Integrated High School Science Year 1

Integrated High School Science Year 1

Rialto Staff

next generation textbooks

AUTHOR
Rialto Staff

To access a customizable version of this book, as well as other interactive content, visit www.ck12.org

CK-12 Foundation is a non-profit organization with a mission to reduce the cost of textbook materials for the K-12 market both in the U.S. and worldwide. Using an open-source, collaborative, and web-based compilation model, CK-12 pioneers and promotes the creation and distribution of high-quality, adaptive online textbooks that can be mixed, modified and printed (i.e., the FlexBook® textbooks).

Printed: June 27, 2017

Contents

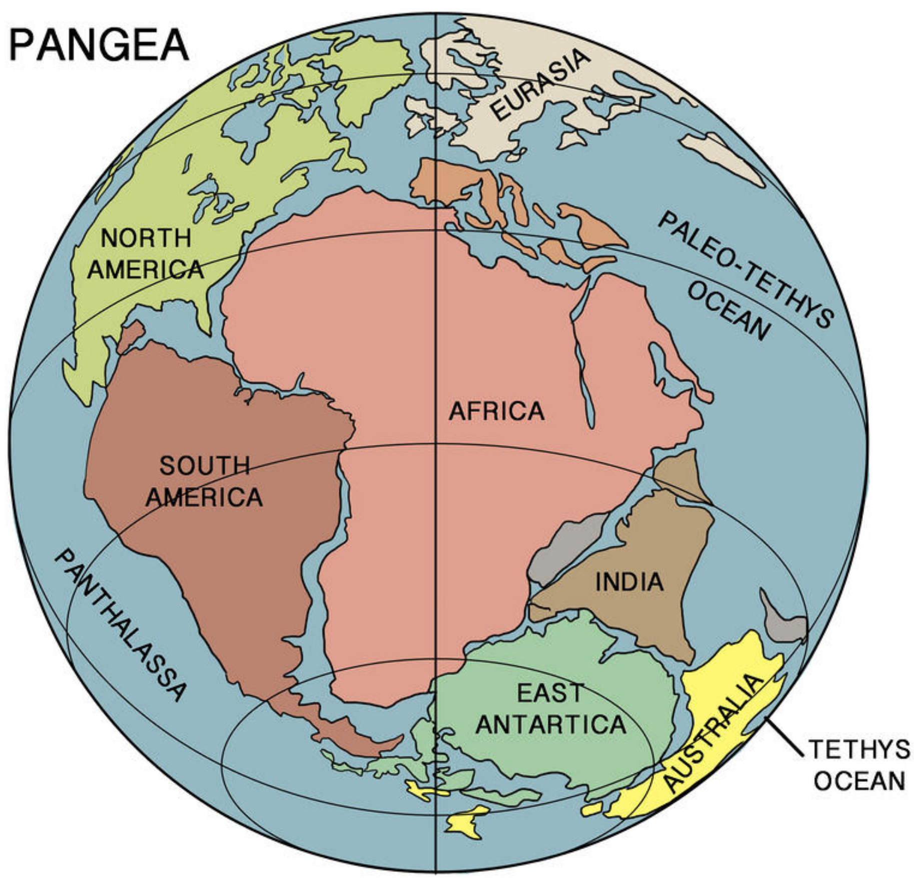
CHAPTER 1 ESS1-5

Chapter Outline

1.1 Continental Drift

Learning Objectives

- Identify the evidence Wegener had in support of his continental drift hypothesis.
- Apply the steps of scientific method to Wegener's scientific investigation.



"Doesn't the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? This is an idea I'll have to pursue." - Alfred Wegener to his future wife, December, 1910.

We can't really get into Alfred Wegener's head, but we can imagine that he started his investigations by trying to answer this question: Why do the continents of Africa and South America appear to fit together so well? Is it an accident that they do, or is there some geological reason?

