ago, when the universe was still young, an incredible force caused dust and gas particles to pull together to form the objects in our solar system (see **Figure** 10.1). From the smallest moon to our enormous sun, this force created not only our solar system, but all the solar systems in all the galaxies of the universe. The force is gravity.

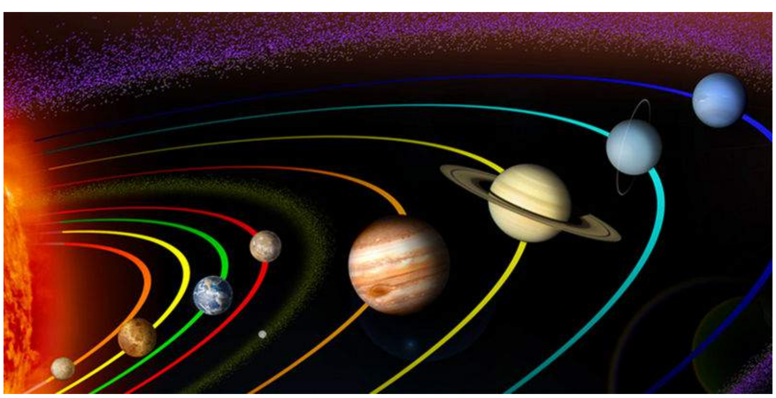


FIGURE 10.1
Gravity helped to form our solar system and all the other solar systems in the universe.

Defining Gravity

Gravity has traditionally been defined as a force of attraction between two masses. According to this conception of gravity, anything that has mass, no matter how small, exerts gravity on other matter. The effect of gravity is that objects exert a pull on other objects. Unlike friction, which acts only between objects that are touching, gravity also acts between objects that are not touching. In fact, gravity can act over very long distances.

Earth's Gravity

You are already very familiar with Earth's gravity. It constantly pulls you toward the center of the planet. It prevents you and everything else on Earth from being flung out into space as the planet spins on its axis. It also pulls objects above the surface, from meteors to skydivers, down to the ground. Gravity between Earth and the moon and between Earth and artificial satellites keeps all these objects circling around Earth. Gravity also keeps Earth moving around the sun.

Gravity and Weight

Weight measures the force of gravity pulling on an object. Because weight measures force, the SI unit for weight is the **newton (N)**. On Earth, a mass of 1 kilogram has a weight of about 10 newtons because of the pull of Earth's gravity On the moon, which has less gravity, the same mass would weigh less. Weight is measured with a scale, like the spring scale in **Figure** 10.2. The scale measures the force with which gravity pulls an object downward.

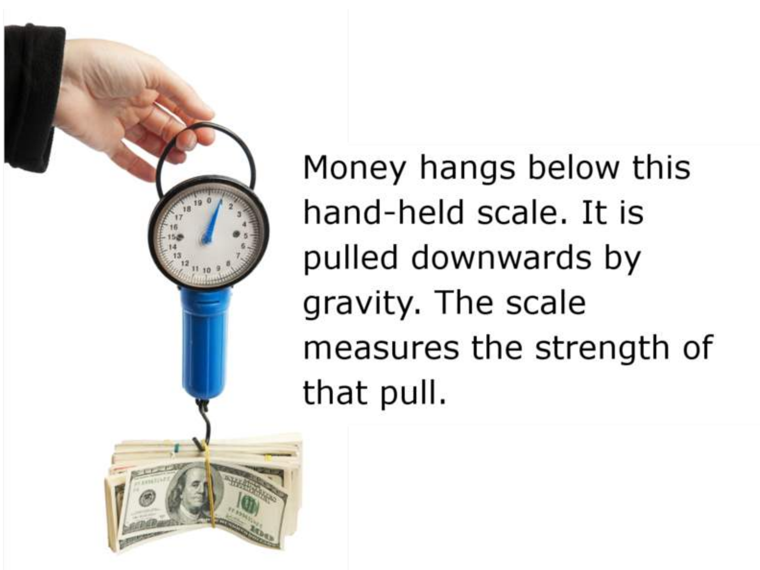


FIGURE 10.2
A scale measures the pull of gravity on an object.

Law of Gravity

People have known about gravity for thousands of years. After all, they constantly experienced gravity in their daily lives. They knew that things always fall toward the ground. However, it wasn't until Sir Isaac Newton developed his law of gravity in the late 1600s that people really began to understand gravity. Newton is pictured in **Figure** 10.3.

FIGURE 10.3
Sir Isaac Newton discovered that gravity is universal.

Newton's Law of Universal Gravitation

Newton was the first one to suggest that gravity is universal and affects all objects in the universe. That's why his law of gravity is called the **law of universal gravitation**. Universal gravitation means that the force that causes an apple to fall from a tree to the ground is the same force that causes the moon to keep moving around Earth. Universal gravitation also means that while Earth exerts a pull on you, you exert a pull on Earth. In fact, there is gravity between you and every mass around you —your desk, your book, your pen. Even tiny molecules of gas are attracted to one another by the force of gravity.

Newton's law had a huge impact on how people thought about the universe. It explains the motion of objects not only on Earth but in outer space as well. You can learn more about Newton's law of gravity in the video at this URL: http://www.youtube.com/watch?v=O-p8yZYxNGc .

Factors that Influence the Strength of Gravity

Newton's law also states that the strength of gravity between any two objects depends on two factors: the masses of the objects and the distance between them.

- Objects with greater mass have a stronger force of gravity. For example, because Earth is so massive, it attracts you and your desk more strongly than you and your desk attract each other. That's why you and the desk remain in place on the floor rather than moving toward one another.
- Objects that are closer together have a stronger force of gravity. For example, the moon is closer to Earth than it is to the more massive sun, so the force of gravity is greater between the moon and Earth than between the moon and the sun. That's why the moon circles around Earth rather than the sun. This is illustrated in **Figure** 10.4.

You can apply these relationships among mass, distance, and gravity by designing your own roller coaster at this URL: http://www.learner.org/interactives/parkphysics/coaster/ .

Einstein's Theory of Gravity

Newton's idea of gravity can predict the motion of most but not all objects. In the early 1900s, Albert Einstein came up with a theory of gravity that is better at predicting how all objects move. Einstein showed mathematically that gravity is not really a force in the sense that Newton thought. Instead, gravity is a result of the warping, or curving,

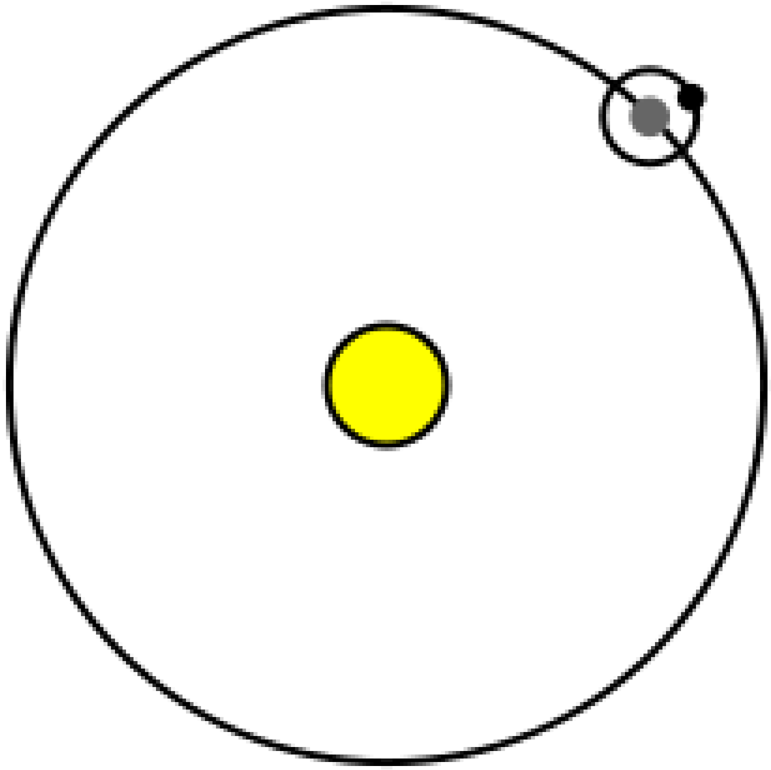


FIGURE 10.4
The moon keeps moving around Earth rather than the sun because it is much closer to Earth.

of space and time. Imagine a bowling ball pressing down on a trampoline. The surface of the trampoline would curve downward instead of being flat. Einstein theorized that Earth and other very massive bodies affect space and time around them in a similar way. This idea is represented in **Figure** 10.5. According to Einstein, objects curve toward one another because of the curves in space and time, not because they are pulling on each other with a force of attraction as Newton thought. You can see an animation of Einstein's theory of gravity at this URL: http://einstein.stanford.edu/Media/Einsteins_Universe_Anima-Flash.html . To learn about recent research that supports Einstein's theory of gravity, go to this URL: http://www.universetoday.com/85401/gravity-probe-b-confirms-two-of-einsteins-space-time-theories/ .

Gravity and Motion

Regardless of what gravity is —a force between masses or the result of curves in space and time —the effects of gravity on motion are well known. You already know that gravity causes objects to fall down to the ground. Gravity affects the motion of objects in other ways as well.

Acceleration Due to Gravity

When gravity pulls objects toward the ground, it causes them to accelerate. Acceleration due to gravity equals 9.8 m/s^2. In other words, the velocity at which an object falls toward Earth increases each second by 9.8 m/s. Therefore, after 1 second, an object is falling at a velocity of 9.8 m/s. After 2 seconds, it is falling at a velocity of 19.6 m/s (9.8 m/s $\times$ 2), and so on. This is illustrated in **Figure** 10.6. You can compare the acceleration due to gravity on Earth, the moon, and Mars with the interactive animation called "Freefall" at this URL: http://jersey.uoregon.edu/vlab/ .

You might think that an object with greater mass would accelerate faster than an object with less mass. After all, its

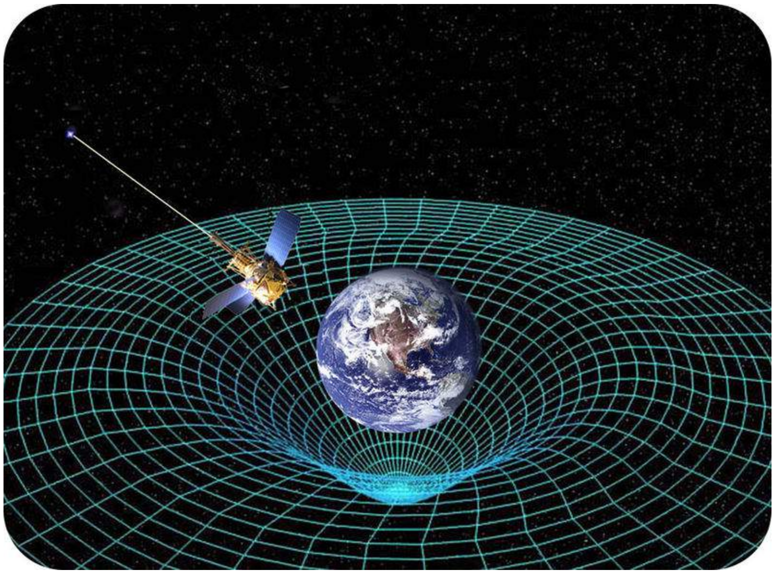


FIGURE 10.5
Einstein thought that gravity is the effect of curves in space and time around massive objects such as Earth. He proposed that the curves in space and time cause nearby objects to follow a curved path. How does this differ from Newton's idea of gravity?

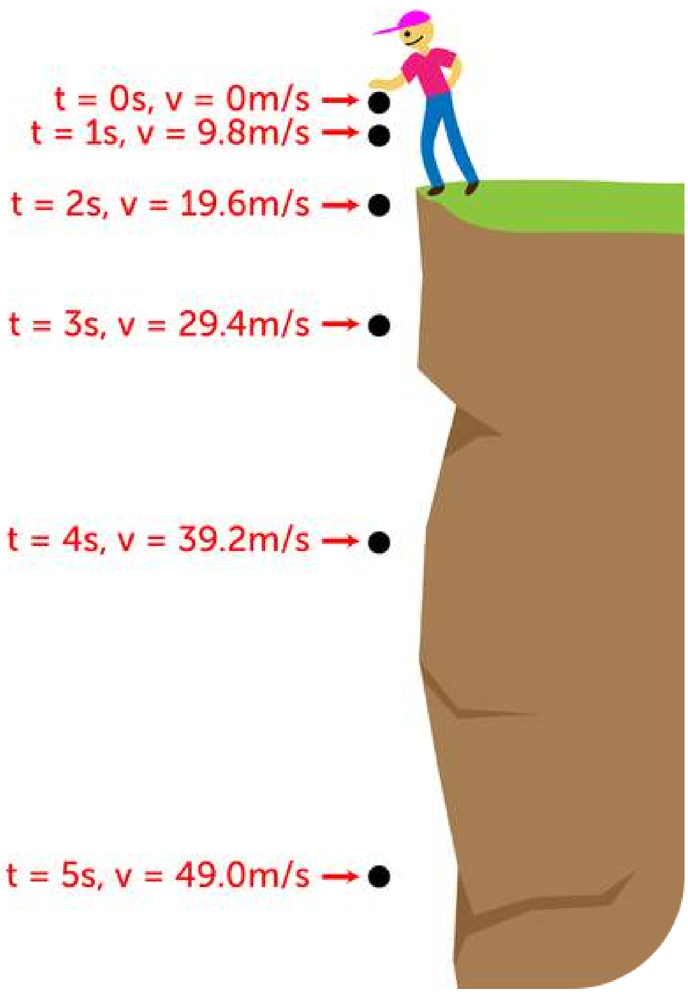


FIGURE 10.6
A boy drops an object at time t = 0 s. At time t = 1 s, the object is falling at a velocity of 9.8 m/s. What is its velocity by time t = 5 ?

greater mass means that it is pulled by a stronger force of gravity. However, a more massive object accelerates at the same rate as a less massive object. The reason? The more massive object is harder to move because of its greater mass. As a result, it ends up moving at the same acceleration as the less massive object.

Consider a bowling ball and a basketball. The bowling ball has greater mass than the basketball. However, if you were to drop both balls at the same time from the same distance above the ground, they would reach the ground together. This is true of all falling objects, unless air resistance affects one object more than another. For example, a falling leaf is slowed down by air resistance more than a falling acorn because of the leaf's greater surface area. However, if the leaf and acorn were to fall in the absence of air (that is, in a vacuum), they would reach the ground at the same time.

Projectile Motion

Earth's gravity also affects the acceleration of objects that start out moving horizontally, or parallel to the ground. Look at **Figure** 10.7. A cannon shoots a cannon ball straight ahead, giving the ball horizontal motion. At the same time, gravity pulls the ball down toward the ground. Both forces acting together cause the ball to move in a curved path. This is called **projectile motion**.

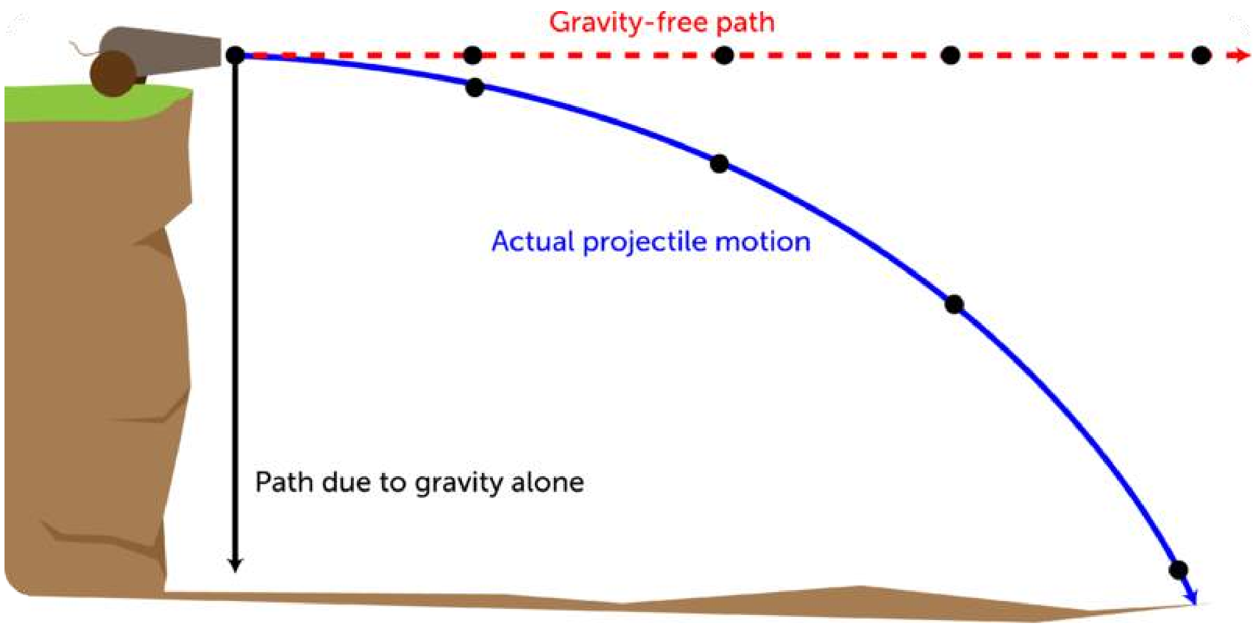


FIGURE 10.7
The cannon ball moves in a curved path because of the combined horizontal and downward forces.

Projectile motion also applies to other moving objects, such as arrows shot from a bow. To hit the bull's eye of a target with an arrow, you actually have to aim for a spot above the bull's eye. That's because by the time the arrow reaches the target, it has started to curve downward toward the ground. **Figure** 10.8 shows what happens if you aim at the bull's eye instead of above it. You can access interactive animations of projectile motion at these URLs:

- http://phet.colorado.edu/en/simulation/projectile-motion
- http://jersey.uoregon.edu/vlab/ *(Select the applet entitled "Cannon.")*

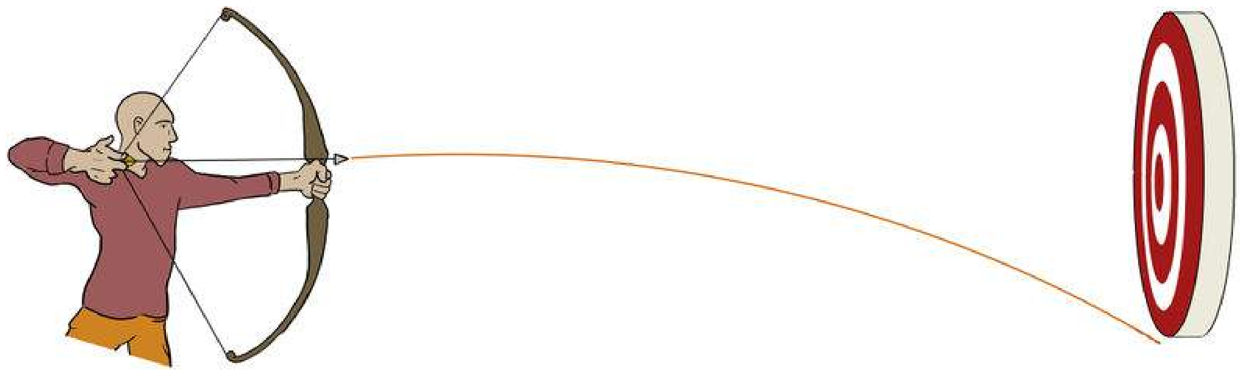


FIGURE 10.8
Aiming at the center of a target is likely to result in a hit below the bull's eye.

Orbital Motion

The moon moves around Earth in a circular path called an **orbit**. Why doesn't Earth's gravity pull the moon down to the ground instead? The moon has enough forward velocity to partly counter the force of Earth's gravity. It constantly falls toward Earth, but it stays far enough away from Earth so that it actually falls around the planet. As a result, the moon keeps orbiting Earth and never crashes into it. The diagram in **Figure** 10.9 shows how this happens. You can explore gravity and orbital motion in depth with the animation at this URL: http://phet.colorado.edu/en/simulation/gravity-and-orbits .

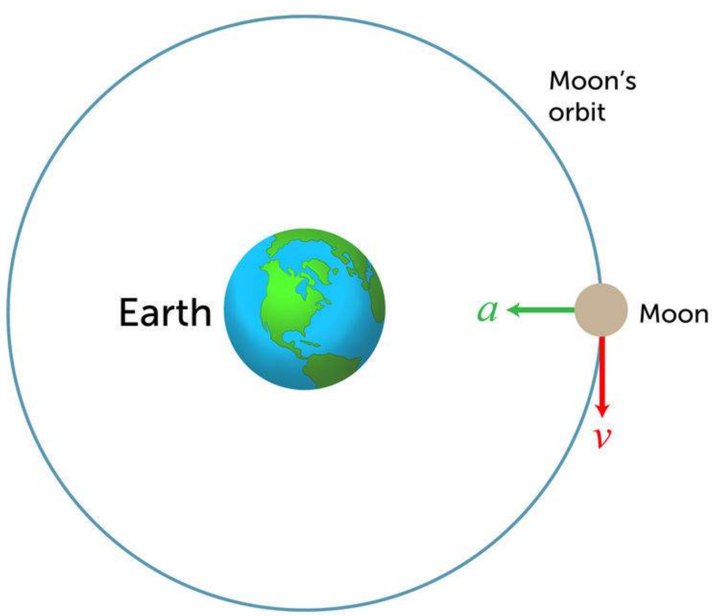


FIGURE 10.9
In this diagram, "v" represents the forward velocity of the moon, and "a" represents the acceleration due to gravity. The line encircling Earth shows the moon's actual orbit, which results from the combination of "v" and "a."

You can see an animated version of this diagram at: http://en.wikipedia.org/wiki/File:Orbital_motion.gif .

Lesson Summary

- Gravity is traditionally defined as a force of attraction between two masses. Weight measures the force of gravity and is expressed in newtons (N).
- According to Newton's law of universal gravitation, gravity is a force of attraction between all objects in the universe, and the strength of gravity depends on the masses of the objects and the distance between them. Einstein's theory of gravity states that gravity is an effect of curves in space and time around massive objects such as Earth.
- Gravity causes falling objects to accelerate at 9.8 m/s^2. Gravity also causes projectile motion and orbital motion.

Lesson Review Questions

Recall

1. What is the traditional definition of gravity?
2. How is weight related to gravity?
3. Summarize Newton's law of universal gravitation.
4. Describe Einstein's idea of gravity.

Apply Concepts

5. Create a poster to illustrate the concept of projectile motion.

Think Critically

6. In the absence of air, why does an object with greater mass fall toward Earth at the same acceleration as an object with less mass?
7. Explain why the moon keeps orbiting Earth.

Points to Consider

The scale you saw in **Figure** 10.2 contains a spring. When an object hangs from the scale, the spring exerts an upward force that partly counters the downward force of gravity. The type of force exerted by a spring is called elastic force, which is the topic of the next lesson.

- Besides springs, what other objects do you think might exert elastic force?
- What other ways might you use elastic force?

10.2 What Is Force?

Lesson Objectives

- Define force, and give examples of forces.
- Describe how forces combine and affect motion.

Lesson Vocabulary

- force
- net force
- newton (N)

Introduction

Any time the motion of an object changes, a force has been applied. Force can cause a stationary object to start moving or a moving object to accelerate. The moving object may change its speed, its direction, or both. How much an object's motion changes when a force is applied depends on the strength of the force and the object's mass. You can explore the how force, mass, and acceleration are related by doing the activity at the URL http://www.harcourtschool.com/activity/newton/ . This will provide you with a good hands-on introduction to the concept of force in physics.

Defining Force

Force is defined as a push or a pull acting on an object. Examples of forces include friction and gravity. Both are covered in detail later in this chapter. Another example of force is applied force. It occurs when a person or thing applies force to an object, like the girl pushing the swing in **Figure** 10.10. The force of the push causes the swing to move.

FIGURE 10.10
When this girl pushes the swing away from her, it causes the swing to move in that direction.

Force as a Vector

Force is a vector because it has both size and direction. For example, the girl in **Figure** 10.10 is pushing the swing away from herself. That's the direction of the force. She can give the swing a strong push or a weak push. That's the size, or strength, of the force. Like other vectors, forces can be represented with arrows. **Figure** 10.11 shows some examples. The length of each arrow represents the strength of the force, and the way the arrow points represents the direction of the force. How could you use an arrow to represent the girl's push on the swing in **Figure** 10.10?

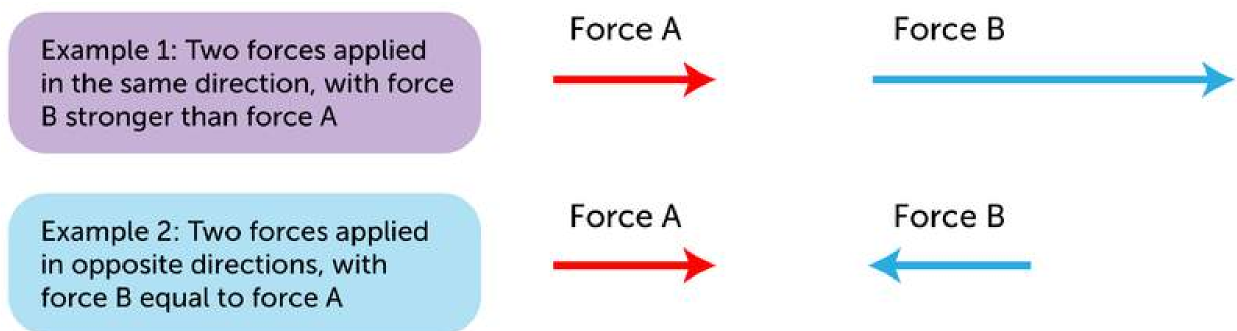


FIGURE 10.11
Forces can vary in both strength and direction.