Wegener's Idea

Alfred Wegener, born in 1880, was a meteorologist and explorer. In 1911, Wegener found a scientific paper that listed identical plant and animal fossils on opposite sides of the Atlantic Ocean. Intrigued, he then searched for and found other cases of identical fossils on opposite sides of oceans. The explanation put out by the scientists of the day was that land bridges had once stretched between these continents.

Instead, Wegener pondered the way Africa and South America appeared to fit together like puzzle pieces. Other scientists had suggested that Africa and South America had once been joined, but Wegener was the idea's most dogged supporter. Wegener amassed a tremendous amount of evidence to support his hypothesis that the continents had once been joined.

Imagine that you're Wegener's colleague. What sort of evidence would you look for to see if the continents had actually been joined and had moved apart?

Wegener's Evidence

Here is the main evidence that Wegener and his supporters collected for the continental drift hypothesis:

- The continents appear to fit together.
- Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated (**Figure** 1.1). Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. His critics suggested that the organisms moved over long-gone land bridges, but Wegener thought that the organisms could not have been able to travel across the oceans.
  - Fossils of the seed fern *Glossopteris* were too heavy to be carried so far by wind.
  - *Mesosaurus* was a swimming reptile, but could only swim in fresh water.
  - *Cynognathus* and *Lystrosaurus* were land reptiles and were unable to swim.

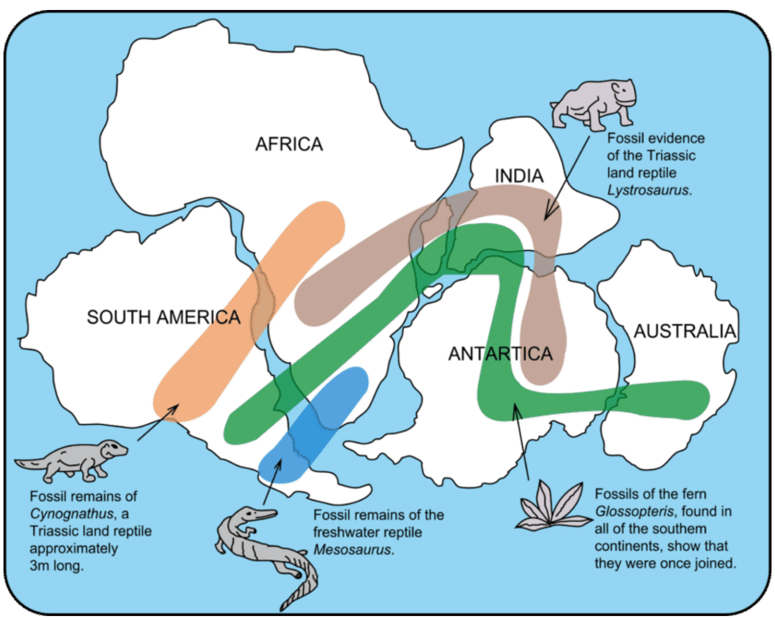


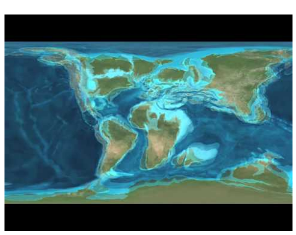
FIGURE 1.1

Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart.

- Identical rocks, of the same type and age, are found on both sides of the Atlantic Ocean. Wegener said the rocks had formed side by side and that the land had since moved apart.
- Mountain ranges with the same rock types, structures, and ages are now on opposite sides of the Atlantic Ocean. The Appalachians of the eastern United States and Canada, for example, are just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway (**Figure** 1.2). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.

FIGURE 1.2
The similarities between the Appalachian and the eastern Greenland mountain ranges are evidences for the continental drift hypothesis.

- Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the Equator. This would indicate that the glaciers either formed in the middle of the ocean and/or covered most of the Earth. Today, glaciers only form on land and nearer the poles. Wegener thought that the glaciers were centered over the southern land mass close to the South Pole and the continents moved to their present positions later on.
- Coral reefs and coal-forming swamps are found in tropical and subtropical environments, but ancient coal seams and coral reefs are found in locations where it is much too cold today. Wegener suggested that these creatures were alive in warm climate zones and that the fossils and coal later drifted to new locations on the continents.
- Wegener thought that mountains formed as continents ran into each other. This got around the problem of the leading hypothesis of the day, which was that Earth had been a molten ball that bulked up in spots as it cooled (the problem with this idea was that the mountains should all be the same age and they were known not to be).



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186128

Summary

- Alfred Wegener did some background reading and made an observation.
- Wegener then asked an important question and set about to answer it.
- He collected a great deal of evidence to support his idea. Wegener's evidence included the fit of the continents, the distribution of ancient fossils, the placement of similar rocks and structures on the opposite sides of oceans,

and indicators of ancient climate found in locations where those climates do not exist today.

Review

1. How did Wegener become interested in the idea that continents could move?
2. What did he need to do to explore the question and make it into a reasonable hypothesis?
3. How did Wegener use fossil evidence to support his hypothesis?
4. How did Wegener use climate evidence from rocks to support his hypothesis?

Explore More

Use this resource to answer the questions that follow.

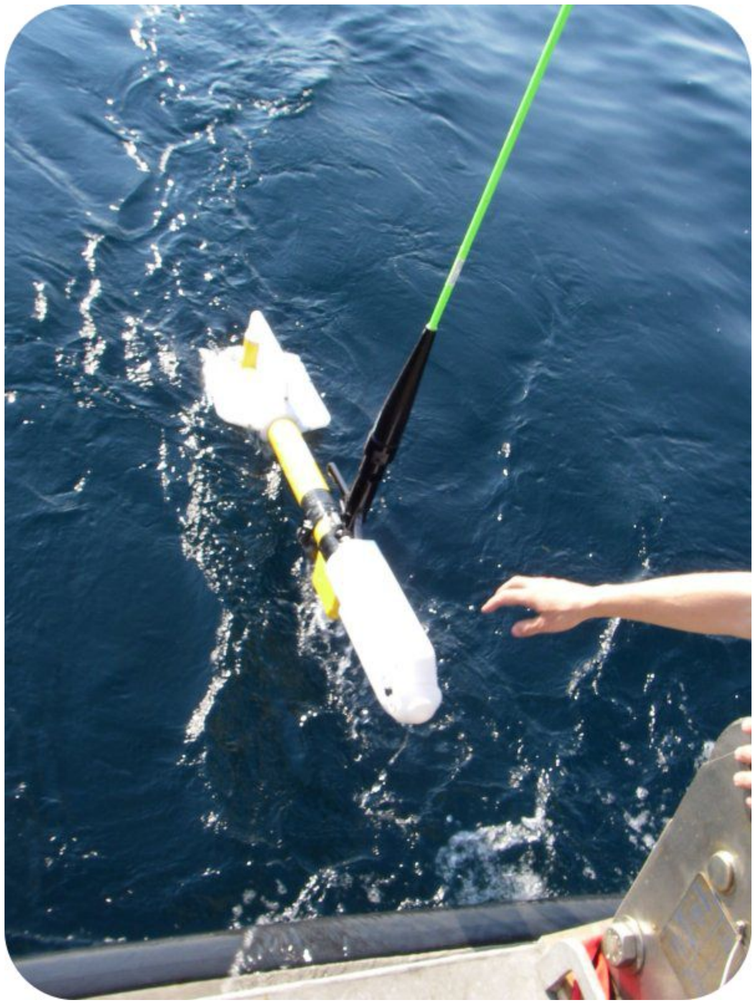
MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/163150

1. What happened in 1910?
2. What happened in 1915?
3. Why was Wegener thought to be "a crazy man?" What did his fellow scientists want him to do?
4. Without a how and why, he had a(n) __________, but with evidence he could have a(n) __________.
5. What happened in 1930?
6. What happened 30 years later?