SI Unit of Force

The SI unit of force is the newton (N). One newton is the amount of force that causes a mass of 1 kilogram to accelerate at 1 m/s^2. Thus, the newton can also be expressed as $kg \cdot m/s^2$. The newton was named for the scientist Sir Isaac Newton, who is famous for his law of gravity. You'll learn more about Sir Isaac Newton later in the chapter.

Combining Forces

More than one force may act on an object at the same time. In fact, just about all objects on Earth have at least two forces acting on them at all times. One force is gravity, which pulls objects down toward the center of Earth. The other force is an upward force that may be provided by the ground or other surface.

Consider the example in **Figure** 10.12. A book is resting on a table. Gravity pulls the book downward with a force of 20 newtons. At the same time, the table pushes the book upward with a force of 20 newtons. The combined forces acting on the book —or any other object —are called the **net force**. This is the overall force acting on an object that takes into account all of the individual forces acting on the object. You can learn more about the concept of net force at this URL: http://www.mansfieldct.org/schools/mms/staff/hand/lawsunbalancedforce.htm .

Forces Acting in Opposite Directions

When two forces act on an object in opposite directions, like the book on the table, the net force is equal to the difference between the two forces. In other words, one force is subtracted from the other to calculate the net force.

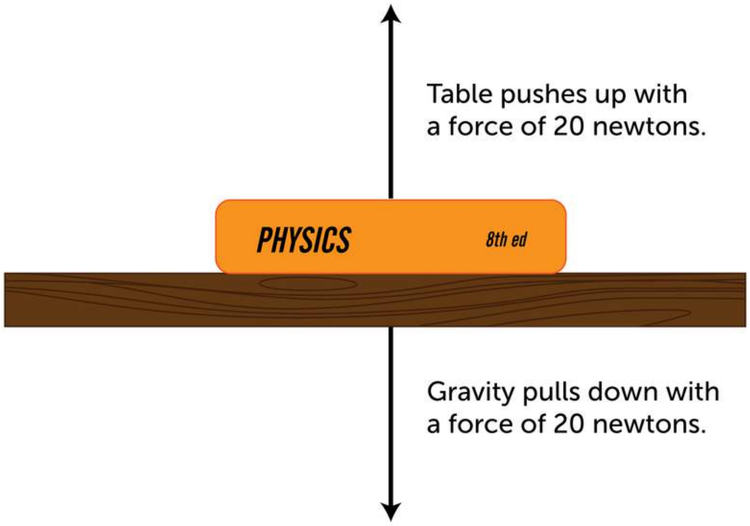


FIGURE 10.12
A book resting on a table is acted on by two opposing forces.

If the opposing forces are equal in strength, the net force is zero. That's what happens with the book on the table. The upward force minus the downward force equals zero (20 N up - 20 N down = 0 N). Because the forces on the book are balanced, the book remains on the table and doesn't move.

In addition to these downward and upward forces, which generally cancel each other out, forces may push or pull an object in other directions. Look at the dogs playing tug-of-war in **Figure** 10.13. One dog is pulling on the rope with a force of 10 newtons to the left. The other dog is pulling on the rope with a force of 12 newtons to the right. These opposing forces are not equal in strength, so they are unbalanced. When opposing forces are unbalanced, the net force is greater than zero. The net force on the rope is 2 newtons to the right, so the rope will move to the right.

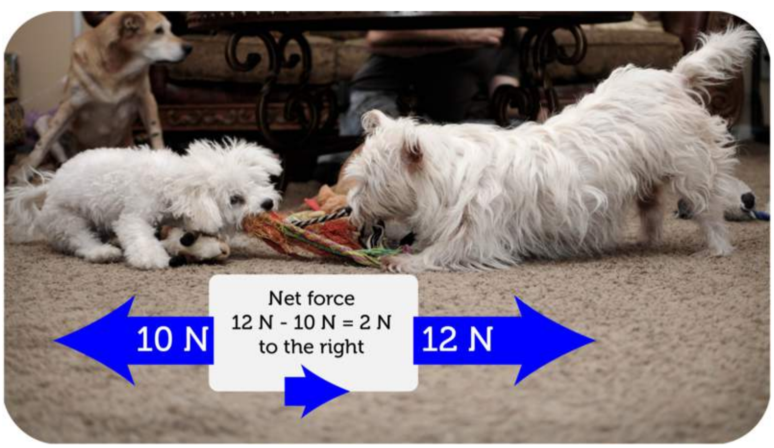


FIGURE 10.13
When unbalanced forces are applied to an object in opposite directions, the smaller force is subtracted from the larger force to yield the net force.

Forces Acting in the Same Direction

Two forces may act on an object in the same direction. You can see an example of this in **Figure** 10.14. After the man on the left lifts up the couch, he will push the couch to the right with a force of 25 newtons. At the same time, the man to the right is pulling the couch to the right with a force of 20 newtons. When two forces act in the same direction, the net force is equal to the sum of the forces. This always results in a stronger force than either of the individual forces alone. In this case, the net force on the couch is 45 newtons to the right, so the couch will move to the right.

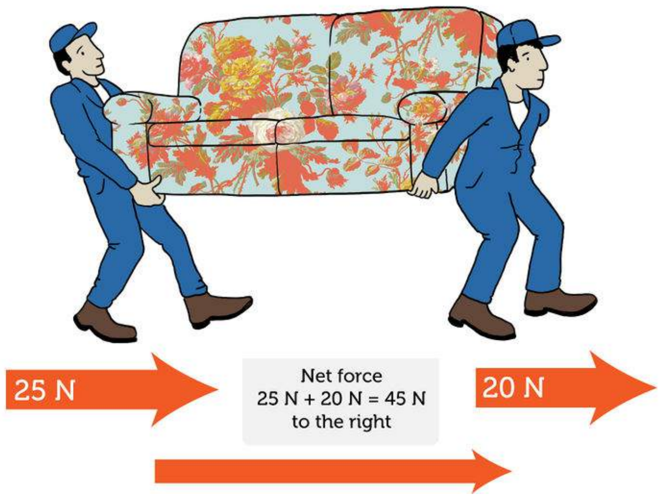
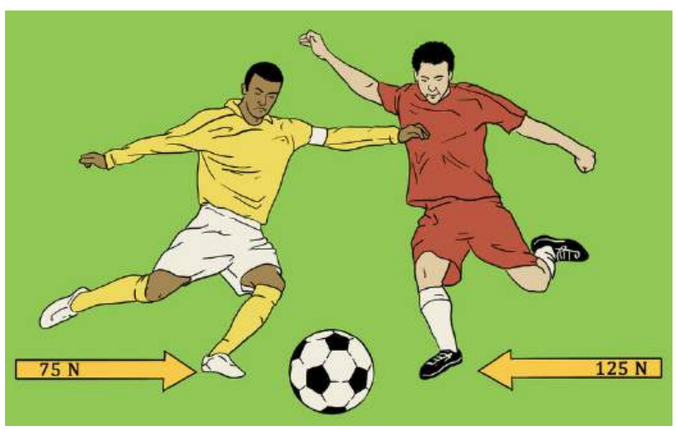


FIGURE 10.14
When two forces are applied to an object in the same direction, the two forces are added to yield the net force.

You Try It!



Problem: The boys in the drawing above are about to kick the soccer ball in opposite directions. What will be the net force on the ball? In which direction will the ball move?

If you need more practice calculating net force, go to this URL: http://www.physicsclassroom.com/class/newtlaws/U2L2d.cfm .

Lesson Summary

- Force is a push or a pull acting on an object. Examples of force include friction and gravity. Force is a vector because it has both size and direction. The SI unit of force is the newton (N).
- The combined forces acting on an object are called the net force. When forces act in opposite directions, they are subtracted to yield the net force. When they act in the same direction, they are added to yield the net force.

Lesson Review Questions

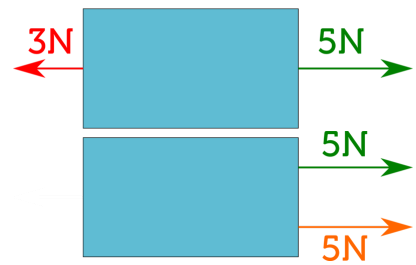
Recall

1. Define force. Give an example of a force.
2. What is a newton?
3. What is net force?
4. Describe an example of balanced forces and an example of unbalanced forces.

Apply Concepts

5. What is the net force acting on the block in each diagram below?

a.
b.



Think Critically

6. Explain how forces are related to motion.

Points to Consider

In the next lesson, "Friction," you will read about the force of friction. You experience this force every time you walk. It prevents your feet from slipping out from under you.

- How would you define friction?
- What do you think causes this force?

10.3 Newton's First Law

Lesson Objectives

- State Newton's first law of motion.
- Define inertia, and explain its relationship to mass.

Lesson Vocabulary

- inertia
- Newton's first law of motion

Introduction

The amusement park ride pictured in **Figure** 10.15 keeps changing direction as it zooms back and forth. Each time it abruptly switches direction, the riders are forced to the opposite side of the car. What force causes this to happen? In this lesson, you'll find out.

FIGURE 10.15
Amusement park rides like this one are exciting because of the strong forces the riders feel.

Force and Motion

Newton's first law of motion states that an object's motion will not change unless an unbalanced force acts on the object. If the object is at rest, it will stay at rest. If the object is in motion, it will stay in motion and its velocity will remain the same. In other words, neither the direction nor the speed of the object will change as long as the net force acting on it is zero. You can watch a video about Newton's first law at this URL: http://videos.howstuffworks.com/discovery/29382-assignment-discovery-newtons-first-law-video.htm .

Look at the pool balls in **Figure** 10.16. When a pool player pushes the pool stick against the white ball, the white ball is set into motion. Once the white ball is rolling, it rolls all the way across the table and stops moving only after it crashes into the cluster of colored balls. Then, the force of the collision starts the colored balls moving. Some may roll until they bounce off the raised sides of the table. Some may fall down into the holes at the edges of the table. None of these motions will occur, however, unless that initial push of the pool stick is applied. As long as the net force on the balls is zero, they will remain at rest.

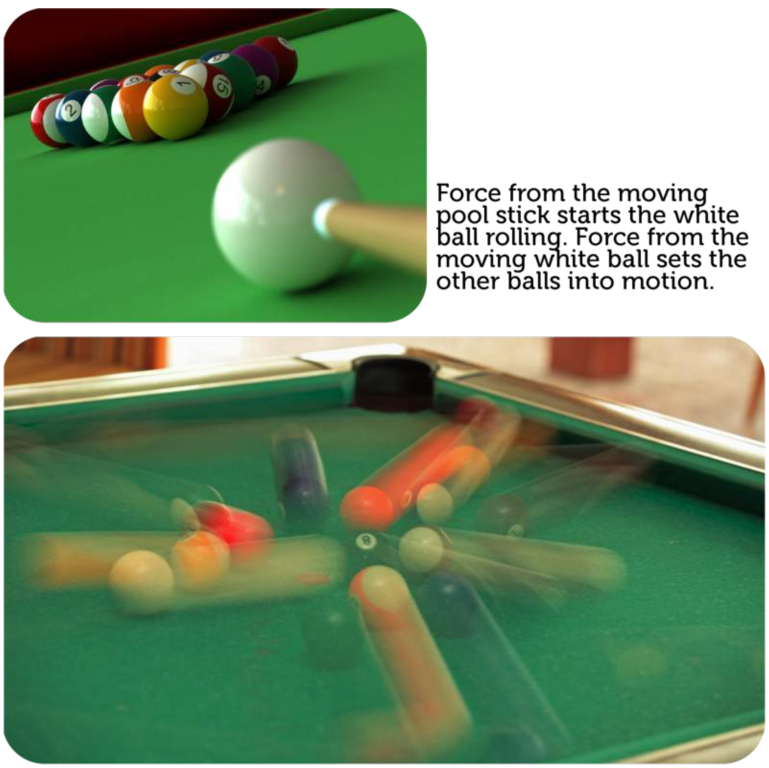


FIGURE 10.16
Pool balls remain at rest until an unbalanced force is applied to them. After they are in motion, they stay in motion until another force opposes their motion.

Inertia

Newton's first law of motion is also called the law of inertia. **Inertia** is the tendency of an object to resist a change in its motion. If an object is already at rest, inertia will keep it at rest. If the object is already moving, inertia will keep it moving.

Think about what happens when you are riding in a car that stops suddenly. Your body moves forward on the seat. Why? The brakes stop the car but not your body, so your body keeps moving forward because of inertia. That's why it's important to always wear a seat belt. Inertia also explains the amusement park ride in **Figure** 10.15. The car keeps changing direction, but the riders keep moving in the same direction as before. They slide to the opposite side of the car as a result. You can see an animation of inertia at this URL: http://www.physicsclassroom.com/mmedia/newtlaws/cci.cfm .

Inertia and Mass

The inertia of an object depends on its mass. Objects with greater mass also have greater inertia. Think how hard it would be to push a big box full of books, like the one in **Figure** 10.17. Then think how easy it would be to push the box if it was empty. The full box is harder to move because it has greater mass and therefore greater inertia.

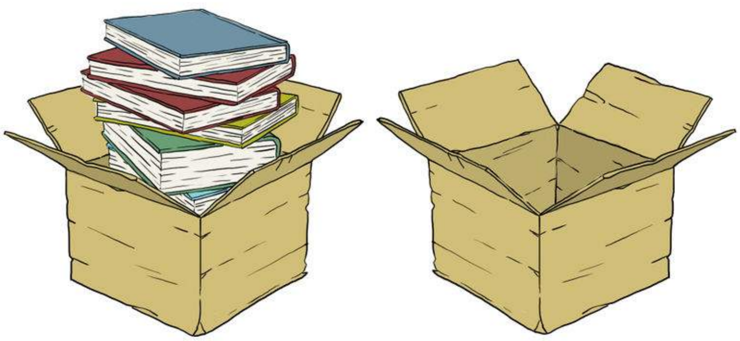


FIGURE 10.17
The tendency of an object to resist a change in its motion depends on its mass. Which box has greater inertia?

Overcoming Inertia

To change the motion of an object, inertia must be overcome by an unbalanced force acting on the object. Until the soccer player kicks the ball in **Figure** 10.18, the ball remains motionless on the ground. However, when the ball is kicked, the force on it is suddenly unbalanced. The ball starts moving across the field because its inertia has been overcome.

FIGURE 10.18
Force must be applied to overcome the inertia of a soccer ball at rest.

Once objects start moving, inertia keeps them moving without any additional force being applied. In fact, they won't stop moving unless another unbalanced force opposes their motion. What if the rolling soccer ball is not kicked by another player or stopped by a fence or other object? Will it just keep rolling forever? It would if another unbalanced force did not oppose its motion. Friction —in this case rolling friction with the ground —will oppose the motion of the rolling soccer ball. As a result, the ball will eventually come to rest. Friction opposes the motion of all moving objects, so, like the soccer ball, all moving objects eventually come to a stop even if no other forces oppose their motion.

Lesson Summary

- Newton's first law of motion states that an object's motion will not change unless an unbalanced force acts on the object. If the object is at rest, it will stay at rest. If the object is in motion, it will stay in motion.
- Inertia is the tendency of an object to resist a change in its motion. The inertia of an object depends on its mass. Objects with greater mass have greater inertia. To overcome inertia, an unbalanced force must be applied to an object.

Lesson Review Questions

Recall

1. State Newton's first law of motion.
2. Define inertia.
3. How does an object's mass affect its inertia?

Apply Concepts

4. Assume you are riding a skateboard and you run into a curb. Your skateboard suddenly stops its forward motion. Apply the concept of inertia to this scenario, and explain what happens next.

Think Critically

5. Why is Newton's first law of motion also called the law of inertia?

Points to Consider

In this lesson, you read that the mass of an object determines its inertia. You also learned that an unbalanced force must be applied to an object to overcome its inertia, whether it is moving or at rest. An unbalanced force causes an object to accelerate.

- Predict how the mass of an object affects its acceleration when an unbalanced force is applied to it.
- How do you think the acceleration of an object is related to the strength of the unbalanced force acting on it?

10.4 Newton's Second Law

Lesson Objectives

- State Newton's second law of motion.
- Identify the relationship between acceleration and weight.

Lesson Vocabulary

- Newton's second law of motion

Introduction

A car's gas pedal, like the one in **Figure** 10.19, is sometimes called the accelerator. That's because it controls the acceleration of the car. Pressing down on the gas pedal gives the car more gas and causes the car to speed up. Letting up on the gas pedal gives the car less gas and causes the car to slow down. Whenever an object speeds up, slows down, or changes direction, it accelerates. Acceleration is a measure of the change in velocity of a moving object. Acceleration occurs whenever an object is acted upon by an unbalanced force.

FIGURE 10.19

The car pedal on the right controls the amount of gas the engine gets. How does this affect the car's acceleration?

Acceleration, Force, and Mass

Newton determined that two factors affect the acceleration of an object: the net force acting on the object and the object's mass. The relationships between these two factors and motion make up **Newton's second law of motion**. This law states that the acceleration of an object equals the net force acting on the object divided by the object's mass. This can be represented by the equation:

$$\text{Acceleration} = \frac{\text{Net force}}{\text{Mass}}, \text{ or}$$
$$a = \frac{F}{m}$$

You can watch a video about how Newton's second law of motion applies to football at this URL: http://science360.gov/obj/video/58e62534-e38d-430b-bfb1-c505e628a2d4 .

Direct and Inverse Relationships

Newton's second law shows that there is a direct relationship between force and acceleration. The greater the force that is applied to an object of a given mass, the more the object will accelerate. For example, doubling the force on the object doubles its acceleration. The relationship between mass and acceleration, on the other hand, is an inverse relationship. The greater the mass of an object, the less it will accelerate when a given force is applied. For example, doubling the mass of an object results in only half as much acceleration for the same amount of force.

Consider the example of a batter, like the boy in **Figure** 10.20. The harder he hits the ball, the greater will be its acceleration. It will travel faster and farther if he hits it with more force. What if the batter hits a baseball and a softball with the same amount of force? The softball will accelerate less than the baseball because the softball has greater mass. As a result, it won't travel as fast or as far as the baseball.

FIGURE 10.20

Hitting a baseball with greater force gives it greater acceleration. Hitting a softball with the same amount of force results in less acceleration. Can you explain why?

Calculating Acceleration

The equation for acceleration given above can be used to calculate the acceleration of an object that is acted on by an unbalanced force. For example, assume you are pushing a large wooden trunk, like the one shown in **Figure** 10.21. The trunk has a mass of 10 kilograms, and you are pushing it with a force of 20 newtons. To calculate the acceleration of the trunk, substitute these values in the equation for acceleration:

$$a = \frac{F}{m} = \frac{20 \text{ N}}{10 \text{ kg}} = \frac{2 \text{ N}}{\text{kg}}$$

Recall that one newton (1 N) is the force needed to cause a 1-kilogram mass to accelerate at 1 m/s^2. Therefore, force can also be expressed in the unit kg·m/s^2. This way of expressing force can be substituted for newtons in the solution to the problem:

$$a = \frac{2 \text{ N}}{\text{kg}} = \frac{2 \text{ kg} \cdot \text{m/s}^2}{\text{kg}} = 2 \text{ m/s}^2$$

Why are there no kilograms in the final answer to this problem? The kilogram units in the numerator and denominator of the fraction cancel out. As a result, the answer is expressed in the correct units for acceleration: m/s^2.

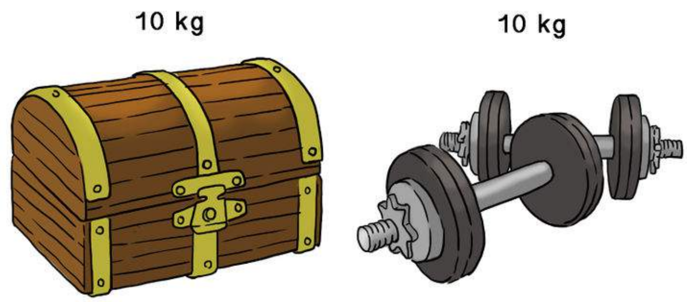


FIGURE 10.21
This empty trunk has a mass of 10 kilograms. The weights also have a mass of 10 kilograms. If the weights are placed in the trunk, what will be its mass? How will this affect its acceleration?

You Try It!

Problem: Assume that you add the weights to the trunk in **Figure** 10.21. If you push the trunk and weights with a force of 20 N, what will be the trunk's acceleration?

Need more practice? You can find additional problems at this URL: http://www.auburnschools.org/ajhs/lmcrowe/Week%2014/WorksheetPracticeProblemsforNewtons2law.pdf .

Acceleration and Weight

Newton's second law of motion explains the weight of objects. Weight is a measure of the force of gravity pulling on an object of a given mass. It's the force (F) in the acceleration equation that was introduced above:

$$a = \frac{F}{m}$$

This equation can also be written as:

$$F = m \times a$$

The acceleration due to gravity of an object equals 9.8 m/s^2, so if you know the mass of an object, you can calculate its weight as:

$$F = m \times 9.8 \text{ m/s}^2$$

As this equation shows, weight is directly related to mass. As an object's mass increases, so does its weight. For example, if mass doubles, weight doubles as well. You can learn more about weight and acceleration at this URL: http://www.nasa.gov/mov/192448main_018_force_equals_mass_time.mov .

Problem Solving

Problem: Daisy has a mass of 35 kilograms. How much does she weigh?

Solution: Use the formula: $F = m \times 9.8 \text{ m/s}^2$.

$F = 35 \text{ kg} \times 9.8 \text{ m/s}^2 = 343.0 \text{ kg} \cdot \text{m/s}^2 = 343.0 \text{ N}$

You Try It!

Problem: Daisy's dad has a mass is 70 kg, which is twice Daisy's mass. Predict how much Daisy's dad weighs. Then calculate his weight to see if your prediction is correct.

Helpful Hints

The equation for calculating weight ($F = m \times a$) works only when the correct units of measurement are used.

- Mass must be in kilograms (kg).
- Acceleration must be in m/s^2.
- Weight (F) is expressed in kg·m/s^2 or in newtons (N).

Lesson Summary

- Newton's second law of motion states that the acceleration of an object equals the net force acting on the object divided by the object's mass.
- Weight is a measure of the force of gravity pulling on an object of a given mass. It equals the mass of the object (in kilograms) times the acceleration due to gravity (9.8 m/s^2).

Lesson Review Questions

Recall

1. State Newton's second law of motion.
2. Describe how the net force acting on an object is related to its acceleration.
3. If the mass of an object increases, how is its acceleration affected, assuming the net force acting on the object remains the same?
4. What is weight?

Apply Concepts

5. Tori applies a force of 20 newtons to move a bookcase with a mass of 40 kg. What is the acceleration of the bookcase?
6. Ollie has a mass of 45 kilograms. What is his weight in newtons?

Think Critically

7. If you know your weight in newtons, how could you calculate your mass in kilograms? What formula would you use?

Points to Consider

Assume that a 5-kilogram skateboard and a 50-kilogram go-cart start rolling down a hill. Both are moving at the same speed. You and a friend want to stop before they plunge into a pond at the bottom of the hill.

- Which will be harder to stop: the skateboard or the go-cart?
- Can you explain why?

10.5 Newton's Third Law

Lesson Objectives

- State Newton's third law of motion.
- Describe momentum and the conservation of momentum.

Lesson Vocabulary

- law of conservation of momentum
- momentum
- Newton's third law of motion

Introduction

Look at the skateboarders in **Figure** 10.22. When they push against each other, it causes them to move apart. The harder they push together, the farther apart they move. This is an example of Newton's third law of motion.

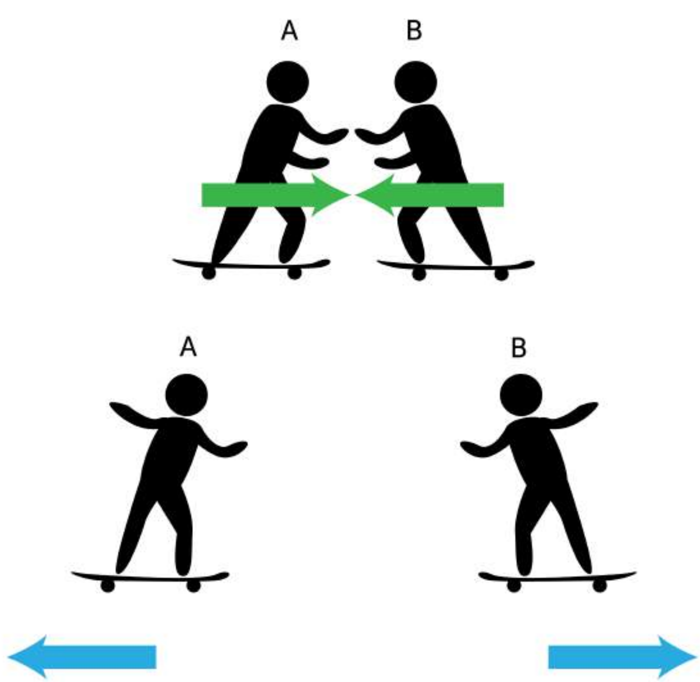


FIGURE 10.22

A and B move apart by first pushing together.