1.2 Magnetic Polarity Evidence for Continental Drift

Learning Objectives

- Identify how magnetic polarity evidence supports the continental drift hypothesis.



"The Wegener hypothesis has been so stimulating and has such fundamental implications in geology..."

"...as to merit respectful and sympathetic interest from every geologist. Some striking arguments in his favor have been advanced, and it would be foolhardy indeed to reject any concept that offers a possible key to the solution of profound problems in the Earth's history." - Chester R. Longwell, "Some Thoughts on the Evidence for Continental Drift," 1944

Wegener and his supporters did all they could do to find evidence to support continental drift. But without a mechanism the idea would not be accepted. What was needed was the development of technologies that would allow scientists to find more evidence for the idea and help them describe a mechanism. But first, they would find still more evidence that the continents had moved.

Magnetic Polarity Evidence

The next breakthrough in the development of the theory of plate tectonics came two decades after Wegener's death. **Magnetite** crystals are shaped like a tiny bar magnet. As basalt lava cools, the magnetite crystals line up in the magnetic field like tiny magnets. When the lava is completely cooled, the crystals point in the direction of magnetic north pole at the time they form. How do you expect this would help scientists see whether continents had moved or not?

FIGURE 1.3
Magnetite crystals.

As a Wegener supporter, (and someone who is omniscient), you have just learned of a new tool that may help you. A **magnetometer** is a device capable of measuring the magnetic field intensity. This allows you to look at the magnetic properties of rocks in many locations. First, you're going to look at rocks on land. Which rocks should you seek out for study?

Magnetic Polarity on the Same Continent with Rocks of Different Ages

Geologists noted important things about the magnetic polarity of different aged rocks on the same continent:

- Magnetite crystals in fresh volcanic rocks point to the current magnetic north pole (**Figure** 1.4) no matter what continent or where on the continent the rocks are located.

- Older rocks that are the same age and are located on the same continent point to the same location, but that location is not the current north magnetic pole.
- Older rocks that are of different ages do not point to the same locations or to the current magnetic north pole.

In other words, although the magnetite crystals were pointing to the magnetic north pole, the location of the pole seemed to wander. Scientists were amazed to find that the north magnetic pole changed location over time (**Figure** 1.5).

Can you figure out the three possible explanations for this? They are:

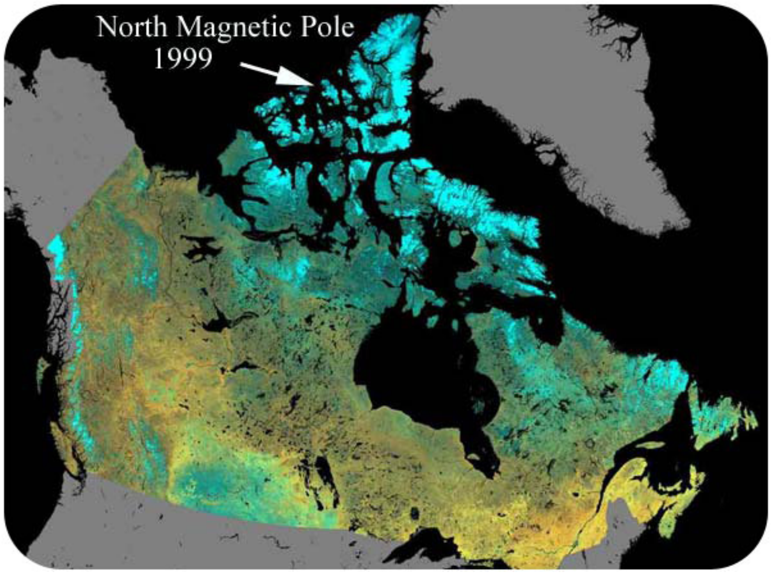


FIGURE 1.4
Earth's current north magnetic pole is in northern Canada.

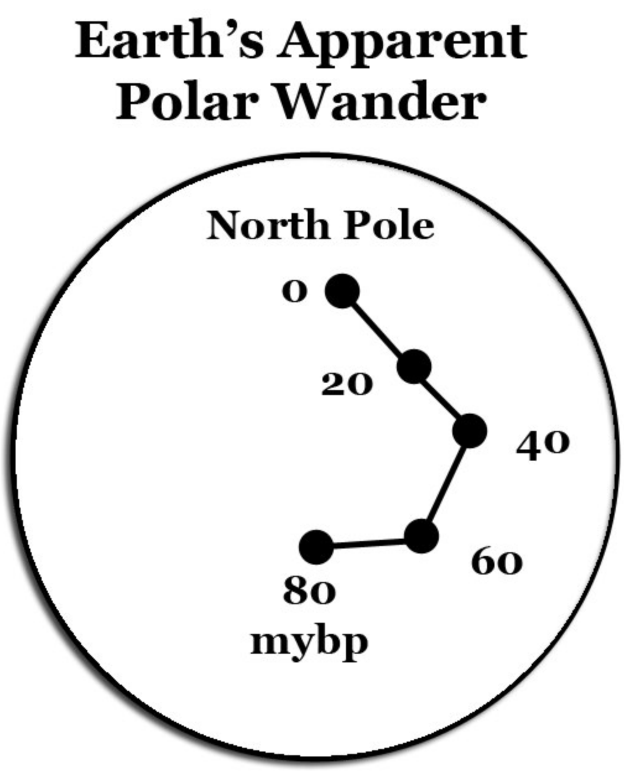


FIGURE 1.5
The location of the north magnetic north pole 80 million years before present (mybp), then 60, 40, 20, and now.

1. The continents remained fixed and the north magnetic pole moved.
2. The north magnetic pole stood still and the continents moved.
3. Both the continents and the north pole moved.

Magnetic Polarity on Different Continents with Rocks of the Same Age

How do you figure out which of those three possibilities is correct? You decide to look at magnetic rocks on different continents. Geologists noted that for rocks of the same age but on different continents, the little magnets pointed to different magnetic north poles.

- 400 million-year-old magnetite in Europe pointed to a different north magnetic pole than magnetite of the same age in North America.
- 250 million years ago, the north poles were also different for the two continents.

Now look again at the three possible explanations. Only one can be correct. If the continents had remained fixed while the north magnetic pole moved, there must have been two separate north poles. Since there is only one north pole today, what is the best explanation? The only reasonable explanation is that the magnetic north pole has remained fixed but that the continents have moved.

Wegener Was Right!

How does this help you to provide evidence for continental drift? To test the idea that the pole remained fixed but the continents moved, geologists fitted the continents together as Wegener had done. It worked! There has only been one magnetic north pole and the continents have drifted (**Figure** 1.6). They named the phenomenon of the magnetic pole that seemed to move but actually did not **apparent polar wander**.