Action and Reaction

Newton's third law of motion states that every action has an equal and opposite reaction. This means that forces always act in pairs. First an action occurs, such as the skateboarders pushing together. Then a reaction occurs that is equal in strength to the action but in the opposite direction. In the case of the skateboarders, they move apart, and the distance they move depends on how hard they first pushed together. You can see other examples of actions and reactions in **Figure** 10.23. You can watch a video about actions and reactions at this URL: http://www.nasa.gov/mov/192449main_019_law_of_action.mov .

FIGURE 10.23

Each example shown here includes an action and reaction.

You might think that actions and reactions would cancel each other out like balanced forces do. Balanced forces, which are also equal and opposite, cancel each other out because they act on the same object. Action and reaction forces, in contrast, act on different objects, so they don't cancel each other out and, in fact, often result in motion. For example, in **Figure** 10.23, the kangaroo's action acts on the ground, but the ground's reaction acts on the kangaroo. As a result, the kangaroo jumps away from the ground. One of the action-reaction examples in the **Figure** 10.23 does not result in motion. Do you know which one it is?

Momentum

What if a friend asked you to play catch with a bowling ball, like the one pictured in **Figure** 10.24? Hopefully, you would refuse to play! A bowling ball would be too heavy to catch without risk of injury —assuming you could even throw it. That's because a bowling ball has a lot of mass. This gives it a great deal of momentum. **Momentum** is a property of a moving object that makes the object hard to stop. It equals the object's mass times its velocity. It can be represented by the equation:

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

This equation shows that momentum is directly related to both mass and velocity. An object has greater momentum if it has greater mass, greater velocity, or both. For example, a bowling ball has greater momentum than a softball when both are moving at the same velocity because the bowling ball has greater mass. However, a softball moving at a very high velocity —say, 100 miles an hour —would have greater momentum than a slow-rolling bowling ball. If an object isn't moving at all, it has no momentum. That's because its velocity is zero, and zero times anything is zero.

FIGURE 10.24
A bowling ball and a softball differ in mass. How does this affect their momentum?

Calculating Momentum

Momentum can be calculated by multiplying an object's mass in kilograms (kg) by its velocity in meters per second (m/s). For example, assume that a golf ball has a mass of 0.05 kg. If the ball is traveling at a velocity of 50 m/s, its momentum is:

$$\text{Momentum} = 0.05 \text{ kg} \times 50 \text{ m/s} = 2.5 \text{ kg} \cdot \text{m/s}$$

Note that the SI unit for momentum is kg·m/s.

Problem Solving

Problem: What is the momentum of a 40-kg child who is running straight ahead with a velocity of 2 m/s?

Solution: The child has momentum of: 40 kg $\times$ 2 m/s = 80 kg·m/s.

You Try It!

Problem: Which football player has greater momentum?

Player A: mass = 60 kg; velocity = 2.5 m/s

Player B: mass = 65 kg; velocity = 2.0 m/s

Conservation of Momentum

When an action and reaction occur, momentum is transferred from one object to the other. However, the combined momentum of the objects remains the same. In other words, momentum is conserved. This is the **law of conservation of momentum**.

Consider the example of a truck colliding with a car, which is illustrated in **Figure** 10.25. Both vehicles are moving in the same direction before and after the collision, but the truck is moving faster than the car before the collision occurs. During the collision, the truck transfers some of its momentum to the car. After the collision, the truck is moving slower and the car is moving faster than before the collision occurred. Nonetheless, their combined momentum is the same both before and after the collision. You can see an animation showing how momentum is conserved in a head-on collision at this URL: http://www.physicsclassroom.com/mmedia/momentum/cthoi.cfm .

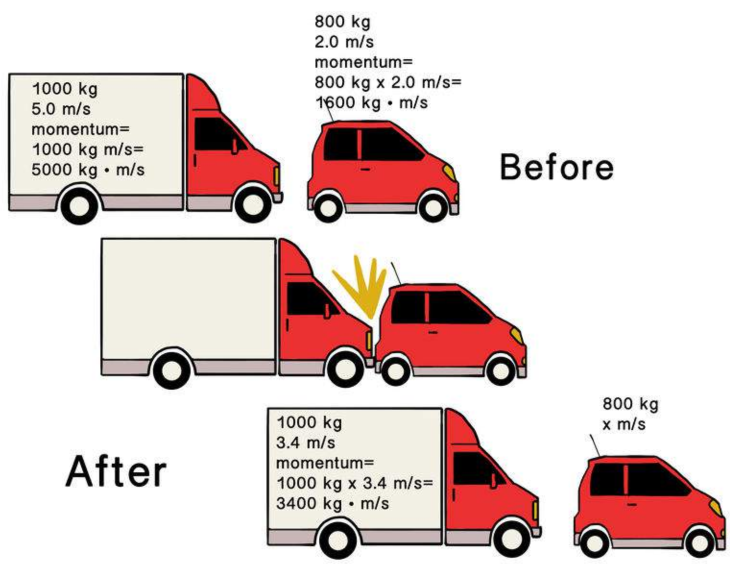


FIGURE 10.25
How can you tell momentum has been conserved in this collision?

Lesson Summary

- Newton's third law of motion states that every action has an equal and opposite reaction.
- Momentum is a property of a moving object that makes it hard to stop. It equals the object's mass times its velocity. When an action and reaction occur, momentum may be transferred from one object to another, but their combined momentum remains the same. This is the law of conservation of momentum.

Lesson Review Questions

Recall

1. State Newton's third law of motion.
2. Define momentum.

3. If you double the velocity of a moving object, how is its momentum affected?

Apply Concepts

4. A large rock has a mass of 50 kg and is rolling downhill at 3 m/s. What is its momentum?
5. Create a diagram to illustrate the transfer and conservation of momentum when a moving object collides with a stationary object.

Think Critically

6. The reaction to an action is an equal and opposite force. Why doesn't this yield a net force of zero?
7. Momentum is a property of an object, but it is different than a physical or chemical property, such as boiling point or flammability. How is momentum different?

Points to Consider

In this chapter, you learned about forces and motions of solid objects, such as balls and cars. In the next chapter, "Fluid Forces," you will learn about forces in fluids, which include liquids and gases.

- How do fluids differ from solids?
- What might be examples of forces in fluids? For example, what force allows some objects to float in water?

10.6 Friction

Lesson Objectives

- Describe friction and how it opposes motion.
- Identify types of friction.

Lesson Vocabulary

- fluid
- friction

Introduction

Did you ever rub your hands together to warm them up, like the girl in **Figure** 10.26? Why does this make your hands warmer? The answer is friction.

FIGURE 10.26
This girl is using friction to make her hands warmer.

What Is Friction?

Friction is a force that opposes motion between two surfaces that are touching. Friction can work for or against us. For example, putting sand on an icy sidewalk increases friction so you are less likely to slip. On the other hand, too much friction between moving parts in a car engine can cause the parts to wear out. Other examples of friction are illustrated in **Figure** 10.27. You can see an animation showing how friction opposes motion at this URL: http://www.darvill.clara.net/enforcemot/friction.htm .

FIGURE 10.27
Sometimes friction is useful. Sometimes it's not.

Why Friction Occurs

Friction occurs because no surface is perfectly smooth. Even surfaces that look smooth to the unaided eye appear rough or bumpy when viewed under a microscope. Look at the metal surfaces in **Figure** 10.28. The metal foil is so smooth that it is shiny. However, when highly magnified, the surface of metal appears to be very bumpy. All those mountains and valleys catch and grab the mountains and valleys of any other surface that contacts the metal. This creates friction.

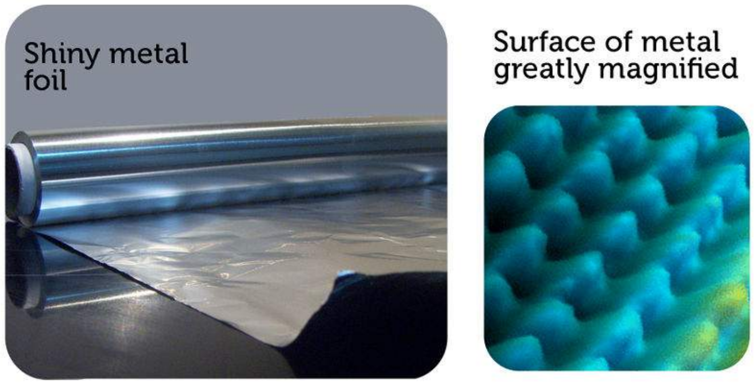


FIGURE 10.28
The surface of metal looks very smooth unless you look at it under a high-powered microscope.

Factors that Affect Friction

Rougher surfaces have more friction between them than smoother surfaces. That's why we put sand on icy sidewalks and roads. Increasing the area of surfaces that are touching also increases the friction between them. That's why you can't slide as far across ice with shoes as you can with skates (see **Figure** 10.29). The greater surface area of shoes causes more friction and slows you down. Heavier objects also have more friction because they press together with greater force. Did you ever try to push boxes or furniture across the floor? It's harder to overcome friction between heavier objects and the floor than it is between lighter objects and the floor.

FIGURE 10.29
The knife-like blades of speed skates minimize friction with the ice.

Friction Produces Heat

You know that friction produces heat. That's why rubbing your hands together makes them warmer. But do you know why the rubbing produces heat? Friction causes the molecules on rubbing surfaces to move faster, so they have more heat energy. Heat from friction can be useful. It not only warms your hands. It also lets you light a match (see **Figure** 10.30). On the other hand, heat from friction can be a problem inside a car engine. It can cause the car to overheat. To reduce friction, oil is added to the engine. Oil coats the surfaces of moving parts and makes them slippery so there is less friction.

FIGURE 10.30
When you rub the surface of a match head across the rough striking surface on the matchbox, the friction produces enough heat to ignite the match.

Types of Friction

There are different ways you could move heavy boxes. You could pick them up and carry them. You could slide them across the floor. Or you could put them on a dolly like the one in **Figure** 10.31 and roll them across the floor. This example illustrates three types of friction: static friction, sliding friction, and rolling friction. Another type of friction is fluid friction. All four types of friction are described below. In each type, friction works opposite the direction of the force applied to a move an object. You can see a video demonstration of the different types of friction at this URL: http://www.youtube.com/watch?v=0bXpYblzkR0 (1:07).

FIGURE 10.31
A dolly with wheels lets you easily roll boxes across the floor.

Static Friction

Static friction acts on objects when they are resting on a surface. For example, if you are walking on a sidewalk, there is static friction between your shoes and the concrete each time you put down your foot (see **Figure** 10.32). Without this static friction, your feet would slip out from under you, making it difficult to walk. Static friction also allows you to sit in a chair without sliding to the floor. Can you think of other examples of static friction?

FIGURE 10.32
Static friction between shoes and the sidewalk makes it possible to walk without slipping.

Sliding Friction

Sliding friction is friction that acts on objects when they are sliding over a surface. Sliding friction is weaker than static friction. That's why it's easier to slide a piece of furniture over the floor after you start it moving than it is to get it moving in the first place. Sliding friction can be useful. For example, you use sliding friction when you write with a pencil and when you put on your bike's brakes.

Rolling Friction

Rolling friction is friction that acts on objects when they are rolling over a surface. Rolling friction is much weaker than sliding friction or static friction. This explains why it is much easier to move boxes on a wheeled dolly than by carrying or sliding them. It also explains why most forms of ground transportation use wheels, including cars, 4-wheelers, bicycles, roller skates, and skateboards. Ball bearings are another use of rolling friction (see **Figure** 10.33). They allow parts of a wheel or other machine to roll rather than slide over one another.

Fluid Friction

Fluid friction is friction that acts on objects that are moving through a fluid. A **fluid** is a substance that can flow and take the shape of its container. Fluids include liquids and gases. If you've ever tried to push your open hand through the water in a tub or pool, then you've experienced fluid friction between your hand and the water. When a skydiver is falling toward Earth with a parachute, fluid friction between the parachute and the air slows the descent (see **Figure** 10.34). Fluid pressure with the air is called air resistance. The faster or larger a moving object is, the

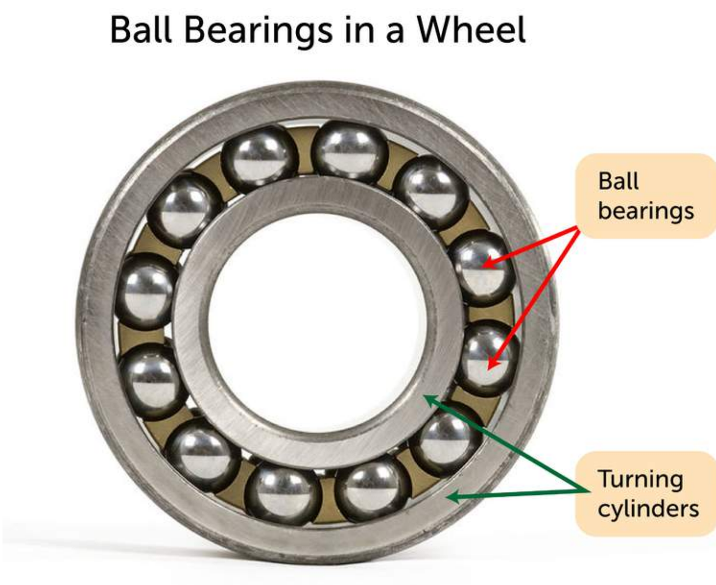


FIGURE 10.33
The ball bearings in this wheel reduce friction between the inner and outer cylinders when they turn.

greater is the fluid friction resisting its motion. The very large surface area of a parachute, for example, has greater air resistance than a skydiver's body.

Lesson Summary

- Friction is a force that opposes motion between two surfaces that are touching. Friction occurs because no surface is perfectly smooth. Friction is greater when objects have rougher surfaces, have more surface area that is touching, or are heavier so they press together with greater force.
- Types of friction include static friction, sliding friction, rolling friction, and fluid friction. Fluid friction with air is called air resistance.

Lesson Review Questions

Recall

1. What is friction?
2. List factors that affect friction.
3. How does friction produce heat?

Apply Concepts

4. Identify two forms of friction that oppose the motion of a moving car.

FIGURE 10.34
Fluid friction of the parachute with the air slows this skydiver as he falls.

Think Critically

5. Explain why friction occurs.
6. Compare and contrast the four types of friction described in this lesson.

Points to Consider

A skydiver like the one in **Figure** 10.34 falls to the ground despite the fluid friction of his parachute with the air. Another force pulls him toward Earth. That force is gravity, which is the topic of the next lesson.

- What do you already know about gravity?
- What do you think causes gravity?

10.7 Buoyancy of Fluids

Lesson Objectives

- Describe the nature of buoyant force.
- State Archimedes' law.

Lesson Vocabulary

- Archimedes' law
- buoyancy
- buoyant force

Introduction

The fishing float in **Figure** 10.35 bobs on the surface of the water. The fish in the figure is suspended in the water near the surface. Why do the float and fish stay on or near the surface? Why don't they sink? The answer is buoyancy, another property of fluids.

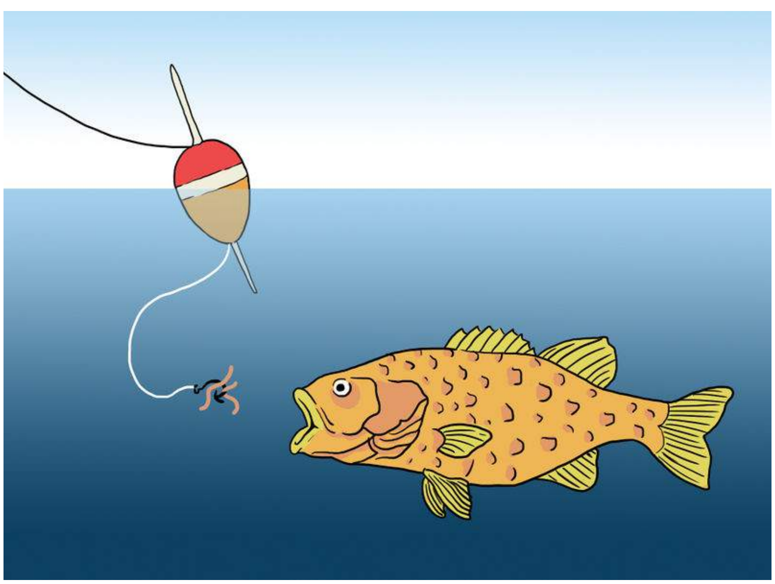


FIGURE 10.35
A fishing float keeps the fishing line near the surface so it doesn't sink to the bottom of the lake.

Buoyant Force

Buoyancy is the ability of a fluid to exert an upward force on any object placed in the fluid. This upward force is called **buoyant force**.

Pressure and Buoyant Force

What explains buoyant force? Recall from the earlier lesson "Pressure of Fluids" that a fluid exerts pressure in all directions but the pressure is greater at greater depth. Therefore, the fluid below an object exerts greater force on the object than the fluid above the object. This is illustrated in **Figure** 10.36. Buoyant force explains why objects may float in water. No doubt you've noticed, however, that some objects do not float in water. If buoyant force applies to all objects in fluids, why do some objects sink instead of float? The answer has to do with their weight.

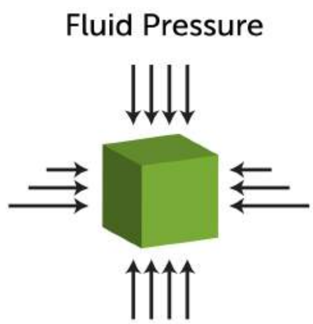


FIGURE 10.36
Fluid pressure exerts force on all sides of this object, but the force is greater at the bottom of the object where the fluid is deeper.

Weight and Buoyant Force

Weight is a measure of the force of gravity pulling down on an object. Buoyant force pushes up on an object. Weight and buoyant force together determine whether an object sinks or floats. This is illustrated in **Figure** 10.37.

- If an object's weight is less than the buoyant force acting on the object, then the object floats. This is the example on the left in **Figure** 10.37.
- If an object's weight is greater than the buoyant force acting on the object, then the object sinks. This is the example on the right in **Figure** 10.37.

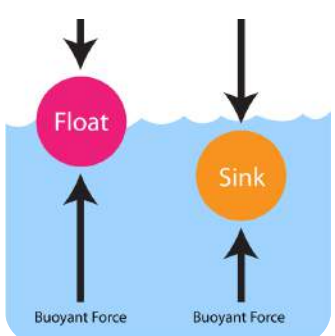
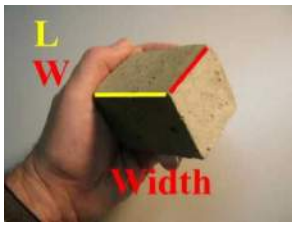


FIGURE 10.37
Whether an object sinks or floats depends on its weight and the strength of the buoyant force acting on it.

Because of buoyant force, objects seem lighter in water. You may have noticed this when you went swimming and could easily pick up a friend or sibling under the water. Some of the person's weight was countered by the buoyant force of the water.

Density and Buoyant Force

Density, or the amount of mass in a given volume, is also related to buoyancy. That's because density affects weight. A given volume of a denser substance is heavier than the same volume of a less dense substance. For example, ice is less dense than liquid water. This explains why ice cubes float in a glass of water. This and other examples of density and buoyant force are illustrated in **Figure** 10.38 and in the video at this URL: http://www.youtube.com/watch?v=VDSYXmvjg6M (12:08).



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Archimedes' Law

Did you ever notice that when you get into a bathtub of water the level of the water rises? More than 2200 years ago, a Greek mathematician named Archimedes noticed the same thing. He observed that both a body and the water in a tub can't occupy the same space at the same time. As a result, some of the water is displaced, or moved out of the way. How much water is displaced? Archimedes determined that the volume of displaced water equals the volume of the submerged object. So more water is displaced by a bigger body than a smaller one.

What does displacement have to do with buoyant force? Everything! Archimedes discovered that the buoyant force acting on an object in a fluid equals the weight of the fluid displaced by the object. This is known as **Archimedes' law** (or Archimedes' Principle).

Archimedes' law explains why some objects float in fluids even though they are very heavy. Remember the oil tanker that opened this chapter? It is extremely heavy, yet it stays afloat. If a steel ball with the same weight as the ship were put into water, it would sink to the bottom (see **Figure** 10.39). That's because the volume of water displaced by the steel ball weighs less than the ball. As a result, the buoyant force is not as great as the force of gravity acting on the ball. The design of the ship's hull, on the other hand, causes it to displace much more water than the ball. In fact, the weight of the displaced water is greater than the weight of the ship, so the buoyant force is greater than the force of gravity acting on the ship. As a result, the ship floats. You can check your understanding of Archimedes' law by doing the brainteaser at this URL: http://www.pbs.org/wgbh/nova/lasalle/buoyquestion.html .

For an entertaining video presentation of Archimedes' law, go to this URL: http://videos.howstuffworks.com/discovery/6540-mythbusters-lets-talk-buoyancy-video.htm .

Lesson Summary

- Buoyancy is the ability of a fluid to exert an upward force on any object placed in it. The upward force is called buoyant force. An object's weight and the buoyant force acting on it determine whether the object sinks

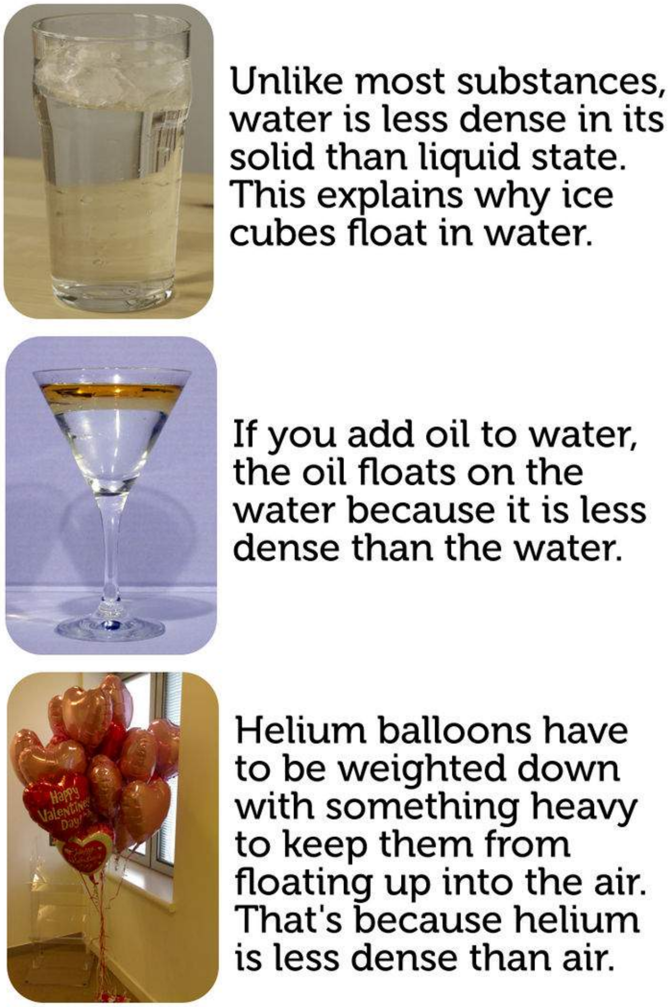

FIGURE 10.38
The substances pictured here float in a fluid because they are less dense than the fluid.

or floats. Less dense objects and fluids float in fluids with greater density.

- The buoyant force acting on an object in a fluid equals the weight of the fluid displaced by the object. This is known as Archimedes' law (or Archimedes' Principle). It explains why some objects float in fluids even though they are very heavy.

Lesson Review Questions

Recall

1. What is buoyancy?
2. Describe how weight and buoyant force determine whether an object sinks or floats.
3. How is density related to buoyancy?

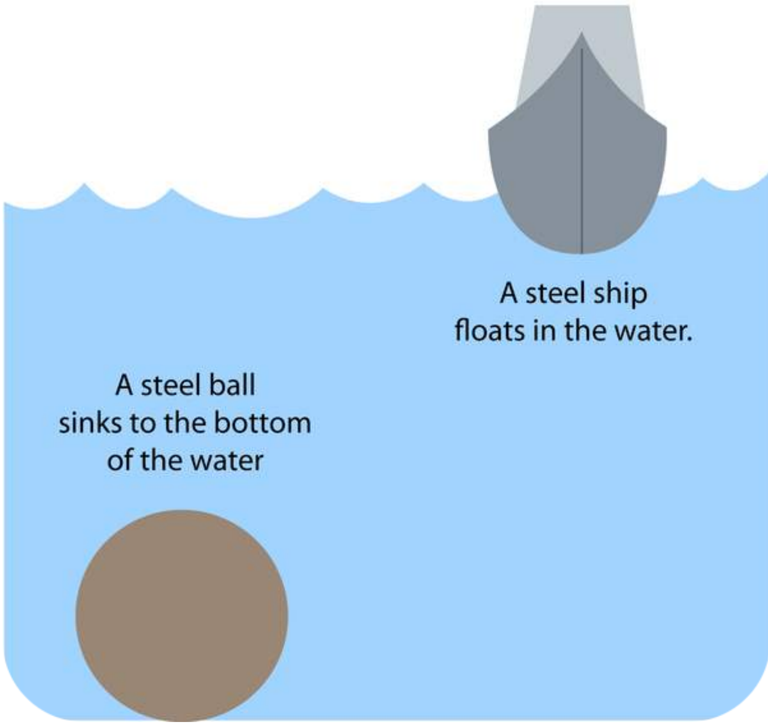

FIGURE 10.39
Archimedes' law explains why a heavy ship floats. Its shape causes it to displace more water than a ball of the same weight.