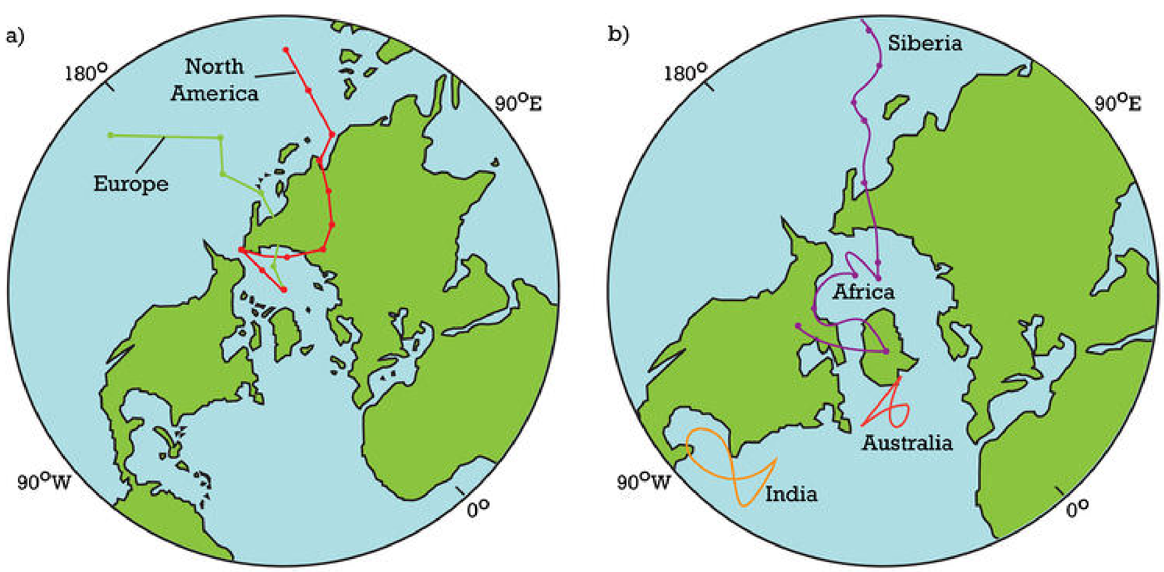
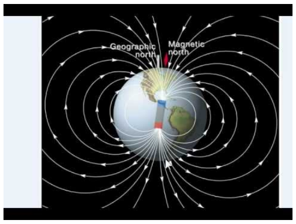


FIGURE 1.6
On the left: The apparent north pole for Europe and North America if the continents were always in their current locations. The two paths merge into one if the continents are allowed to drift.

This evidence for continental drift gave geologists renewed interest in understanding how continents could move about on the planet's surface.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186134

Summary

- Using magnetic evidence found on a single continent in the 1950s, scientists showed that either the north magnetic pole was in a different spot in Earth's past or that the continents had moved.
- When they added magnetic evidence from a second continent, they showed that in the past there had either been two magnetic north poles or the continents had moved.
- Since there is only one magnetic north pole today, they concluded that the simplest explanation is that the continents have moved.

Review

1. What is apparent polar wander?
2. How does magnetic evidence from one continent show that either the north magnetic pole has moved or the continents have moved?
3. How does magnetic evidence from two continents show that the continents have moved?

1.3 Bathymetric Evidence for Seafloor Spreading

Learning Objectives

- Describe how seafloor bathymetry allows scientists to study features of the seafloor.
- Identify features of the seafloor and describe how they provide evidence for the theory of plate tectonics.

Let's go to sea!

To understand what came next, we need to go to sea aboard a research vessel. From the photo you can probably tell that a research vessel is no cruise ship. It's a lot smaller, and community spaces are filled with science labs, not swimming pools. The food ranges from barely edible to tasty and filling, but is rarely sumptuous. But with a research vessel we can gather data to explore the seafloor. Let's go on one now!

Life at Sea

We'll go out on the research vessel (R/V in ship-speak) Atlantis, owned by the US Navy and operated by the Woods Hole Oceanographic Institution for the oceanographic community.

The Atlantis has six science labs and storage spaces, precise navigation systems, seafloor-mapping sonar and satellite communications. Most importantly, the ship has all of the heavy equipment necessary to deploy and operate Alvin, the manned research submersible.

The ship has 24 bunks available for scientists, including two for the chief scientists. The majority of these bunks are below waterline, which makes for good sleeping in the daytime. Ship time is really expensive research, so vessels operate all night and so do the scientists. Your “watch”, as your time on duty is called, may be 12-4, 4-8 or 8-12 - that’s AM and PM. Alternately, if you’re on the team doing a lot of diving in Alvin, you may just be up during the day. If you’re mostly doing operations that don’t involve Alvin, you may just be up at night. For safety reasons, Alvin is deployed and recovered only in daylight.

FIGURE 1.7

Alvin is deployed from the stern of the R/V Atlantis.