Apply Concepts

4. Apply Archimedes' law to explain why some very heavy objects float in water.

Think Critically

5. Relate displacement of a fluid by an object to the buoyant force acting on the object.

Points to Consider

In this chapter, you saw how pressure and buoyancy of fluids can be used to make work easier —from raising a car on a lift to floating a ship on the ocean. Devices that make work easier are called machines in physics.

- What are some examples of machines?
- How do these machines make work easier?

10.8 Pressure of Fluids

Lesson Objectives

- Describe pressure and how to calculate it.
- Relate fluid depth and density to pressure.
- State Pascal's and Bernoulli's laws.

Lesson Vocabulary

- Bernoulli's law
- pascal (Pa)
- Pascal's law

Introduction

Did you ever use a bicycle pump like the one in **Figure** 10.40? The pump forces air into a tire through a small hole. Like other fluids (both liquids and gases), air can flow and take the shape of its container. The air that enters the tire from the pump quickly spreads out to fill the entire tire evenly. As the tire fills with air, it feels firmer. That's because the air exerts pressure against the inside surface of the tire.

FIGURE 10.40
You can use a bicycle pump to force air into a tire.

What Is Pressure?

All fluids exert pressure like the air inside a tire. The particles of fluids are constantly moving in all directions at random. As the particles move, they keep bumping into each other and into anything else in their path. These collisions cause pressure, and the pressure is exerted equally in all directions. When particles are crowded together in one part of their container, they quickly spread out to fill their container. They always move from an area of higher pressure to an area of lower pressure. That's why air entering a tire quickly spreads throughout the tire.

Pressure, Force, and Area

Pressure is the result of force acting on a given area. It can be represented by the equation:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Pressure shows how concentrated the force is on a given area. The smaller the area to which force is applied, the greater the pressure is. Think about pressing a pushpin, like the one in **Figure** 10.41, into a bulletin board. You apply force with your thumb to the broad head of the pushpin. However, the force that the pushpin applies to the bulletin board acts only over the tiny point of the pin. This is a much smaller area, so the pressure the point applies to the bulletin board is much greater than the pressure you apply with you thumb. As a result, the pin penetrates the bulletin board with ease.

FIGURE 10.41
A pushpin concentrates the force you apply to it. Can you explain how?

SI Unit for Pressure

In the equation for pressure, force is expressed in newtons (N) and area is expressed in square meters (m^2). Therefore, pressure is expressed in N/m^2, which is the SI unit for pressure. This unit is also called the **pascal (Pa)**. It is named for the scientist Blaise Pascal, whose discovery about pressure in fluids is described later in this lesson. Pressure may also be expressed in the kilopascal (kPa), which equals 1000 pascals. For example, the correct air pressure inside a mountain bike tire is usually about 200 kPa.

Calculating Pressure or Force

When you know how much force is acting on a given area, you can calculate the pressure that is being applied to the area using the equation for pressure given above. For example, assume that a big rock weighs 500 newtons and is resting on the ground on an area of 0.5 m^2. The pressure exerted on the ground by the rock is:

$$\text{Pressure} = \frac{500 \text{ N}}{0.5 \text{ m}^2} = 1000 \text{ N/m}^2 = 1000 \text{ Pa, or } 1 \text{ kPa}$$

Sometimes pressure but not force is known. To calculate force, the equation for pressure can be rewritten as:

$$\text{Force} = \text{Pressure} \times \text{Area}$$

For example, suppose another rock exerts 2 kPa of pressure over an area of 0.3 m^2. How much does the rock weigh? Change 2 kPa to 2000 N/m^2 and substitute it for pressure in the force equation:

$$\text{Force (Weight)} = 2000\ \text{N/m}^2 \times 0.3\ \text{m}^2 = 600\ \text{N}$$

Problem Solving

Problem: A break dancer has a weight of 450 N. She is balancing on the ground on one hand. The palm of her hand has an area of 0.02 m^2. How much pressure does her hand exert on the ground?

Solution: Use the equation Pressure $= \frac{\text{Force}}{\text{Area}}$.

$$\text{Pressure} = \frac{450\ \text{N}}{0.02\ \text{m}^2} = 22500\ \text{Pa, or } 22.5\ \text{kPa}$$

You Try It!

Problem: If the break dancer lies down on the ground on her back, her weight is spread over an area of 0.75 m^2. How much pressure does she exert on the ground in this position?

Pressure in the Ocean and the Atmosphere

Both the water in the ocean and the air in the atmosphere exert pressure because of their moving particles. The ocean and atmosphere also illustrate two factors that affect pressure in fluids: depth and density.

- A fluid exerts more pressure at greater depths. Deeper in a fluid, all of the fluid above results in more weight pressing down. This causes greater pressure.
- Denser fluids such as water exert more pressure than less dense fluids such as air. The particles of denser fluids are closer together, so there are more collisions in a given area. This is illustrated in **Figure** 10.42 for water and air.

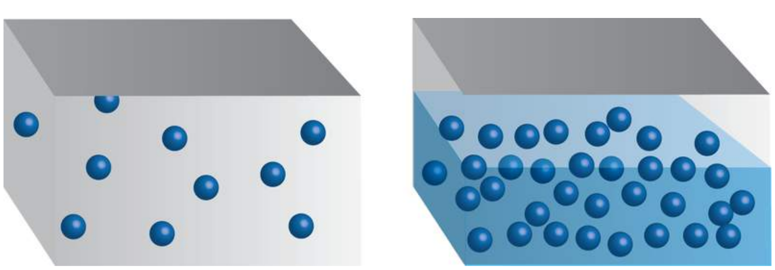

FIGURE 10.42
Differences in density between water and air lead to differences in pressure.

Water Pressure

As you go deeper in the ocean, the pressure exerted by the water increases steadily. The diagram in **Figure** 10.43 shows how pressure changes with depth. For every additional meter below the surface, pressure increases by 10 kPa. At 30 meters below the surface, the pressure is double the pressure at the surface. At a depth greater than 500 meters, the pressure is too great for humans to withstand without special equipment to protect them. Around 9000 meters below the surface, in the deepest part of the ocean, the pressure is tremendous. You can see a video demonstration of changes in water pressure with depth at this URL: http://www.youtube.com/watch?v=dL08xX4lBQg (0:42).

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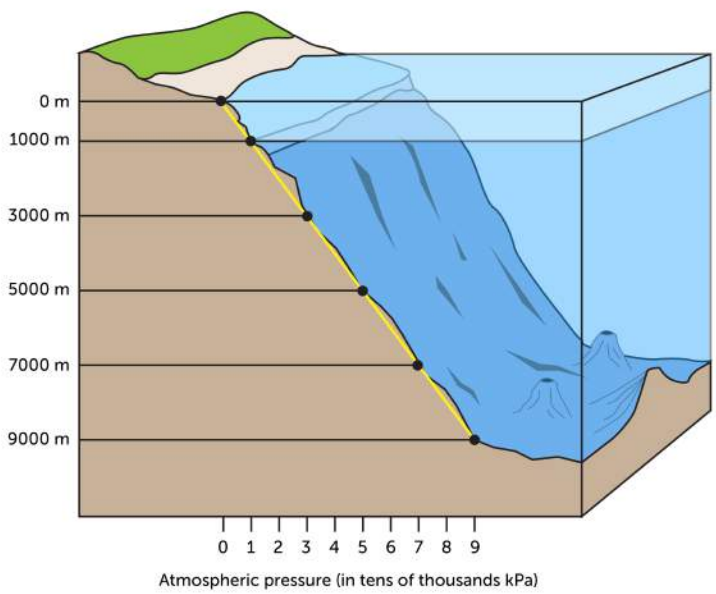

FIGURE 10.43

The pressure of ocean water increases rapidly as the water gets deeper.

Because of the pressure of the water, divers who go deeper than about 40 meters below the surface must return to the surface slowly and stop for several minutes at one or more points in their ascent. That's what the divers in **Figure** 10.44 are doing. The stops are needed to let the pressure inside their body adjust to the decreasing pressure of the water as they swim closer to the surface. If they were to rise to the surface too quickly, the gases dissolved in their blood would form bubbles and cause serious health problems.

Air Pressure

Like water in the ocean, air in the atmosphere exerts pressure that increases with depth. Most gas molecules in the atmosphere are pulled close to Earth's surface by gravity. As a result, air pressure decreases quickly at lower altitudes and then more slowly at higher altitudes. This is illustrated in **Figure** 10.45. Air pressure is greatest at sea level, where the depth of the atmosphere is greatest. At higher altitudes, the pressure is less because the depth of

FIGURE 10.44
These scuba divers are taking a rest stop on their way up to the surface to adjust to decreasing water pressure.

the atmosphere is less. For example, on top of Mount Everest, the tallest mountain on Earth, air pressure is only about one-third of the pressure at sea level. At such high altitudes, low air pressure makes it hard to breathe and is dangerous to human health.

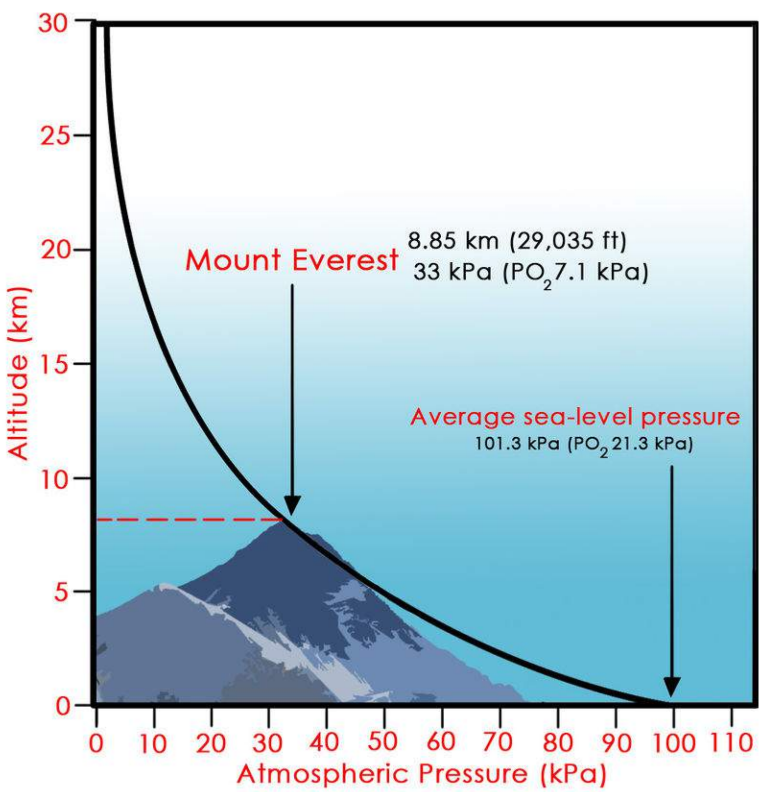

FIGURE 10.45
This graph shows how air pressure decreases with increasing altitude.

The pressure of air in the atmosphere allows you to do many things, from sipping through a straw to simply breathing (see **Figure** 10.46).

- When you first suck on a straw, you remove air from the straw, so the air pressure in the straw is lower than

the air pressure on the surface of the drink. Because fluid flows from an area of high to low pressure, the drink moves up the straw and into your mouth.
- When you breathe, a muscle called the diaphragm causes the rib cage and lungs to expand or contract. When they expand, the air in the lungs is under less pressure than the air outside the body, so air flows into the lungs. When the ribs and lungs contract, air in the lungs is under greater pressure than air outside the body, so air flows out of the lungs.

For more examples of how we use air pressure, watch the video at this URL: http://www.youtube.com/watch?v=ZG29OJyZpyA (3:06).

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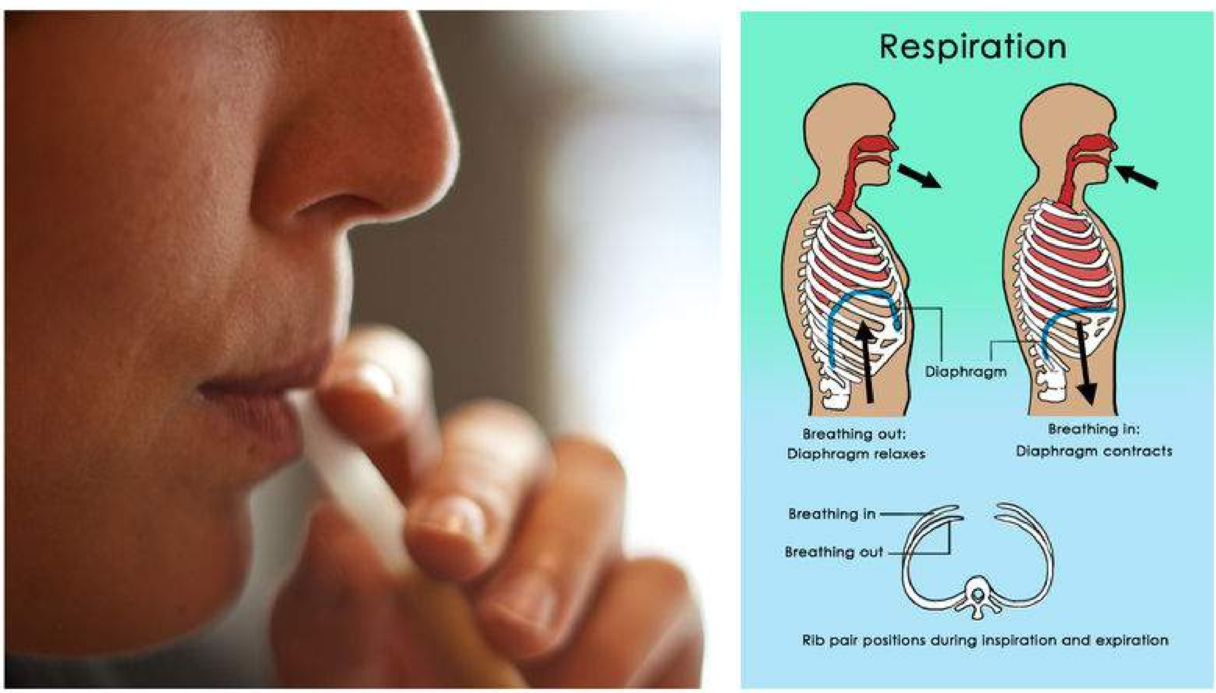

FIGURE 10.46
Both drinking through a straw and moving air into and out of the lungs is possible because of differences in air pressure. Can you think of other ways that differences in air pressure are useful?

Laws of Fluid Pressure

Some of the earliest scientific research on fluids was conducted by a French mathematician and physicist named Blaise Pascal (1623–1662). Pascal was a brilliant thinker. While still a teen, he derived an important theorem in mathematics and also invented a mechanical calculator. One of Pascal's contributions to our understanding of fluids is known as Pascal's law.

Pascal's Law

Pascal's law states that a change in pressure at any point in an enclosed fluid is transmitted equally throughout the fluid. A simple example may help you understand Pascal's law. Assume you have a small packet of ketchup, like the one in **Figure** 10.47. If you open one end of the packet and then apply pressure to the other end, what will happen? Ketchup will squirt out the open end. The pressure you exert on the packet is transmitted throughout the ketchup. When the pressure reaches the open end, it forces ketchup out of the packet. To see a video about Pascal's law, go to this URL: http://www.youtube.com/watch?v=4uRnPTQxZtw (2:59).

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FIGURE 10.47

Ketchup is a fluid, so it transmits pressure from one end of the packet to the other.

The ability of fluids to transmit pressure in this way can be very useful —besides providing ketchup for your French fries! For example, the hydraulic car lift in **Figure** 10.48 contains fluid that transmits pressure and raises a car so a mechanic can work on it from below. The fluid used, usually a type of oil, can't be compressed. Force is placed on the fluid in a narrow cylinder, and the fluid transmits the pressure throughout the hydraulic system. When the pressure reaches the fluid in the wide cylinder, it forces the cylinder upward, along with the car. The force applied to the car is much greater than the force applied to the fluid in the narrow cylinder. Why? When pressure acts over a wider area, it creates a larger force. That's because force equals pressure multiplied by the area over which it acts, as you saw above in the equation Force = Pressure $\times$ Area.

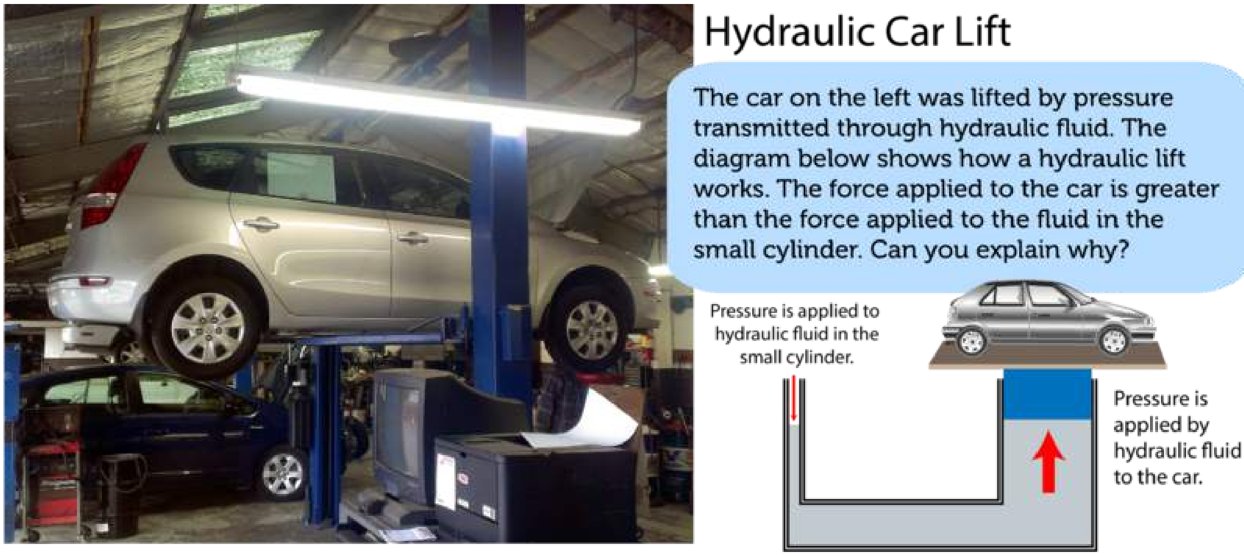


FIGURE 10.48
Pascal's law explains why fluid can be used to transmit pressure in a car lift.

Besides hydraulic car lifts, other equipment that uses hydraulic fluid to increase force ranges from brakes to bulldozers. Even the controls in airplanes use hydraulics. Because of the force-multiplying effect, a flick of a switch can raise or lower heavy wing flaps or landing gear. You can see animations of hydraulic systems at these URLs:

- http://science.howstuffworks.com/transport/engines-equipment/hydraulic1.htm
- http://home.wxs.nl/~brink494/hydr_e.htm

Bernoulli's Law

Another important law about pressure in fluids was described by Daniel Bernoulli, a Swiss mathematician who lived during the 1700s. Bernoulli used mathematics to arrive at his law. **Bernoulli's law** states that pressure in a moving fluid is less when the fluid is moving faster. For an animation of this law, go to the URL below.

http://mitchellscience.com/bernoulli_law_animation

Bernoulli's law explains how the wings of both airplanes and birds create lift that allows flight (see **Figure** 10.49). The shape of the wings causes air to flow more quickly —and air pressure to be lower —above the wings than below them. This allows the wings to lift the plane or bird above the ground against the pull of gravity. A spoiler on a race car, like the one in **Figure** 10.49, works in the opposite way. Its shape causes air to flow more slowly —and air pressure to be greater —above the spoiler than below it. As a result, air pressure pushes the car downward, giving its wheels better traction on the track.

Lesson Summary

- All fluids exert pressure because their particles are constantly moving at random in all directions and bumping into things. Pressure can be represented by the equation: Pressure $= \frac{\text{Force}}{\text{Area}}$. The SI unit for pressure is the

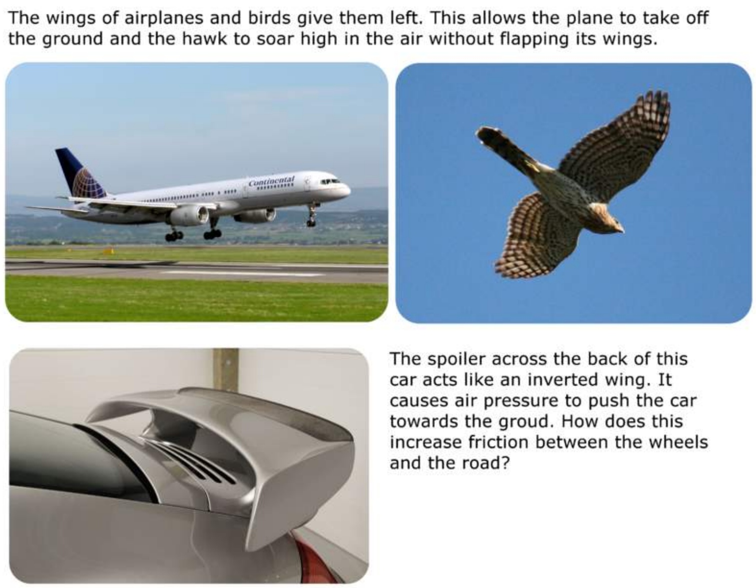


FIGURE 10.49

How does Bernoulli's law explain each of these examples?

pascal (Pa), which equals 1 N/m^2.

- Two factors that affect the pressure of fluids are depth and density. This explains why water pressure is greater deeper in the ocean and air pressure is greatest at sea level. Denser fluids, such as water, exert more pressure than less dense fluids, such as air.
- Pascal's law states that a change in pressure at any point in an enclosed fluid is transmitted equally throughout the fluid. This law is the basis of hydraulic equipment, such as hydraulic car lifts. Bernoulli's law states that pressure in a moving fluid is less when the fluid is moving faster. This law explains how the wings of both airplanes and birds create lift.

Lesson Review Questions

Recall

1. Define pressure.
2. What is the SI unit for pressure?
3. Identify two factors that affect the pressure of fluids.
4. Describe how pressure changes with depth in fluids.

Apply Concepts

5. Apply Pascal's law to explain why squeezing one end of a toothpaste tube causes toothpaste to squirt out the other end.
6. A box weighing 200 N is resting on the ground on an area of 1 m^2. How much pressure is the box exerting on the ground?

Think Critically

7. Explain why fluids exert pressure.

8. Relate Bernoulli's law to lift in an airplane.

Points to Consider

If you've ever floated in water, you may have noticed that filling your lungs with air helps to keep you afloat.

- Why do you think having more air in your lungs helps you float in water?
- What other things float in water? What things don't float? How do they differ?

10.9 Convection

- Define convection, and explain how it occurs.
- Describe convection currents.
- Give examples of the transfer of thermal energy by convection.

Do you see the water bubbling in this pot? The water is boiling hot. How does all of the water in the pot get hot when it is heated only from the bottom by the gas flame? The answer is convection.

Defining Convection

Convection is the transfer of thermal energy by particles moving through a fluid (either a gas or a liquid). Thermal energy is the total kinetic energy of moving particles of matter, and the transfer of thermal energy is called heat. Convection is one of three ways that thermal energy can be transferred (the other ways are conduction and thermal radiation). Thermal energy is always transferred from matter with a higher temperature to matter with a lower temperature.

How Does Convection Occur?

The **Figure** 10.50 shows how convection occurs, using hot water in a pot as an example. When particles in one area of a fluid (in this case, the water at the bottom of the pot) gain thermal energy, they move more quickly, have more collisions, and spread farther apart. This decreases the density of the particles, so they rise up through the fluid. As they rise, they transfer their thermal energy to other particles of the fluid and cool off in the process. With less energy, the particles move more slowly, have fewer collisions, and move closer together. This increases their density, so they sink back down through the fluid. When they reach the bottom of the fluid, the cycle repeats. The result is a loop of moving particles called a **convection current**. You can learn more about convection currents by watching the cartoon video called "Convection" at this URL: http://www.sciencehelpdesk.com/unit/science2/3

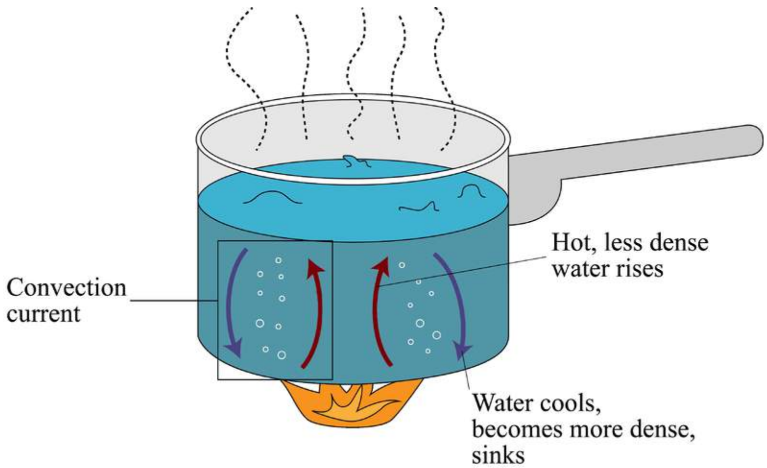


FIGURE 10.50

Examples of Convection

Convection currents transfer thermal energy through many fluids, not just hot water in a pot. For example, convection currents transfer thermal energy through molten rock below Earth's surface, through water in the oceans, and through air in the atmosphere. Convection currents in the atmosphere create winds. You can see one way this happens in the **Figure** 10.51. The land heats up and cools off faster than the water because it has lower specific heat. Therefore, the land gets warmer during the day and cooler at night than the water does. During the day, warm air rises above the land and cool air from the water moves in to take its place. During the night, the opposite happens. Warm air rises above the water and cool air from the land moves out to take its place.

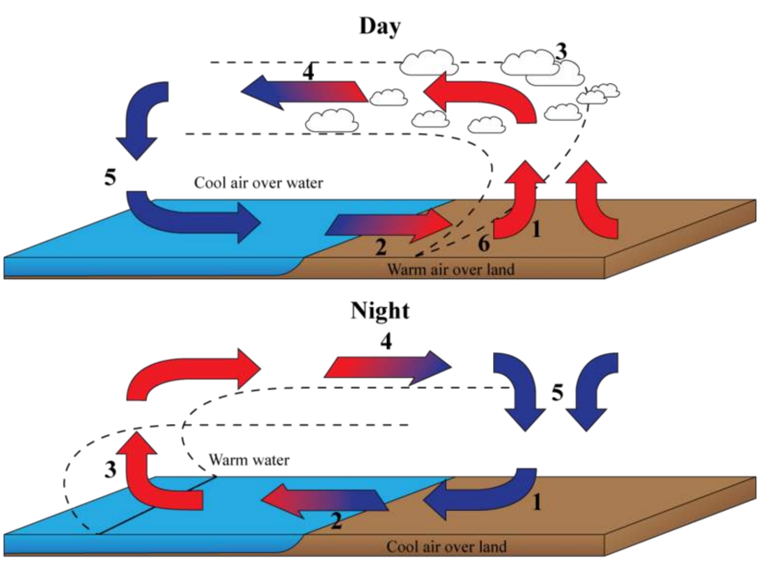


FIGURE 10.51

Q: During the day, in which direction is thermal energy of the air transferred? In which direction is it transferred during the night?

A: During the day, thermal energy is transferred from the air over the land to the air over the water. During the night, thermal energy is transferred in the opposite direction.

Summary

- Convection is the transfer of thermal energy by particles moving through a fluid. Thermal energy is always transferred from an area with a higher temperature to an area with a lower temperature.
- Moving particles transfer thermal energy through a fluid by forming convection currents.
- Convection currents move thermal energy through many fluids, including molten rock inside Earth, water in the oceans, and air in the atmosphere.

Vocabulary

- **convection**: Transfer of thermal energy by particles moving through a fluid.
- **convection current**: Flow of particles in a fluid that occurs because of differences in temperature and density.

Practice

Watch the video at the following URL, and then answer the questions below. http://video.google.com/videoplay?docid=1902141755519014330#docid=7379647004466944857

1. Describe what you observed in the video.
2. Explain your observations.
3. Predict what you would observe if the procedure in the video continued.

Review

1. What is convection?
2. Describe how convection occurs and why convection currents form.
3. Add arrows representing convection currents to the room in the **Figure** 10.52 to show how thermal energy moves from the radiator to the rest of the room. Label areas of the room that are warm and cool.

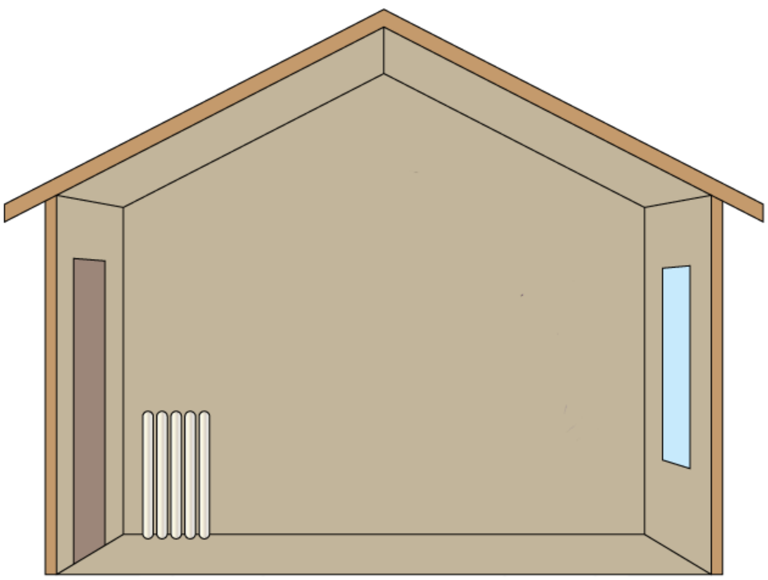


FIGURE 10.52

10.10 The Electromagnetic Spectrum

Lesson Objectives

- Define the electromagnetic spectrum.
- Describe radio waves and their uses.
- Identify three forms of light.
- Describe X rays and gamma rays.

Lesson Vocabulary

- electromagnetic spectrum
- gamma ray
- infrared light
- microwave
- radar
- radio wave
- ultraviolet light
- visible light
- X ray

Introduction

Imagine playing beach volleyball, like the young men in **Figure** 10.53. They may not realize it, but they are being bombarded by electromagnetic radiation as play in the sunlight. The only kinds of radiation they can detect are visible light, which allows them to see, and infrared light, which they feel as warmth on their skin. What other kinds of electromagnetic radiation are they being exposed to in sunlight? In this lesson, you'll find out.

What Is The Electromagnetic Spectrum?

Electromagnetic radiation occurs in waves of different wavelengths and frequencies. Infrared light and visible light make up just a small part of the full range of electromagnetic radiation, which is called the **electromagnetic spectrum**. The electromagnetic spectrum is summarized in the diagram in **Figure** 10.54.

- On the far left of the diagram are radio waves, which include microwaves. They have the longest wavelengths and lowest frequencies of all electromagnetic waves. They also have the least amount of energy.
- On the far right are X rays and gamma rays. The have the shortest wavelengths and highest frequencies of all electromagnetic waves. They also have the greatest amount of energy.

FIGURE 10.53
Electromagnetic radiation from the sun reaches Earth across space. It strikes everything on Earth's surface, including these volleyball players.

- Between these two extremes, wavelength, frequency, and energy change continuously from one side of the spectrum to the other. Waves in this middle section of the electromagnetic spectrum are commonly called light.

As you will read below, the properties of electromagnetic waves influence how the different waves behave and how they can be used.

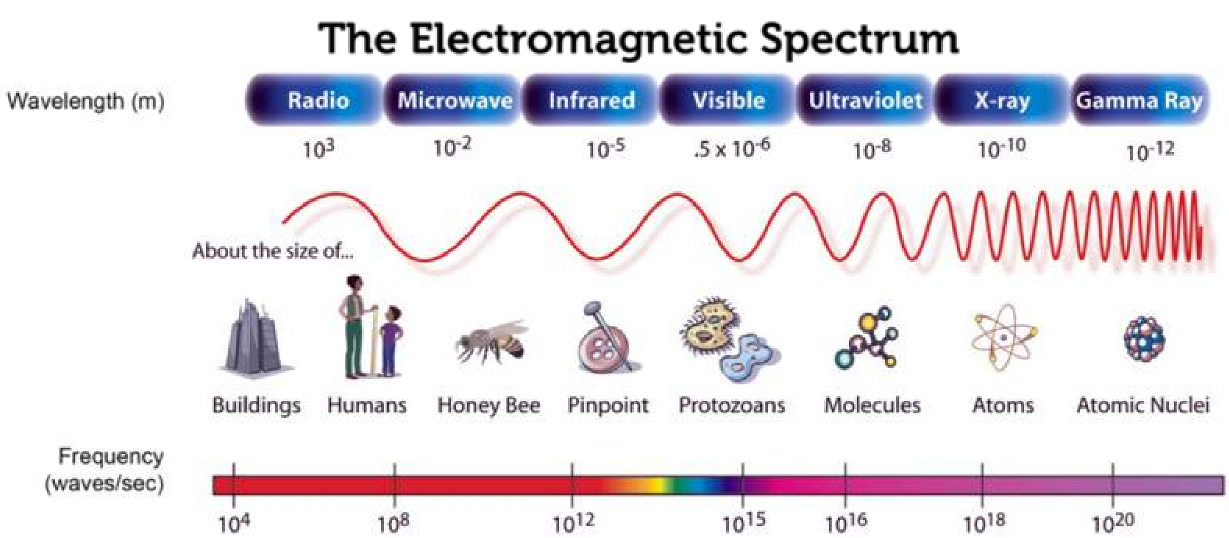
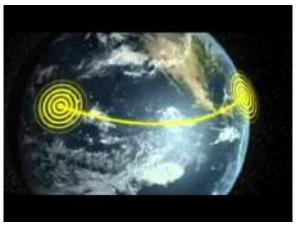


FIGURE 10.54
How do the wavelength and frequency of waves change across the electromagnetic spectrum?

Radio Waves

Radio waves are the broad range of electromagnetic waves with the longest wavelengths and lowest frequencies. In **Figure** 10.54, you can see that the wavelength of radio waves may be longer than a soccer field. With their low frequencies, radio waves have the least energy of electromagnetic waves, but they still are extremely useful. They are used for radio and television broadcasts, microwave ovens, cell phone transmissions, and radar. You can learn more about radio waves, including how they were discovered, at this URL: http://www.youtube.com/watch?v=al7sFP4C2TY (3:58).



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AM and FM Radio

In radio broadcasts, sounds are encoded in radio waves that are sent out through the atmosphere from a radio tower. A receiver detects the radio waves and changes them back to sounds. You've probably listened to both AM and FM radio stations. How sounds are encoded in radio waves differs between AM and FM broadcasts.

- AM stands for amplitude modulation. In AM broadcasts, sound signals are encoded by changing the amplitude of radio waves. AM broadcasts use longer–wavelength radio waves than FM broadcasts. Because of their longer wavelengths, AM radio waves reflect off a layer of the upper atmosphere called the ionosphere. You can see how this happens in **Figure** 10.55. This allows AM radio waves to reach radio receivers that are very far away from the radio tower.
- FM stands for frequency modulation. In FM broadcasts, sound signals are encoded by changing the frequency of radio waves. Frequency modulation allows FM waves to encode more information than does amplitude modulation, so FM broadcasts usually sound clearer than AM broadcasts. However, because of their shorter wavelength, FM waves do not reflect off the ionosphere. Instead, they pass right through it and out into space (see **Figure** 10.55). As a result, FM waves cannot reach very distant receivers.

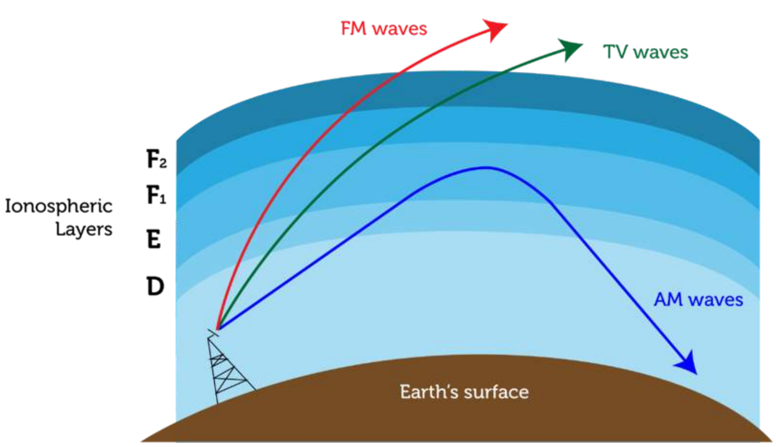

FIGURE 10.55

AM radio waves reflect off the ionosphere and travel back to Earth. Radio waves used for FM radio and television pass through the ionosphere and do not reflect back.

Television

Television broadcasts also use radio waves. Sounds are encoded with frequency modulation, and pictures are encoded with amplitude modulation. The encoded radio waves are broadcast from a TV tower like the one in **Figure** 10.56. When the waves are received by television sets, they are decoded and changed back to sounds and pictures.

FIGURE 10.56
This television tower broadcasts signals using radio waves.

Microwaves

The shortest wavelength, highest frequency radio waves are called **microwaves** (see **Figure** 10.54). Microwaves have more energy than other radio waves. That's why they are useful for heating food in microwave ovens. Microwaves have other important uses as well, including cell phone transmissions and **radar**, which is a device for determining the presence and location of an object by measuring the time for the echo of a radio wave to return from it and the direction from which it returns. These uses are described in **Figure** 10.57. You can learn more about microwaves and their uses in the video at this URL: http://www.youtube.com/watch?v=YgQQb1BVnu8 (3:23).

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Light

Mid-wavelength electromagnetic waves are commonly called light. This range of electromagnetic waves has shorter wavelengths and higher frequencies than radio waves, but not as short and high as X rays and gamma rays. Light includes visible light, infrared light, and ultraviolet light. If you look back at **Figure** 10.54, you can see where these different types of light waves fall in the electromagnetic spectrum.

Visible Light

The only light that people can see is called **visible light**. It refers to a very narrow range of wavelengths in the electromagnetic spectrum that falls between infrared light and ultraviolet light. Within the visible range, we see light

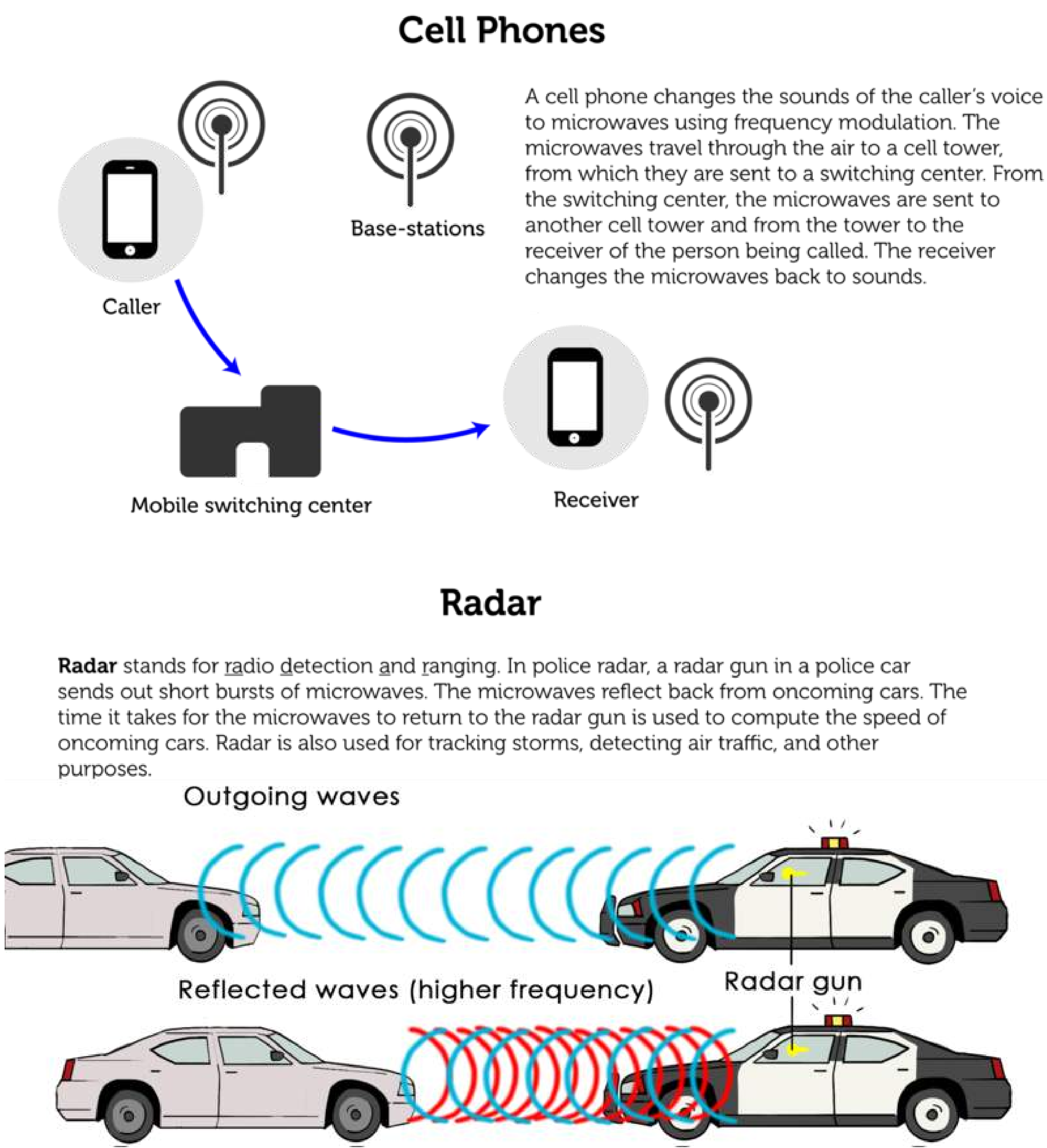

FIGURE 10.57

Microwaves are used for cell phones and radar.

of different wavelengths as different colors of light, from red light, which has the longest wavelength, to violet light, which has the shortest wavelength. You can see the spectrum of colors of visible light in **Figure** 10.58. When all of the wavelengths are combined, as they are in sunlight, visible light appears white. You can learn more about visible light in the chapter "Visible Light" and at the URL below.

http://www.youtube.com/watch?v=PMtC34pzKGc (4:50)

MEDIA

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FIGURE 10.58

Red light (right) has the longest wavelength, and violet light (left) has the shortest wavelength.

Infrared Light

Light with the longest wavelengths is called **infrared light**. The term *infrared* means "below red." Infrared light is the range of light waves that have longer wavelengths than red light in the visible spectrum. You can't see infrared light waves, but you can feel them as heat on your skin. The sun gives off infrared light as do fires and living things. The picture of a cat that opened this chapter was made with a camera that detects infrared light waves and changes their energy to colored light in the visible range. Night vision goggles, which are used by law enforcement and the military, also detect infrared light waves. The goggles convert the invisible waves to visible images. For a deeper understanding of infrared light, watch the video at this URL: http://www.youtube.com/watch?v=2–0q0XlQJ0 (6:46).

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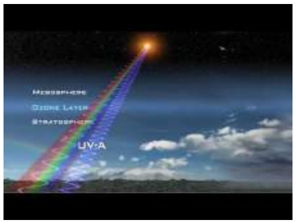
Ultraviolet Light

Light with wavelengths shorter than visible light is called **ultraviolet light**. The term *ultraviolet* means "above violet." Ultraviolet light is the range of light waves that have shorter wavelengths than violet light in the visible spectrum. Humans can't see ultraviolet light, but it is very useful nonetheless. It has higher-frequency waves than visible light, so it has more energy. It can be used to kill bacteria in food and to sterilize laboratory equipment (see **Figure** 10.59). The human skin also makes vitamin D when it is exposed to ultraviolet light. Vitamin D is needed for strong bones and teeth. You can learn more about ultraviolet light and its discovery at this URL: http://www.youtube.com/watch?v=QW5zeVy8aE0 (3:40).



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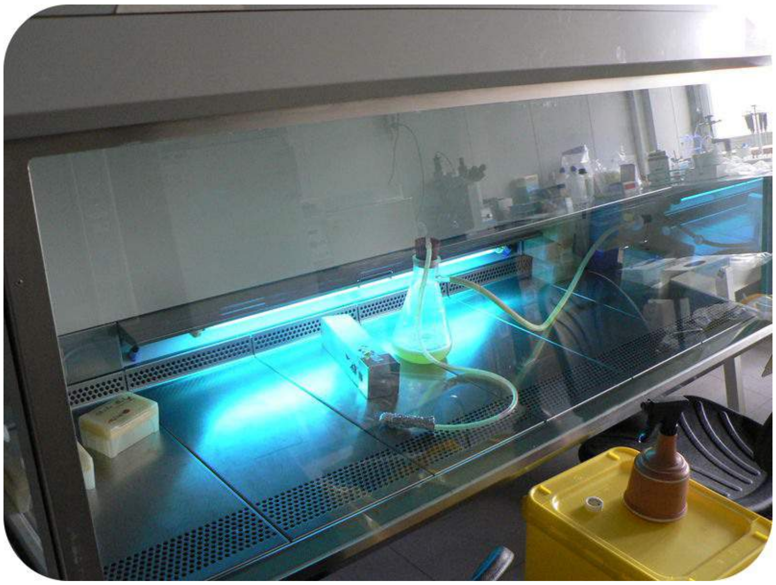

FIGURE 10.59

This sterilizer for laboratory equipment uses ultraviolet light to kill bacteria.

Too much exposure to ultraviolet light can cause sunburn and skin cancer. You can protect your skin from ultraviolet light by wearing clothing that covers your skin and by applying sunscreen to any exposed areas. The SPF, or sun-protection factor, of sunscreen gives a rough idea of how long it protects the skin from sunburn (see **Figure** 10.60). A sunscreen with a higher SPF protects the skin longer. You should use sunscreen with an SPF of at least 15 even on cloudy days, because ultraviolet light can travel through clouds. Sunscreen should be applied liberally and often. You can learn more about the effects of ultraviolet light on the skin at this URL: http://www.youtube.com/watch?v=np-BBJyl-go (5:59).

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X Rays and Gamma Rays

The shortest-wavelength, highest-frequency electromagnetic waves are X rays and gamma rays. These rays have so much energy that they can pass through many materials. This makes them potentially very harmful, but it also makes them useful for certain purposes.

FIGURE 10.60
If your skin normally burns in 10 minutes of sun exposure, using sunscreen with an SPF of 30 means that, ideally, your skin will burn only after 30 times 10 minutes, or 300 minutes, of sun exposure. How long does sunscreen with an SPF of 50 protect skin from sunburn?

X Rays

X rays are high-energy electromagnetic waves. They have enough energy to pass through soft tissues such as skin but not enough to pass through bones and teeth, which are very dense. The bright areas on the X ray film in **Figure** 10.61 show where X rays were absorbed by the teeth. X rays are used not only for dental and medical purposes but also to screen luggage at airports (see **Figure** 10.61). Too much X ray exposure may cause cancer. If you've had dental X rays, you may have noticed that a heavy apron was placed over your body to protect it from stray X rays. The apron is made of lead, which X rays cannot pass through. You can learn about the discovery of X rays as well as other uses of X rays at this URL: http://www.guardian.co.uk/science/blog/2010/oct/26/x-ray-visions-disease-forgeries .

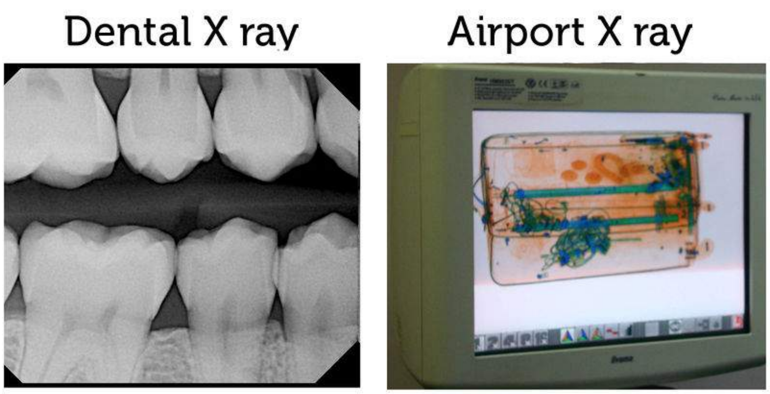
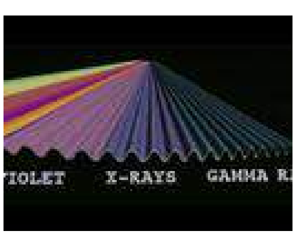


FIGURE 10.61
Two common uses of X rays are illustrated here.