Scientists come from all over to meet a research ship in a port. An oceanographer these days doesn’t need to be near the ocean, he or she just needs to have access to an airport!

Let’s begin this cruise in Woods Hole, Massachusetts, Atlantis’ home port. Our first voyage will be out to the Mid-Atlantic Ridge. Transit time to the research site can take days. By doing this virtually, we don’t have to spend days in transit to our research site, and we don’t have to get seasick!

As we head to the site, we will run the echo sounder. Let’s see what we can find!

Echo Sounding

The people who first mapped the seafloor were aboard military vessels during World War II. As stated in the Earth as a Planet chapter, echo sounders used sound waves to search for submarines, but also produced a map of seafloor depths. Depth sounding continued in earnest after the war. Scientists pieced together the ocean depths to produce bathymetric maps of the seafloor. During WWII and in the decade or so later, echo sounders had only one beam, so they just returned a line showing the depth beneath the ship. Later echo sounders sent out multiple beams and could create a bathymetric map of the seafloor below.

We will run a multi-beam echo sounder as we go from Woods Hole out to the Mid-Atlantic Ridge.

Features of the Seafloor

Although they expected an expanse of flat, featureless plains, scientists were shocked to find tremendous features like mountain ranges, rifts, and trenches. This work continues on oceanographic research vessels as they sail across the seas today. The map in the **Figure** 1.8 is a modern map with data from several decades.

The major features of the ocean basins and their colors on the map in **Figure** 1.8 include:

- **mid-ocean ridges**: these features rise up high above the deep seafloor as a long chain of mountains, e.g. the light blue gash in middle of Atlantic Ocean.
- rift zones: in the middle of the mid-ocean ridges is a rift zone that is lower in elevation than the mountains surrounding it.
- deep sea **trenches**: these features are found at the edges of continents or in the sea near chains of active volcanoes, e.g. the very deepest blue, off of western South America.
- **abyssal plains**: these features are flat areas, although many are dotted with volcanic mountains, e.g. consistent blue off of southeastern South America.

See if you can identify each of these features in **Figure** 1.8.

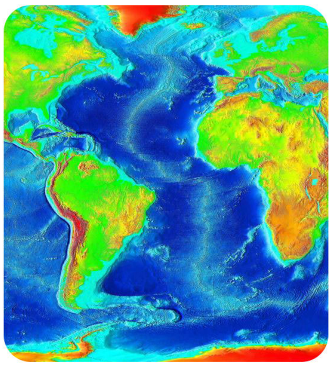


FIGURE 1.8
A modern map of the southeastern Pacific and Atlantic Oceans.

When they first observed these bathymetric maps, scientists wondered what had formed these features. It turns out that they were crucial for fitting together ideas about seafloor spreading.

Continental Margin

As we have seen, the ocean floor is not flat: mid-ocean ridges, deep sea trenches, and other features all rise sharply above or plunge deeply below the abyssal plains. In fact, Earth's tallest mountain is Mauna Kea volcano, which rises 10,203 m (33,476 ft.)meters) from the Pacific Ocean floor to become one of the volcanic mountains of Hawaii. The deepest canyon is also on the ocean floor, the Challenger Deep in the Marianas Trench, 10,916 m (35,814 ft).

The **continental margin** is the transition from the land to the deep sea or, geologically speaking, from continental crust to oceanic crust. More than one-quarter of the ocean basin is continental margin. (**Figure** 1.9).

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186137

Summary

- Much of what went into developing plate tectonics theory involved work done at sea.