Gamma Rays

Gamma rays are the most energetic of all electromagnetic waves. They can pass through most materials, including bones and teeth. Nonetheless, even these waves are useful. For example, they can be used to treat cancer. A medical device sends gamma rays the site of the cancer, and the rays destroy the cancerous cells. If you want to learn more about gamma rays, watch the video at the URL below.

http://www.youtube.com/watch?v=okyynBaSOtA (2:45)



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Lesson Summary

- The electromagnetic spectrum is the full range of wavelengths and frequencies of electromagnetic radiation. Wavelength, frequency, and energy change continuously across the electromagnetic spectrum.
- Radio waves are the broad range of electromagnetic waves with the longest wavelengths and lowest frequencies. They are used for radio and television broadcasts, microwave ovens, cell phone transmissions, and radar.
- Mid-wavelength electromagnetic waves are called light. Light consists of visible, infrared, and ultraviolet light. Humans can see only visible light. Infrared light has longer wavelengths than visible light and is perceived as warmth. Ultraviolet light has shorter wavelengths than visible light and has enough energy to kill bacteria. It can also harm the skin.
- X rays and gamma rays are the electromagnetic waves with the shortest wavelengths and highest frequencies. X rays are used in medicine and dentistry and to screen luggage at airports. Gamma rays are used to kill cancer cells.

Lesson Review Questions

Recall

1. What is the electromagnetic spectrum?
2. Describe how wave frequency changes across the electromagnetic spectrum, from radio waves to gamma rays.
3. List three uses of radio waves.
4. How are X rays and gamma rays used in medicine?

Apply Concepts

5. Create a public service video warming people of the dangers of ultraviolet light. Include tips for protecting the skin from ultraviolet light.

Think Critically

6. Explain two ways that sounds can be encoded in electromagnetic waves.
7. Explain how radar works.
8. Compare and contrast infrared, visible, and ultraviolet light.

Points to Consider

This chapter introduces visible light. The chapter "Visible Light" discusses visible light in greater detail.

- In this lesson, you read that visible light consists of light of different colors. Do you know how visible light can be separated into its different colors? (*Hint:* How does a rainbow form?)
- In the next chapter, *Visible Light*, you'll read that visible light interacts with matter in certain characteristic ways. Based on your own experiences with visible light, how does it interact with matter? (*Hint:* What happens to visible light when it strikes a wall, window, or mirror?)

10.11 Electromagnetic Waves

Lesson Objectives

- Describe electromagnetic waves.
- Explain how electromagnetic waves begin.
- State how electromagnetic waves travel.
- Summarize the wave-particle theory of light.
- Identify sources of electromagnetic waves.

Lesson Vocabulary

- electromagnetic radiation
- electromagnetic wave
- photon

Introduction

Both infrared light and visible light are examples of electromagnetic radiation. **Electromagnetic radiation** is the transfer of energy by waves traveling through matter or across empty space. The waves that transfer this energy are called electromagnetic waves. In this lesson, you'll learn how electromagnetic waves differ from mechanical waves such as ocean waves and sound waves. For an excellent video introduction to electromagnetic waves, go to this URL: http://www.youtube.com/watch?v=cfXzwh3KadE (5:20).

MEDIA

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What Are Electromagnetic Waves?

An **electromagnetic wave** is a wave that consists of vibrating electric and magnetic fields. A familiar example will help you understand the fields that make up an electromagnetic wave. Think about a common bar magnet. It exerts magnetic force in an area surrounding it, called the magnetic field. You can see the magnetic field of a bar magnet in **Figure** 10.62. Because of this force field, a magnet can exert force on objects without touching them. They just have to be in its magnetic field. An electric field is similar to a magnetic field (see **Figure** 10.62). An electric field is an area of electrical force surrounding a charged particle. Like a magnetic field, an electric field can exert force on objects over a distance without actually touching them.

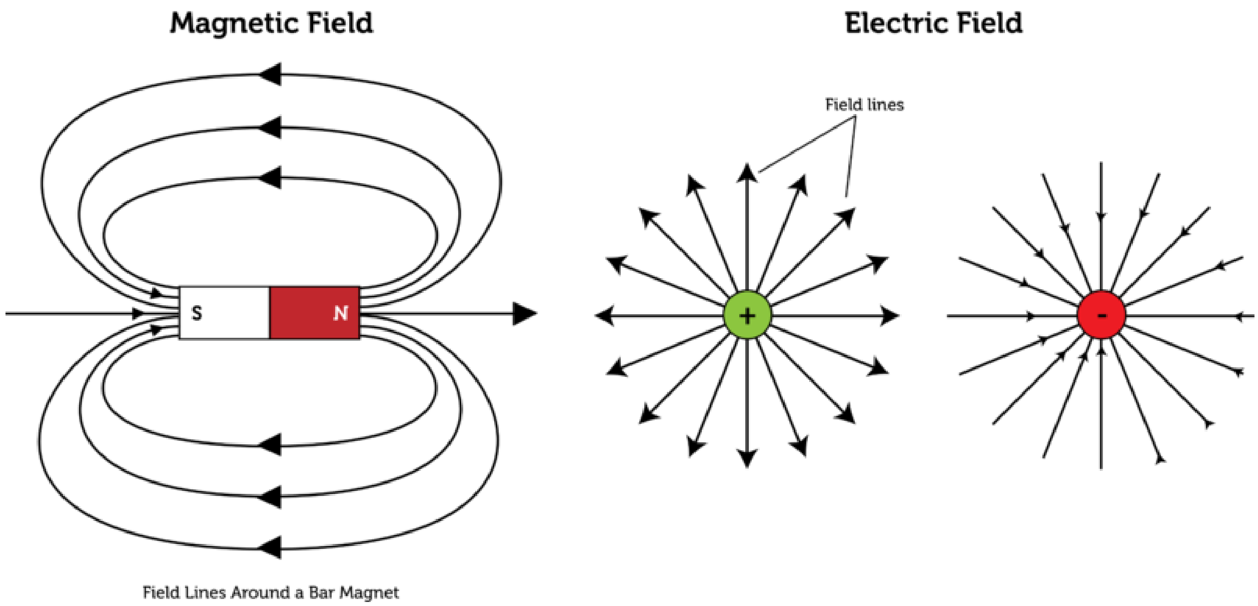
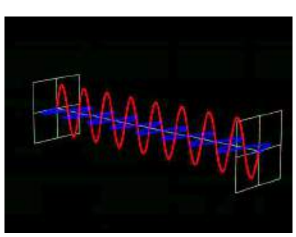


FIGURE 10.62

Magnetic and electric fields are invisible areas of force surrounding magnets and charged particles. The field lines in the diagrams represent the direction and location of the force.

How Electromagnetic Waves Begin

An electromagnetic wave begins when an electrically charged particle vibrates. This is illustrated in **Figure** 10.63. When a charged particle vibrates, it causes the electric field surrounding it to vibrate as well. A vibrating electric field, in turn, creates a vibrating magnetic field (you can learn how this happens in the chapter "Electromagnetism"). The two types of vibrating fields combine to create an electromagnetic wave. You can see an animation of an electromagnetic wave at this URL: http://www.youtube.com/watch?v=Qju7QnbrOhM (1:31).



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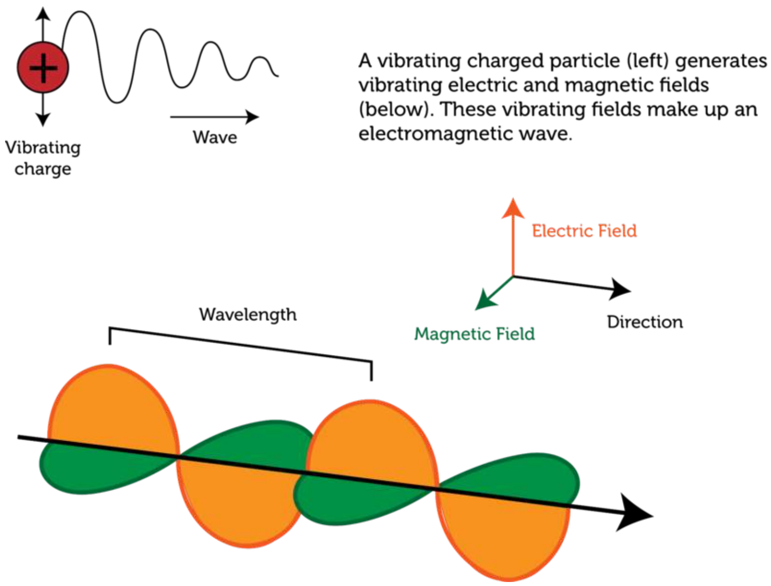

FIGURE 10.63
An electromagnetic wave starts with a vibrating charged particle.

How Electromagnetic Waves Travel

As you can see in **Figure** 10.63, the electric and magnetic fields that make up an electromagnetic wave occur are at right angles to each other. Both fields are also at right angles to the direction that the wave travels. Therefore, an electromagnetic wave is a transverse wave.

No Medium Required

Unlike a mechanical transverse wave, which requires a medium, an electromagnetic transverse wave can travel through space without a medium. Waves traveling through a medium lose some energy to the medium. However, when an electromagnetic wave travels through space, no energy is lost, so the wave doesn't get weaker as it travels. However, the energy is "diluted" as it spreads out over an ever-larger area as it travels away from the source. This is similar to the way a sound wave spreads out and becomes less intense farther from the sound source.

Wave Interactions

Electromagnetic waves can travel through matter as well as across space. When they strike matter, they interact with it in the same ways that mechanical waves interact with matter. They may reflect (bounce back), refract (bend when traveling through different materials), or diffract (bend around objects). They may also be converted to other forms of energy. Microwaves are a familiar example. They are a type of electromagnetic wave that you can read about later on in this chapter, in the lesson "The Electromagnetic Spectrum." When microwaves strike food in a microwave oven, they are converted to thermal energy, which heats the food.

Wave or Particle?

Electromagnetic radiation behaves like waves of energy most of the time, but sometimes it behaves like particles. As evidence accumulated for this dual nature of electromagnetic radiation, the famous physicist Albert Einstein developed a new theory about electromagnetic radiation, called the wave-particle theory. This theory explains how electromagnetic radiation can behave as both a wave and a particle. In brief, when an electron returns to a lower energy level, it is thought to give off a tiny "packet" of energy called a **photon** (see **Figure** 10.64). The amount of energy in a photon may vary. It depends on the frequency of electromagnetic radiation. The higher the frequency is, the more energy a photon has.

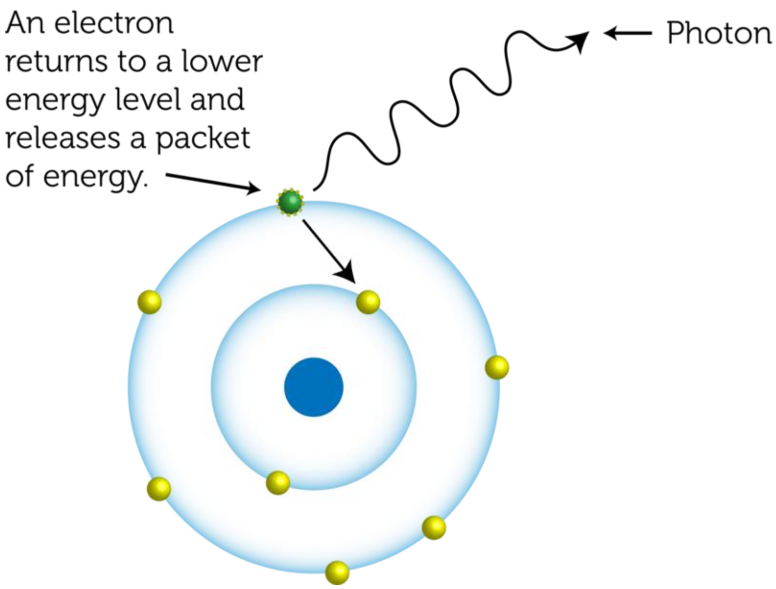

FIGURE 10.64
A photon of light energy is given off when an electron returns to a lower energy level.

Sources of Electromagnetic Radiation

The most important source of electromagnetic radiation on Earth is the sun. Electromagnetic waves travel from the sun to Earth across space and provide virtually all the energy that supports life on our planet. Many other sources of electromagnetic waves that people use depend on technology. Radio waves, microwaves, and X rays are examples. We use these electromagnetic waves for communications, cooking, medicine, and many other purposes. You'll learn about all these types of electromagnetic waves in this chapter's lesson on "The Electromagnetic Spectrum."

Lesson Summary

- An electromagnetic wave consists of vibrating electric and magnetic fields.
- An electromagnetic wave begins when an electrically charged particle vibrates.
- Electromagnetic waves are transverse waves that can travel across space without a medium. When the waves strike matter, they may reflect, refract, or diffract, or they may be converted to other forms of energy.
- Electromagnetic radiation behaves like particles as well as waves. This prompted Albert Einstein to develop his wave-particle theory.
- The most important source of electromagnetic waves on Earth is the sun, which provides virtually all the energy that supports life on Earth. Other sources of electromagnetic radiation depend on technology and are used for communications, cooking, and other purposes.

Lesson Review Questions

Recall

1. Define electromagnetic radiation.
2. What is an electromagnetic wave?
3. How do electromagnetic waves interact with matter?
4. What is a photon?
5. Identify sources of electromagnetic waves.

Apply Concepts

6. Create a diagram to represent an electromagnetic wave. Explain your diagram to another student who has no prior knowledge of electromagnetic waves.

Think Critically

7. Explain how an electromagnetic wave begins.
8. Compare and contrast mechanical transverse waves and electromagnetic transverse waves.

Points to Consider

In this lesson, you learned that electromagnetic waves are transverse waves. Like other transverse waves, electromagnetic waves have certain properties.

- Based on your knowledge of other transverse waves, such as waves in a rope, what is the wavelength of an electromagnetic wave? How is it measured?
- How do you think the wavelengths of electromagnetic waves are related to their frequencies? (*Hint:* How is the speed of waves calculated?)

10.12 Temperature and Heat

Lesson Objectives

- Explain the relationship between temperature and thermal energy.
- Define heat and specific heat.

Lesson Vocabulary

- heat
- specific heat

Introduction

The hot air and sand in Death Valley have a lot of thermal energy, or the kinetic energy of moving particles. But even cold objects have some thermal energy. That's because the particles of all matter are in constant random motion. If cold as well as hot objects have moving particles, what, if anything, does temperature have to do with thermal energy?

Temperature

No doubt you already have a good idea of what temperature is. You might define it as how hot or cold something feels. In physics, temperature is defined as the average kinetic energy of the particles in an object. When particles move more quickly, temperature is higher and an object feels warmer. When particles move more slowly, temperature is lower and an object feels cooler.

Temperature and Thermal Energy

If two objects have the same mass, the object with the higher temperature has greater thermal energy. Temperature affects thermal energy, but temperature isn't the same thing as thermal energy. That's because an object's mass also affects its thermal energy. The examples in **Figure** 10.65 make this clear. In the figure, the particles of cocoa are moving faster than the particles of bathwater. Therefore, the cocoa has a higher temperature. However, the bath water has more thermal energy because there is so much more of it. It has many more moving particles. Bill Nye the Science Guy cleverly discusses these concepts at this URL: http://www.youtube.com/watch?v=f1eAOygDP5s&feature=related (2:06).

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If you're still not clear about the relationship between temperature and thermal energy, watch the animation "Temperature" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

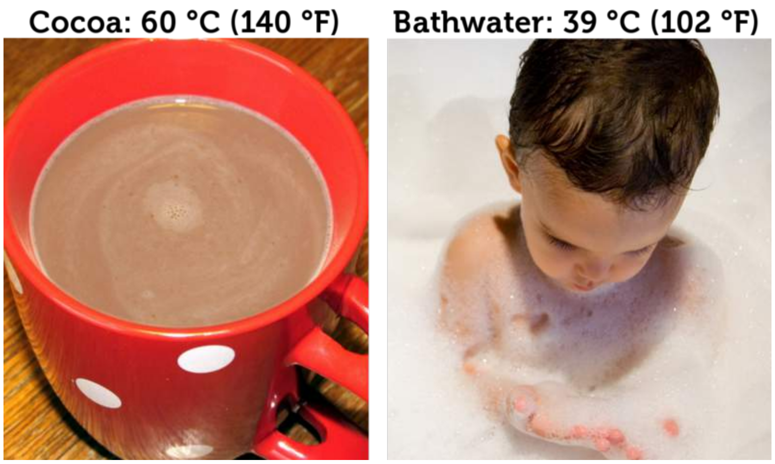

FIGURE 10.65

The cocoa is scalding hot. The bath water is comfortably warm. Why does the bath water have more thermal energy than the cocoa?

Measuring Temperature

Temperature is measured with a thermometer. A thermometer shows how hot or cold something is relative to two reference temperatures, usually the freezing and boiling points of water. Scientists often use the Celsius scale for temperature. On this scale, the freezing point of water is 0°C and the boiling point is 100°C. To learn more about measuring temperature, watch the animation "Measuring Temperature" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

Did you ever wonder how a thermometer works? Look at the thermometer in **Figure** 10.66. Particles of the red liquid have greater energy when they are warmer, so they move more and spread apart. This causes the liquid to expand and rise higher in the glass tube. Like the liquid in a thermometer, most types of matter expand to some degree when they get warmer. Gases usually expand the most when heated, followed by liquids. Solids generally expand the least. (Water is an exception; it takes up more space as a solid than as a liquid.)

Heat

Something that has a high temperature is said to be hot. Does temperature measure heat? Is heat just another word for thermal energy? The answer to both questions is no. **Heat** is the transfer of thermal energy between objects that have different temperatures. Thermal energy always moves from an object with a higher temperature to an object with a lower temperature. When thermal energy is transferred in this way, the warm object becomes cooler and the cool object becomes warmer. Sooner or later, both objects will have the same temperature. Only then does the transfer of thermal energy end. For a visual explanation of these concepts, watch the animation "Temperature vs. Heat" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

FIGURE 10.66
The red liquid in this thermometer is alcohol. Alcohol expands uniformly over a wide range of temperatures. This makes it ideal for use in thermometers.

Example of Thermal Energy Transfer

Figure 10.67 illustrates an example of thermal energy transfer. Before the spoon was put into the steaming hot coffee, it was cool to the touch. Once in the coffee, the spoon heated up quickly. The fast-moving particles of the coffee transferred some of their energy to the slower-moving particles of the spoon. The spoon particles started moving faster and became warmer, causing the temperature of the spoon to rise. Because the coffee particles lost some of their kinetic energy to the spoon particles, the coffee particles started to move more slowly. This caused the temperature of the coffee to fall. Before long, the coffee and spoon had the same temperature.

FIGURE 10.67
A cool spoon gets warmer when it is placed in a hot liquid. Can you explain why?

Specific Heat

The girls in **Figure** 10.68 are having fun at the beach. It's a warm, sunny day, and the sand feels hot under their bare hands and feet. The water, in contrast, feels much cooler. Why does the sand get so hot while the water does not? The answer has to do with specific heat.

Specific heat is the amount of energy (in joules) needed to raise the temperature of 1 gram of a substance by 1°C. Specific heat is a property that is specific to a given type of matter. **Table** 10.1 lists the specific heat of four

FIGURE 10.68
Sand on a beach heats up quickly in the sun because sand has a relatively low specific heat.

different substances. Metals such as iron have relatively low specific heat. It doesn't take much energy to raise their temperature. That's why a metal spoon heats up quickly when placed in hot coffee. Sand also has a relatively low specific heat, whereas water has a very high specific heat. It takes a lot more energy to increase the temperature of water than sand. This explains why the sand on a beach gets hot while the water stays cool. Differences in the specific heat of water and land also affect climate. To learn how, watch the video at this URL: http://www.youtube.com/watch?v=dkBStF2Rnu4 (7:07).

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In **Table** 10.1, how much greater is the specific heat of water than sand?

TABLE 10.1: Specific Heat of Some Common Substances

Substances	Specific Heat (joules)
iron	0.45
sand	0.67
wood	1.76
water	4.18

Lesson Summary

- Temperature is the average kinetic energy of particles of an object. Warmer objects have faster particles and higher temperatures. If two objects have the same mass, the object with the higher temperature has greater thermal energy. Temperature is measured with a thermometer.
- Heat is the transfer of thermal energy between objects that have different temperatures. Thermal energy always moves from an object with a higher temperature to an object with a lower temperature. Specific heat is the amount of energy (in joules) needed to raise the temperature of 1 gram of a substance by 1°C. Substances differ in their specific heat.

5. Glass has a specific heat of 0.84 J/g·°C. Copper has a specific heat of 0.39 J/kg·°C. Which material takes more energy to warm up?

Think Critically

6. Explain how a cooler object can have more thermal energy than a warmer object.
7. Relate heat to temperature.

Points to Consider

In this lesson, you read that heat is the transfer of thermal energy from one object to another.

- How do you think the transfer of thermal energy occurs? For example, how does thermal energy move from hot sand to bare feet when someone walks on a beach?
- Do you think there might be more than one way that thermal energy can be transferred? For example, how does thermal energy move from a bonfire to a nearby person who isn't touching the flames?

10.13 Properties of Electromagnetic Waves

Lesson Objectives

- Describe the speed of electromagnetic waves.
- Relate wavelength and frequency of electromagnetic waves.

Lesson Vocabulary

- speed of light

Introduction

Some electromagnetic waves are harmless. The light we use to see is a good example. Other electromagnetic waves are very harmful. They can penetrate virtually anything and destroy living cells. Why do electromagnetic waves vary in these ways? It depends on their properties. Like other waves, electromagnetic waves have properties of speed, wavelength, and frequency.

Speed of Electromagnetic Waves

All electromagnetic waves travel at the same speed through empty space. That speed, called the **speed of light**, is 300 million meters per second (3.0×10^8 m/s). Nothing else in the universe is known to travel this fast. If you could move that fast, you would be able to travel around Earth 7.5 times in just 1 second! The sun is about 150 million kilometers (93 million miles) from Earth, but it takes electromagnetic radiation only 8 minutes to reach Earth from the sun. Electromagnetic waves travel more slowly through a medium, and their speed may vary from one medium to another. For example, light travels more slowly through water than it does through air (see **Figure** 10.69). You can learn more about the speed of light at this URL: http://videos.howstuffworks.com/discovery/29407-assignment-discovery-speed-of-light-video.htm .

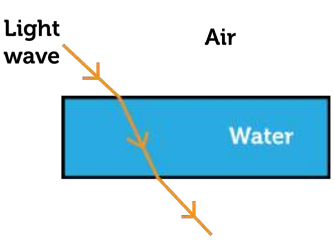


FIGURE 10.69
Light slows down when it enters water from the air. This causes the wave to refract, or bend.

Wavelength and Frequency of Electromagnetic Waves

Although all electromagnetic waves travel at the same speed, they may differ in their wavelength and frequency.

Defining Wavelength and Frequency

Wavelength and frequency are defined in the same way for electromagnetic waves as they are for mechanical waves. Both properties are illustrated in **Figure** 10.70.

- Wavelength is the distance between corresponding points of adjacent waves. Wavelengths of electromagnetic waves range from many kilometers to a tiny fraction of a millimeter.
- Frequency is the number of waves that pass a fixed point in a given amount of time. Frequencies of electromagnetic waves range from thousands to trillions of waves per second. Higher frequency waves have greater energy.

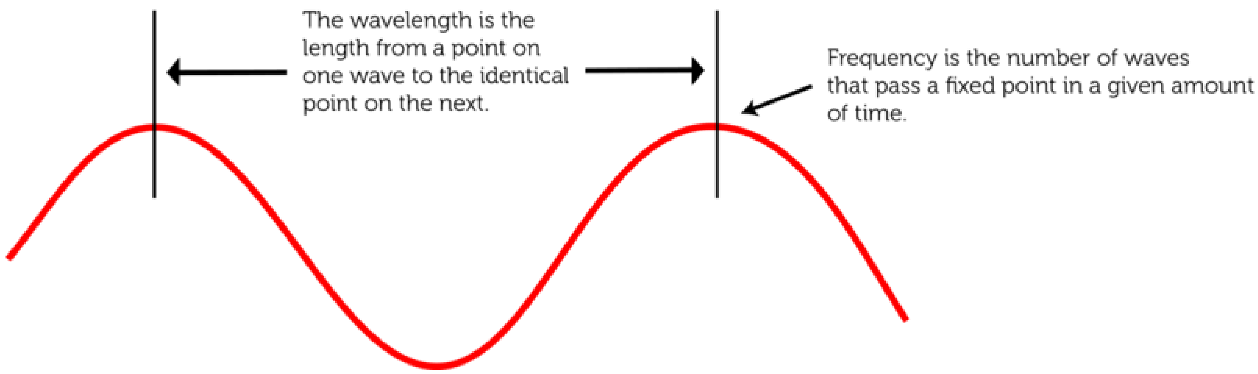


FIGURE 10.70
Wavelength and frequency of electromagnetic waves.

Speed, Wavelength, and Frequency

The speed of a wave is a product of its wavelength and frequency. Because all electromagnetic waves travel at the same speed through space, a wave with a shorter wavelength must have a higher frequency, and vice versa. This relationship is represented by the equation:

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

The equation for wave speed can be rewritten as:

$$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}} \text{ or Wavelength} = \frac{\text{Speed}}{\text{Frequency}}$$

Therefore, if either wavelength or frequency is known, the missing value can be calculated. Consider an electromagnetic wave that has a wavelength of 3 meters. Its speed, like the speed of all electromagnetic waves, is 3.0×10^8 meters per second. Its frequency can be found by substituting these values into the frequency equation:

$$\text{Frequency} = \frac{3.0 \times 10^8 \text{ m/s}}{3.0 \text{ m}} = 1.0 \times 10^8 \text{ waves/s, or } 1.0 \times 10^8 \text{ hertz (Hz)}$$

You Try It!

Problem: What is the wavelength of an electromagnetic wave that has a frequency of 3.0×10^8 hertz?

For more practice calculating the frequency and wavelength of electromagnetic waves, go to these URLs:

- http://www.youtube.com/watch?v=GwZvtfZRNKk
- http://www.youtube.com/watch?v=wjPk108Ua8k

Lesson Summary

- All electromagnetic waves travel at the same speed through space, called the speed of light, which equals 3.0×10^8 meters per second. Electromagnetic waves travel more slowly through a medium.
- Electromagnetic waves differ in their wavelengths and frequencies. The higher the frequency of an electromagnetic wave, the greater its energy. The speed of an electromagnetic wave is the product of its wavelength and frequency, so a wave with a shorter wavelength has a higher frequency, and vice versa.

Lesson Review Questions

Recall

1. What is the speed of light?
2. What is the wavelength of an electromagnetic wave?
3. Describe the range of frequencies of electromagnetic waves.

Apply Concepts

4. If an electromagnetic wave has a wavelength of 1 meter, what is its frequency?

Think Critically

5. Explain why light waves bend when they pass from air to water at an angle.
6. Explain the relationship between frequency and wavelength of electromagnetic waves.

Points to Consider

In this lesson, you learned that electromagnetic waves vary in their wavelength and frequency. The complete range of wavelengths and frequencies of electromagnetic waves is outlined in the next lesson, "The Electromagnetic

Spectrum."

- What do you think are the longest-wavelength electromagnetic wave?
- What might be the electromagnetic waves with the highest frequencies?

10.14 Transfer of Thermal Energy

Lesson Objectives

- Describe the conduction of thermal energy.
- Explain how convection transfers thermal energy.
- Give an example of the radiation of thermal energy.

Lesson Vocabulary

- conduction
- convection
- convection current
- thermal conductor
- thermal insulator

Introduction

Did you ever cook over a campfire? The man in the **Figure** 10.71 is waiting for his lunch to finish cooking over the campfire. Thermal energy from the fire heats the water. Eventually, all the water in the pot will be boiling hot. The man also feels warm from the flames, even though he isn't touching them. Thermal energy is transferred from the fire in three ways: conduction, convection, and radiation. You'll read about each way in this lesson. For an animated preview of the three ways, go to this URL: http://www.nd.edu/~ysun/Yang/PhysicsAnimation/collection/transportP.swf .

FIGURE 10.71
Thermal energy from the fire is transferred to the pot and water and to the man sitting by the fire.

Conduction

Conduction is the transfer of thermal energy between particles of matter that are touching. When energetic particles collide with nearby particles, they transfer some of their thermal energy. From particle to particle, like dominoes falling, thermal energy moves throughout a substance. In **Figure** 10.71, conduction occurs between particles of the metal in the pot and between particles of the pot and the water. **Figure** 10.72 shows additional examples of conduction. For a deeper understanding of this method of heat transfer, watch the animation "Conduction" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

Hands feel cold when they're holding ice because they lose thermal energy to the ice.

Hair feels warm after a hot curling iron passes over it because it gains thermal energy from the curling iron.

FIGURE 10.72
How is thermal energy transferred in each of these examples?

Thermal Conductors

Conduction is usually faster in liquids and certain solids than in gases. Materials that are good conductors of thermal energy are called **thermal conductors**. Metals are excellent thermal conductors. They have freely moving electrons that can transfer energy quickly and easily. That's why the metal pot in **Figure** 10.71 soon gets hot all over, even though it gains thermal energy from the fire only at the bottom of the pot. In **Figure** 10.72, the metal heating element of the curling iron heats up almost instantly and quickly transfers energy to the strands of hair that it touches.

Thermal Insulators

Particles of gases are farther apart and have fewer collisions, so they are not good at transferring thermal energy. Materials that are poor thermal conductors are called **thermal insulators**. **Figure** 10.73 shows several examples. Fluffy yellow insulation inside the roof of a home is full of air. The air prevents the transfer of thermal energy into the house on hot days and out of the house on cold days. A puffy down jacket keeps you warm in the winter for the same reason. Its feather filling holds trapped air that prevents energy transfer from your warm body to the cold air outside. Solids like plastic and wood are also good thermal insulators. That's why pot handles and cooking utensils are often made of these materials.

Convection

Convection is the transfer of thermal energy by particles moving through a fluid. Particles transfer energy by moving from warmer to cooler areas. That's how energy is transferred in the soup in **Figure** 10.73. Particles of soup near the bottom of the pot get hot first. They have more energy so they spread out and become less dense. With lower density, these particles rise to the top of the pot (see **Figure** 10.74). By the time they reach the top of the pot they have cooled off. They have less energy to move apart, so they become denser. With greater density, the particles sink to the bottom of the pot, and the cycle repeats. This loop of moving particles is called a **convection current**.

Convection currents move thermal energy through many fluids, including molten rock inside Earth, water in the oceans, and air in the atmosphere. In the atmosphere, convection currents create wind. You can see one way this happens in **Figure** 10.75. Land heats up and cools off faster than water because it has lower specific heat. Therefore,

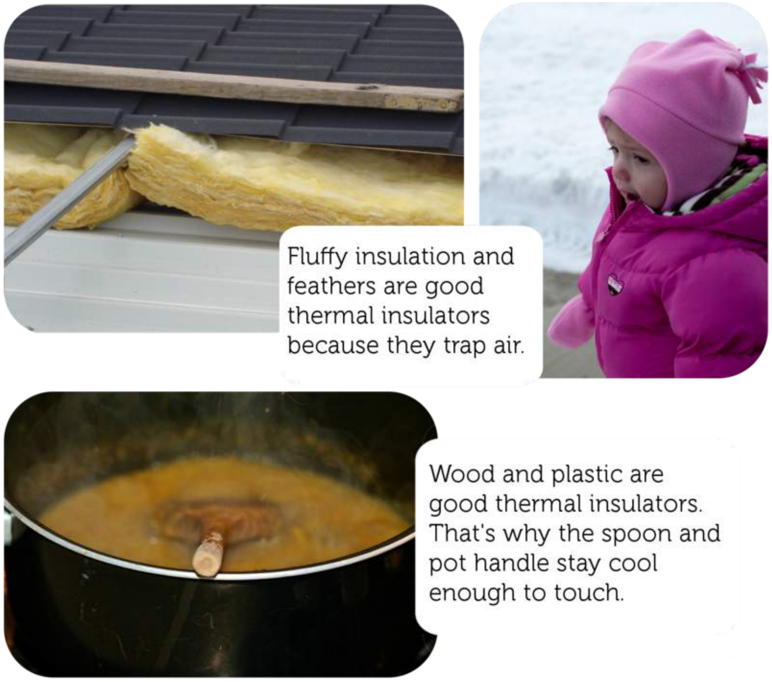


FIGURE 10.73
Thermal insulators have many practical uses. Can you think of others?

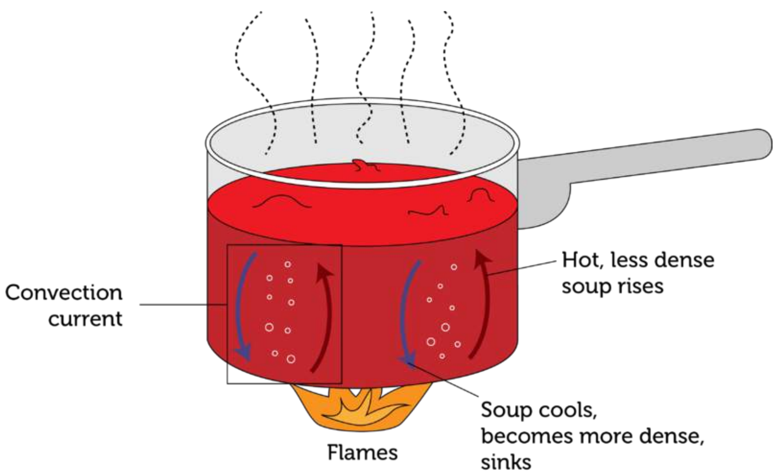


FIGURE 10.74
Convection currents carry thermal energy throughout the soup in the pot.

land is warmer during the day and cooler at night than water. Air close to the surface gains or loses heat as well. Warm air rises because it is less dense, and when it does, cool air moves in to take its place. This creates a convection current that carries air from the warmer to the cooler area. You can learn more about convection currents by watching "Convection" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

Radiation

Both conduction and convection transfer energy through matter. Radiation is the only way of transferring energy that doesn't require matter. Radiation is the transfer of energy by waves that can travel through empty space. When the waves reach objects, they transfer energy to the objects, causing them to warm up. This is how the sun's energy

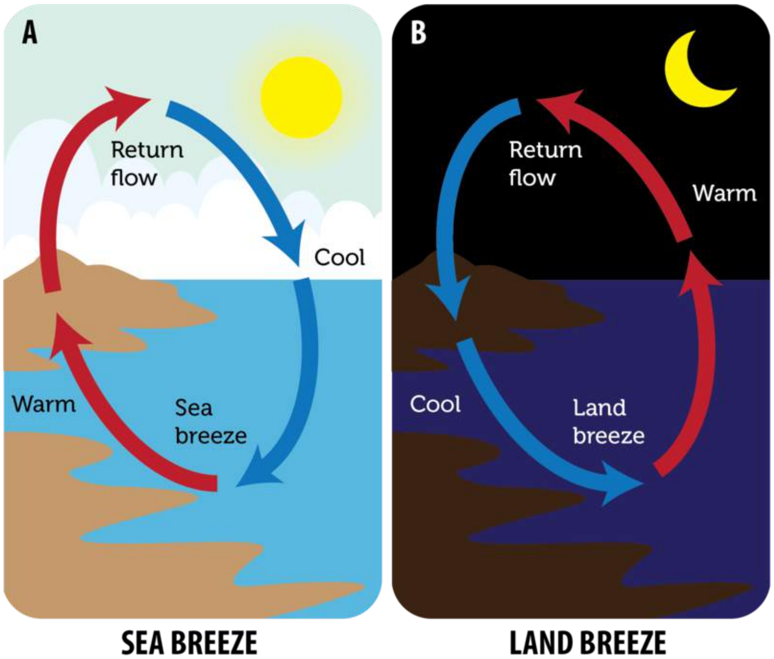


FIGURE 10.75
A sea breeze blows toward land during the day, and a land breeze blows toward water at night. Why does the wind change direction after the sun goes down?

reaches Earth and heats its surface (see **Figure** 10.76). Radiation is also how thermal energy from a campfire warms people nearby. You might be surprised to learn that all objects radiate thermal energy, including people. In fact, when a room is full of people, it may feel noticeably warmer because of all the thermal energy the people radiate! To learn more about thermal radiation, watch "Radiation" at the URL below.

http://www.sciencehelpdesk.com/unit/science2/3

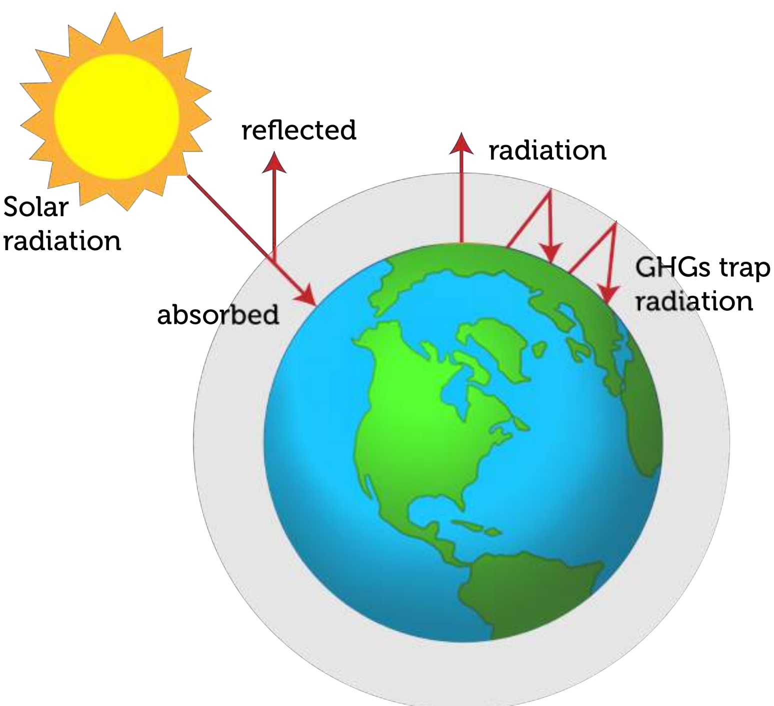


FIGURE 10.76
Earth is warmed by energy that radiates from the sun. Earth radiates some of the energy back into space. Greenhouse gases (GHGs) trap much of the re-radiated energy, causing an increase in the temperature of the atmosphere close to the surface.

Lesson Summary

- Conduction is the transfer of thermal energy between particles of matter that are touching. Thermal conductors are materials that are good conductors of thermal energy. Thermal insulators are materials that are poor conductors of thermal energy. Both conductors and insulators have important uses.
- Convection is the transfer of thermal energy by particles moving through a fluid. The particles transfer energy by moving from warmer to cooler areas. They move in loops called convection currents.
- Radiation is the transfer of thermal energy by waves that can travel through empty space. When the waves reach objects, they transfer thermal energy to the objects. This is how the sun's energy reaches and warms Earth.

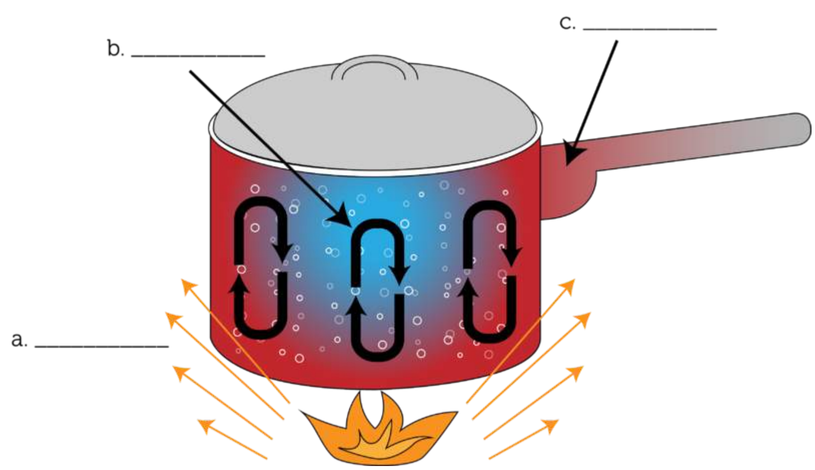
Lesson Review Questions

Recall

1. Define conduction.
2. What is convection?
3. Define the radiation of thermal energy.

Apply Concepts

4. Fill in each blank in the diagram below with the correct method of heat transfer.



5. How could you insulate an ice cube to keep it from melting? What material(s) would you use?

Think Critically

6. Why does convection occur only in fluids?
7. George says that insulation keeps out the cold. Explain why this statement is incorrect. What should George have said?

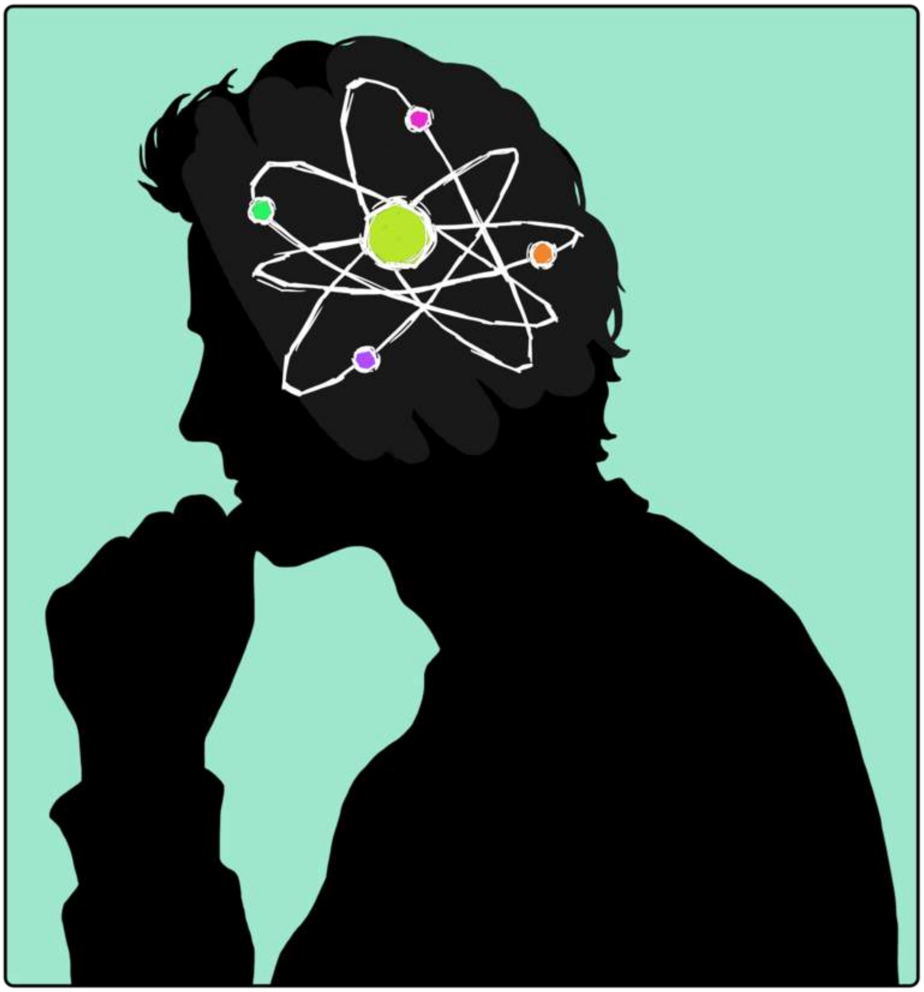
Points to Consider

Thermal energy is very useful. For example, we use thermal energy to keep our homes warm and our motor vehicles moving.

- How does thermal energy heat a house? What devices and systems are involved?
- How does thermal energy run a car? How does burning gas in the engine cause the wheels to turn?

10.15 Atoms to Molecules

- Describe atoms and isotopes.



What is your brain made of?

Everything you can see, touch, smell, feel, and taste is made of atoms. Atoms are the basic building-block of all matter (including you and me, and everyone else you'll ever meet), so if we want to know about what Earth is made of, then we have to know a few things about these incredibly small objects.

Atoms

Everyday experience should convince you that matter is found in myriad forms, yet all the matter you have ever seen is made of atoms, or atoms stuck together in configurations of dizzying complexity. A chemical **element** is a substance that cannot be made into a simpler form by ordinary chemical means. The smallest unit of a chemical element is an **atom**, and all atoms of a particular element are identical.

Parts of an Atom

There are two parts to an atom (**Figure** 10.77):

- At the center of an atom is a **nucleus** made up of two types of particles called protons and neutrons.
  - **Protons** have a positive electrical charge. The number of protons in the nucleus determines what element the atom is.
  - **Neutrons** are about the size of protons but have no charge.
- **Electrons**, much smaller than protons or neutrons, have a negative electrical charge, move at nearly the speed of light, and orbit the nucleus at exact distances, depending on their energy.

An introduction to the atom is seen in this video: http://www.khanacademy.org/video/introduction-to-the-atom .

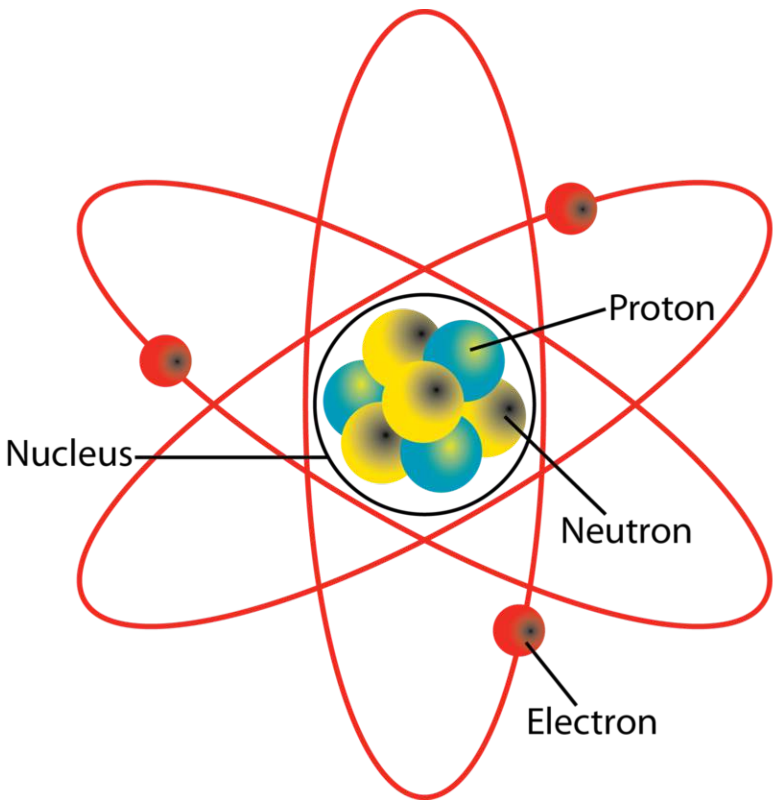


FIGURE 10.77
Major parts of an atom. What chemical element is this? (Hint: 3 protons, 3 electrons)

Atomic Mass

Because electrons are minuscule compared with protons and neutrons, the number of protons plus neutrons gives the atom its **atomic mass**. All atoms of a given element always have the same number of protons, but may differ in the number of neutrons found in the nucleus.

Isotopes

Atoms of an element with differing numbers of neutrons are called **isotopes**. For example, carbon always has 6 protons but may have 6, 7, or 8 neutrons. This means there are three isotopes of carbon: carbon-12, carbon-13, and carbon-14, however, carbon-12 is by far the most abundant.

Ions

Atoms are stable when they have a full outermost electron energy level. To fill its outermost shell, an atom will give, take, or share electrons. When an atom either gains or loses electrons, this creates an **ion**. Ions have either a positive or a negative electrical charge. What is the charge of an ion if the atom loses an electron? An atom with the same number of protons and electrons has no overall charge, so if an atom loses the negatively charged electron, it has a positive charge. What is the charge of an ion if the atom gains an electron? If the atom gains an electron, it has a negative charge.

Molecules

In the previous section we said that many atoms are more stable when they have a net charge: they are more stable as ions. When a cation gets close to an anion, they link up because of their different net charges —positive charges attract negative charges and vice versa. When two or more atoms link up, they create a **molecule**. A molecule of water is made of two atoms of hydrogen (H) and one atom of oxygen (O). The **molecular mass** is the sum of the masses of all the atoms in the molecule. A collection of molecules is called a compound.

Summary

- An atom has negatively-charged electrons in orbit around its nucleus, which is composed of positively-charged protons and neutrons, which have no charge.
- Isotopes of an element must have a given number of protons but may have variety of numbers of neutrons.
- An atom that gains or loses electrons is an ion.

Practice

Use this resource to answer the questions that follow.

Basic Atomic Structure http://www.youtube.com/watch?v=lP57gEWcisY

1. What is found at the center of an atom?

2. What makes up the nucleus?

3. What is the charge on the nucleus?

4. What is equal in neutral atoms?

5. List the parts of an atom and identify the charge of each.

Review

1. If an atom has 8 protons, 8 neutrons, and 8 electrons and then loses an electron, what is it? If it loses a neutron, what is it?

2. What charge(s) does an ion have, positive, negative, or neutral?

3. What is a molecule made of and what is its molecular mass?

10.16 Ions

- State why atoms are neutral in electric charge.
- Describe ions.
- Explain how ions form.
- Identify properties of ions.

The incredible green lights in this cold northern sky consist of charged particles known as ions. Their swirling pattern is caused by the pull of Earth's magnetic north pole. Called the northern lights, this phenomenon of nature shows that ions respond to a magnetic field. Do you know what ions are? Read on to find out.

Atoms Are Neutral

The northern lights aren't caused by atoms, because atoms are not charged particles. An atom always has the same number of electrons as protons. Electrons have an electric charge of -1 and protons have an electric charge of +1. Therefore, the charges of an atom's electrons and protons "cancel out." This explains why atoms are neutral in electric charge.

Q: What would happen to an atom's charge if it were to gain extra electrons?

A: If an atom were to gain extra electrons, it would have more electrons than protons. This would give it a negative charge, so it would no longer be neutral.

Atoms to Ions

Atoms cannot only gain extra electrons. They can also lose electrons. In either case, they become **ions**. Ions are atoms that have a positive or negative charge because they have unequal numbers of protons and electrons. 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 (see **Figure** 10.78). 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 an electric charge of -1.

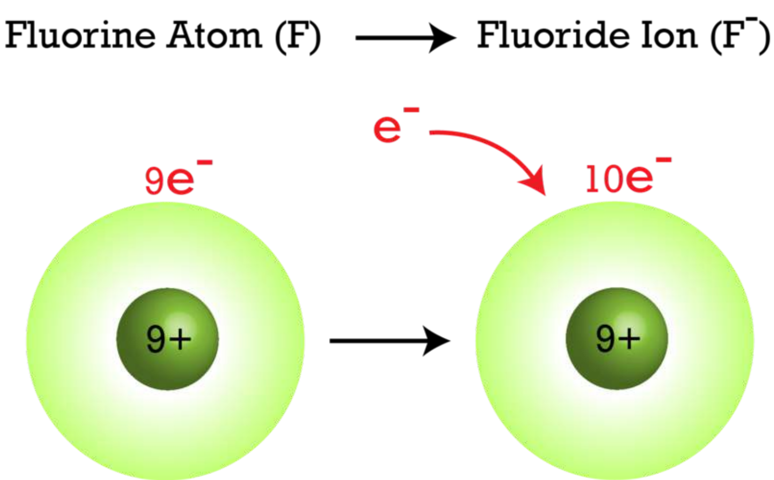


FIGURE 10.78

Names and Symbols

Like fluoride, other negative ions usually have names ending in *–ide*. Positive ions, on the other hand, are just given the element name followed by the word *ion*. For example, when a sodium atom loses an electron, it becomes a positive sodium ion. The charge of an ion is indicated by a plus (+) or minus sign (-), which is written to the right of and just above the ion's chemical symbol. For example, the fluoride ion is represented by the symbol F^-, and the sodium ion is represented by the symbol Na^+. If the charge is greater than one, a number is used to indicate it. For example, iron (Fe) may lose two electrons to form an ion with a charge of plus two. This ion would be represented by the symbol Fe^{2+}. This and some other common ions are listed with their symbols in the **Table** 10.2.

TABLE 10.2: **Some Common Ions**

Cations		Anions	
Name of Ion	**Chemical Symbol**	**Name of Ion**	**Chemical Symbol**
Calcium ion	Ca^{2+}	Chloride	Cl^-
Hydrogen ion	H^+	Fluoride	F^-
Iron(II) ion	Fe^{2+}	Bromide	Br^-
Iron(III) ion	Fe^{3+}	Oxide	O^{2-}

Q: How does the iron(III) ion differ from the iron(II) ion?

A: The iron(III) ion has a charge of +3, so it has one less electron than the iron(II) ion, which has a charge of +2.

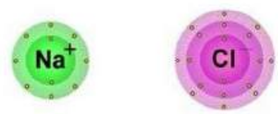
Q: What is the charge of an oxide ion? How does its number of electrons compare to its number of protons?

A: An oxide ion has a charge of -2. It has two more electrons than protons.

How Ions Form

The process in which an atom becomes an ion is called ionization. It may occur when atoms are exposed to high levels of radiation. The radiation may give their outer electrons enough energy to escape from the attraction of the positive nucleus. However, most ions form when atoms transfer electrons to or from other atoms or molecules. For example, sodium atoms may transfer electrons to chlorine atoms. This forms positive sodium ions (Na^+) and negative chloride ions (Cl^-). You can see an animation of this process at the URL below.

http://www.youtube.com/watch?v=xTx_DWboEVs (0:20)



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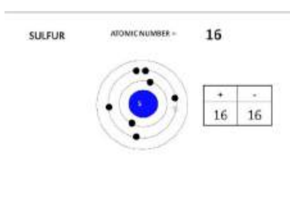
Q: Why do you think atoms lose electrons to, or gain electrons from, other atoms?

A: Atoms form ions by losing or gaining electrons because it makes them more stable and this state takes less energy to maintain. The most stable state for an atom is to have its outermost energy level filled with the maximum possible number of electrons. In the case of metals such as lithium, with just one electron in the outermost energy level, a more stable state can be achieved by losing that one outer electron. In the case of nonmetals such as fluorine, which has seven electrons in the outermost energy level, a more stable state can be achieved by gaining one electron and filling up the outer energy level. You can learn more about why ions form by watching the video at this URL:

http://www.youtube.com/watch?v=CV53wfl-oV8 (9:35)



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Properties of Ions

Ions are highly reactive, especially as gases. They usually react with ions of opposite charge to form neutral compounds. For example, positive sodium ions and negative chloride ions react to form the neutral compound sodium chloride, commonly known as table salt. This occurs because oppositely charged ions attract each other. Ions with the same charge, on the other hand, repel each other. Ions are also deflected by a magnetic field, as you saw in the opening image of the northern lights.

Summary

- Atoms have equal numbers of positive protons and negative electrons, so they are neutral in electric charge.
- Atoms can gain or lose electrons and become ions, which are atoms that have a positive or negative charge because they have unequal numbers of protons and electrons.
- The process in which an atom becomes an ion is called ionization. It may occur when atoms are exposed to high levels of radiation or when atoms transfer electrons to or from other atoms.
- Ions are reactive, attracted or repulsed by other charged particles, and deflected by a magnetic field.

Vocabulary

- **ion**: Positively or negatively charged form of an atom that has lost or gained electron(s).

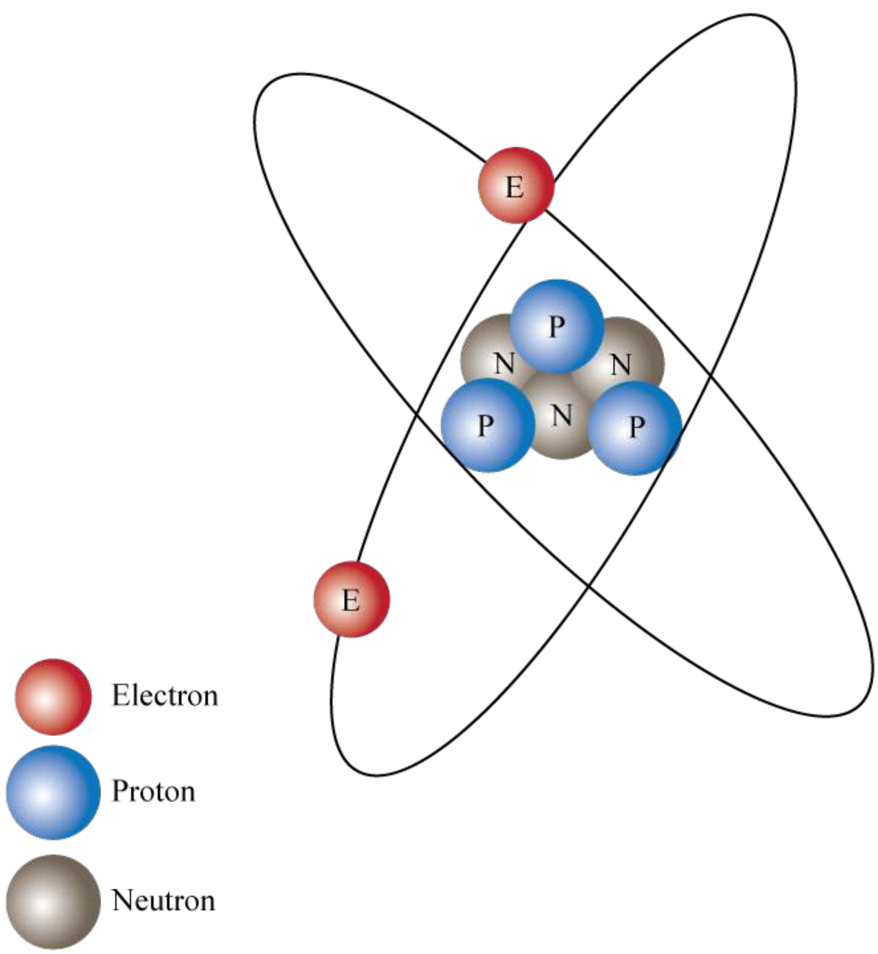
Practice

At the following URL, scroll down to the middle of the page and download "Ion Worksheet." Then fill in the missing information in the worksheet.

http://www.powayusd.com/teachers/kvalentine/worksheetspage.htm

Review

1. Why are atoms neutral in electric charge?
2. Define ion.
3. Compare and contrast cations and anions, and give an example of each.
4. Describe how ions form.
5. List properties of ions.
6. The model in the illustration below represents an atom of lithium (Li). If the lithium atom becomes an ion, which type of ion will it be, a cation or an anion? What will be the electric charge of this ion? What will the ion be named? What symbol will be used to represent it?



10.17 Half-life and Radioactive Dating

- Define radioactive dating.
- Describe how radioactive dating works.
- Explain how carbon-14 dating can be used to date the remains of living things.

The Grand Canyon, pictured above, was carved by the rushing waters of the Colorado River over millions of years. The exposed rocks at the bottom of the canyon are almost 2 billion years old. The youngest rocks near the top are about 230 million years old. Therefore, from top to bottom, the rocks provide a continuous record of more than 1.5 billion years of geological history in this region.

Q: How have scientists been able to determine the ages of rocks in the Grand Canyon?

A: The ages are based on the gradual decay, or break down, of radioactive isotopes.

What Is Radioactive Dating?

Radioactive isotopes, or radioisotopes, can be used to estimate the ages of not only of rocks, but also of fossils and artifacts made long ago by human beings. Even the age of Earth has been estimated on the basis of radioisotopes. The general method is called **radioactive dating**. To understand how radioactive dating works, you need to understand radioisotopes and radioactive decay.

Radioisotopes and Radioactive Decay

A radioisotope has atoms with unstable nuclei. Unstable nuclei naturally decay, or break down. They lose energy and particles and become more stable. As nuclei decay, they gain or lose protons, so the atoms become different elements. This is illustrated in the **Figure** 10.79. The original, unstable nucleus is called the parent nucleus. After it

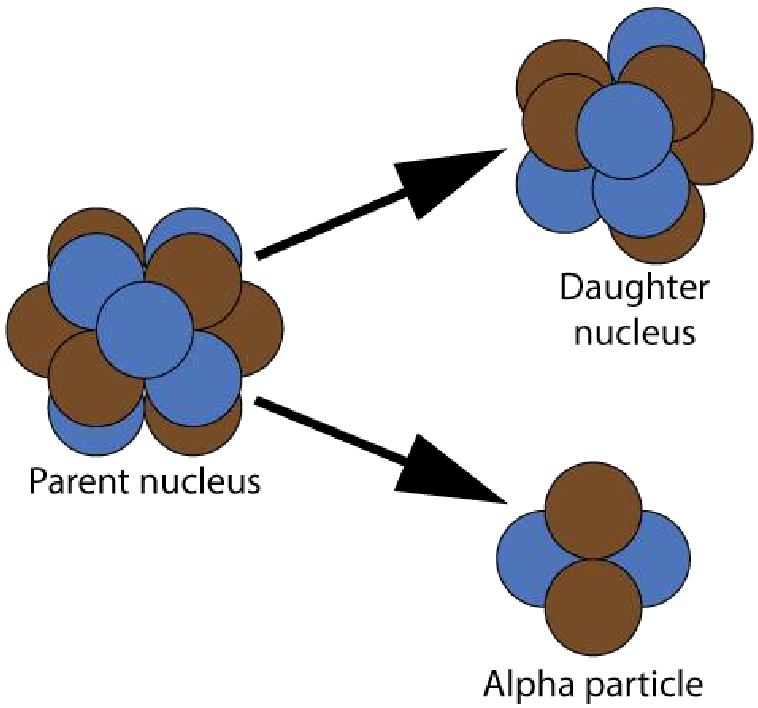


FIGURE 10.79

loses a particle (in this case a type of particle called an alpha particle), it forms a daughter nucleus, with a different number of protons.

The nucleus of a given radioisotope decays at a constant rate that is unaffected by temperature, pressure, or other conditions outside the nucleus. This rate of decay is called the half-life. The half-life is the length of time it takes for half of the original amount of the radioisotope to decay to another element.

Q: How can the half-life of a radioisotope be used to date a rock?

A: After a rock forms, nuclei of a radioisotope inside the rock start to decay. As they decay, the amount of the original, or parent, isotope decreases, while the amount of its stable decay product, or daughter isotope, increases. By measuring the relative amounts of parent and daughter isotopes and knowing the rate of decay, scientists can determine how long the parent isotope has been decaying. This provides an estimate of the rock's age.

Different Isotopes, Different Half-Lives

Different radioisotopes decay at different rates. You can see some examples in the **Table** 10.3. Radioisotopes with longer half-lives are used to date older rocks or other specimens, and those with shorter half-lives are used to date younger ones. For example, the oldest rocks at the bottom of the Grand Canyon were dated by measuring the amounts of potassium-40 in the rocks. Carbon-14 dating, in contrast, is used to date specimens that are much younger than the rocks in the Grand Canyon. You can read more carbon-14 dating below.

TABLE 10.3: **Half-Lives of Some Radioisotopes**

Parent Isotope	Daughter Isotope	Half-Life
potassium-40	argon-40	1.3 billion years
uranium-235	lead-207	700 million years
uranium-234	thorium-230	80,000 years
carbon-14	nitrogen-14	5,700 years

Focus on Carbon-14 Dating

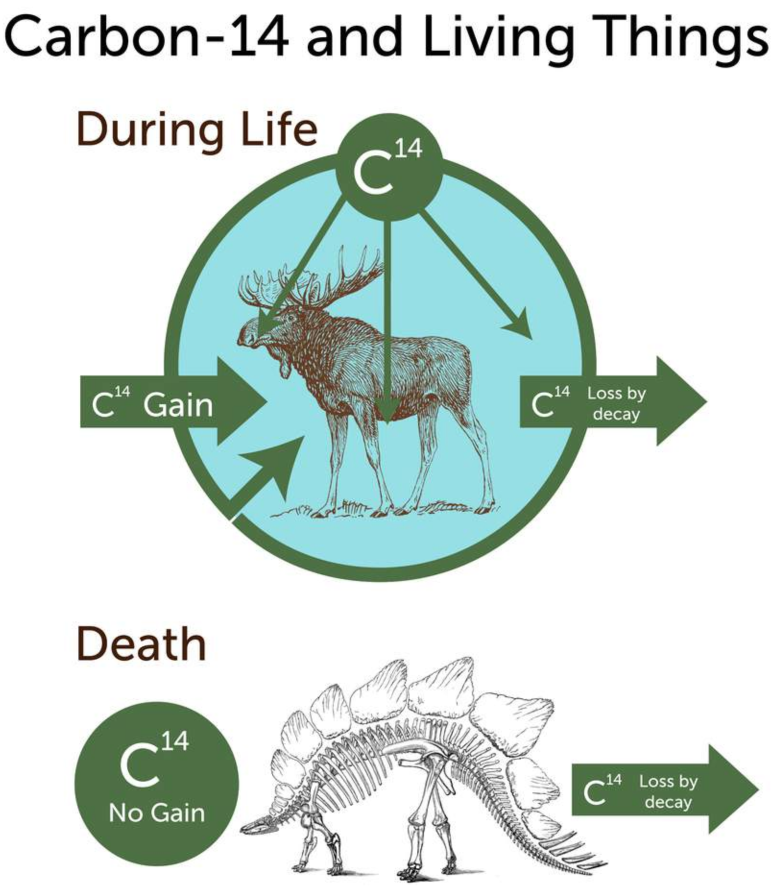


FIGURE 10.80

Summary

- The age of a rock or other specimen can be estimated from the remaining amount of a radioisotope it contains and the radioisotope's known rate of decay, or half-life. This method of dating specimens is called radioactive dating.
- Radioisotopes with longer half-lives are used to date older specimens, and those with shorter half-lives are used to date younger ones.
- Carbon-14 dating is used to date specimens younger than about 60,000 years old. It is commonly used to date fossils of living things and human artifacts.

Vocabulary

- **radioactive dating**: Method of determining the age of fossils or rocks that is based on the rate of decay of radioisotopes.

Practice

Play the radioactive dating game at the following URL, and then answer the questions below. http://phet.colorado.edu/en/simulation/radioactive-dating-game

1. What is the half-life of carbon-14? What is the half-life of uranium-238?

2. Compare the decay rates of carbon-14 and uranium-238. How long does it take for 75 percent of a sample of carbon-14 atoms to decay? How long does it take for 75 percent of a sample of uranium-238 to decay? Do these rates depend on the number of atoms in the samples?
3. What percentage of carbon-14 remains in a sample after 10,000 years? How many years does it take for uranium-238 to decay to this same percentage?
4. Why would you not use carbon-14 to measure the age of the rock?

Review

1. What is radioactive dating?
2. Which radioisotope in the **Table** 10.3 could you use to date a fossil thought to be about 500 million years old? Explain your choice.
3. Why does the amount of carbon-14 in an organism remain the same throughout the organism's life? Why does the amount change after the organism dies?

10.18 Chemical Bonding

- Explain how different types of chemical bonds form.

How do compounds stick together?

When you think of bonding, you may not think of ions. Like most of us, you probably think of bonding between people. Like people, molecules bond —and some bonds are stronger than others. It's hard to break up a mother and baby, or a molecule made up of one oxygen and two hydrogens!

Chemical Bonding

Ions come together to create a molecule so that electrical charges are balanced; the positive charges balance the negative charges and the molecule has no electrical charge. To balance electrical charge, an atom may share its electron with another atom, give it away, or receive an electron from another atom.

The joining of ions to make molecules is called **chemical bonding**. There are three main types of chemical bonds that are important in our discussion of minerals and rocks:

- **Ionic bond**: Electrons are transferred between atoms. An ion will give one or more electrons to another ion. Table salt, sodium chloride (NaCl), is a common example of an ionic compound. Note that sodium is on the left side of the periodic table and that chlorine is on the right side of the periodic table. In the **Figure** 10.82, an atom of lithium donates an electron to an atom of fluorine to form an ionic compound. The transfer of the electron gives the lithium ion a net charge of +1, and the fluorine ion a net charge of -1. These ions bond because they experience an attractive force due to the difference in sign of their charges.

- **Covalent bond** : In a covalent bond, an atom shares one or more electrons with another atom.

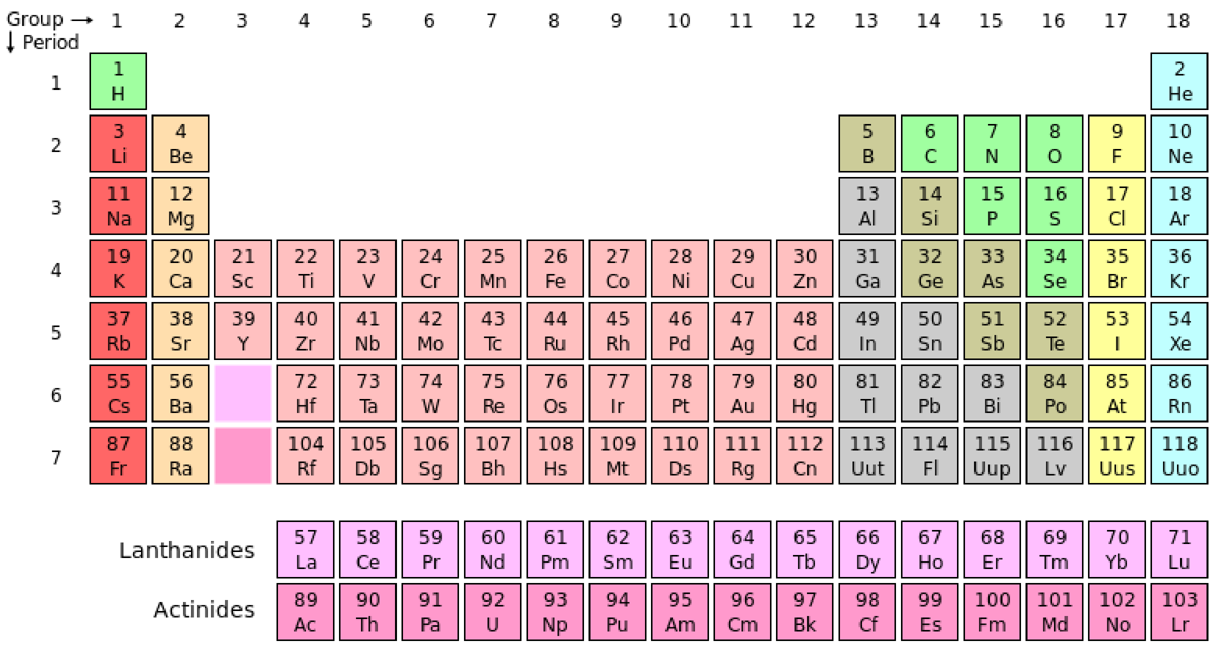


FIGURE 10.81

Periodic Table of the Elements.

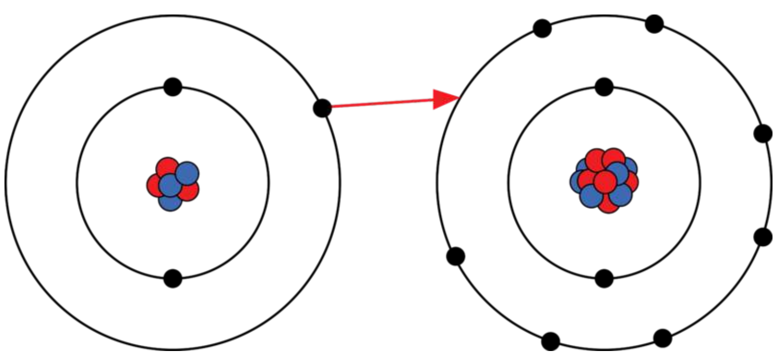


FIGURE 10.82

Lithium (left) and fluorine (right) form an ionic compound called lithium fluoride.

In the picture of methane (CH_4) below (**Figure** 10.83), the carbon ion (with a net charge of +4) shares a single electron from each of the the four hydrogens. Covalent bonding is prevalent in organic compounds. In fact, your body is held together by electrons shared by carbons and hydrogens! Covalent bonds are also very strong, meaning it takes a lot of energy to break them apart.

- **Hydrogen bond**: These weak, intermolecular bonds are formed when the positive side of one polar molecule is attracted to the negative side of another polar molecule.

Water is a classic example of a **polar molecule** because it has a slightly positive side, and a slightly negative side. In fact, this property is why water is so good at dissolving things. The positive side of the molecule is attracted to

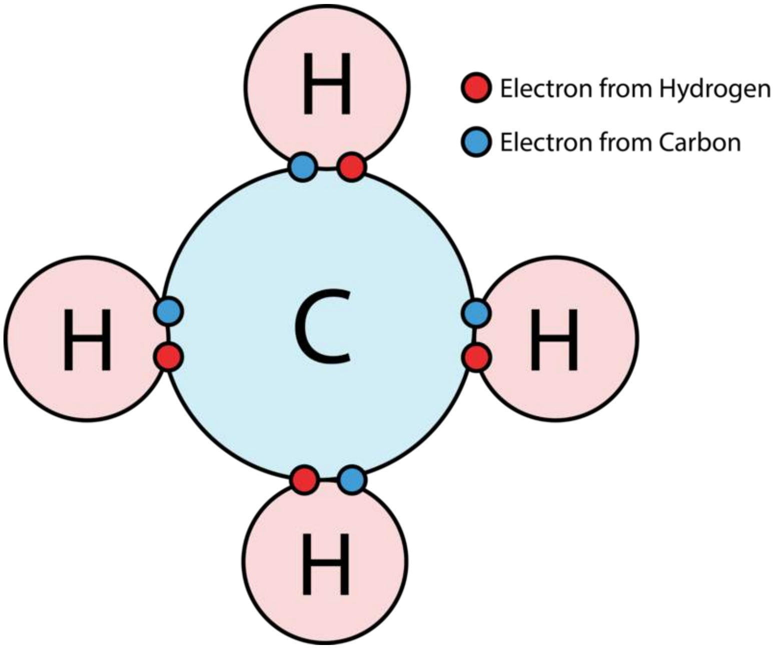


FIGURE 10.83
Methane is formed when four hydrogens and one carbon covalently bond.

negative ions and the negative side is attracted to positive ions.

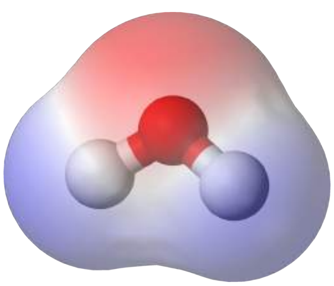


FIGURE 10.84
Water is a polar molecule. Because the oxygen atom has the electrons most of the time, the hydrogen side (blue) of the molecule has a slightly positive charge while the oxygen side (red) has a slightly negative charge.

A video about chemical bonding: http://www.khanacademy.org/video/ionic–covalent–and-metallic-bonds .

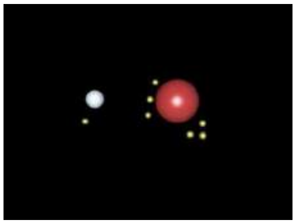
Water is a covalently bonded, polar molecule. Watch this animation to see how it forms: http://www.youtube.com/watch?v=qmgE0w6E6ZI .

Summary

- In an ionic bond, an atom gives away one or more electrons to another atom.
- In a covalent bond, two atoms share one or more electrons.
- A hydrogen bond is a relatively weak bond between two oppositely charged sides of two or more molecules. Water is a polar molecule.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What is ionic bonding?
2. How many valence electrons does sodium have?
3. How many valence electrons does chlorine have?
4. What is the charge on a sodium ion?
5. What is covalent bonding?
6. How many valence electrons does oxygen have?

Review

1. How is a covalent bond different from an ionic bond?
2. Why is a hydrogen bond a relatively weak bond?
3. Diagram the polarity of a water molecule.

10.19 References

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