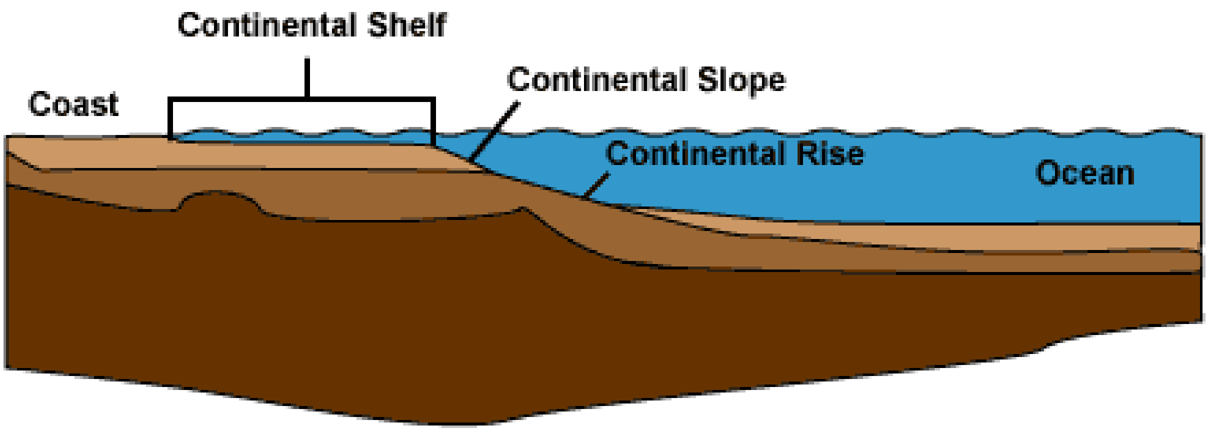


FIGURE 1.9
The continental margin is divided into the continental shelf, continental slope, and continental rise, based on the steepness of the slope.

- Echo sounders used to search for enemy submarines during World War II allowed scientists to piece together bathymetric maps of the seafloor. Multi-beam sounders work on research vessels today.
- These maps revealed amazing features like mid—ocean ridges, deep sea trenches, and abyssal plains.

Review

1. How does an echo sounder create a bathymetric map?
2. What are the important features located on the seafloor?
3. What do you think Alfred Wegener would have done with these bathymetric maps had he had access to them?

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/177976

1. What was the first way to chart the ocean floor?

2. What happened in the 1920s?
3. How do we have maps of most of the seafloor? How does this method work?
4. Does this give a direct bathymetry?
5. What needs to happen to get an accurate view of the bathymetry of the seafloor?

1.4 Magnetic Evidence for Seafloor Spreading

Learning Objectives

- 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** 1.10).
- Stripes end abruptly at the edges of continents, sometimes at a deep sea trench (**Figure** 1.11).

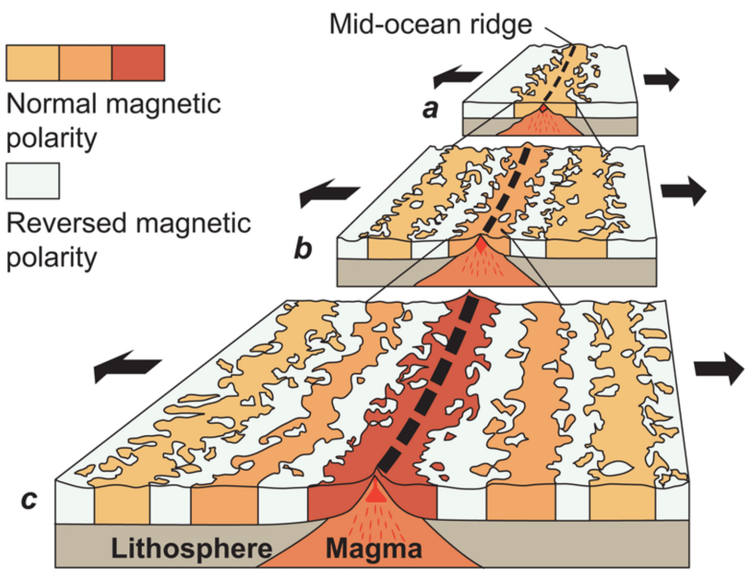


FIGURE 1.10
Magnetic polarity is normal at the ridge crest but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

The magnetic stripes are what created the **Figure** 1.10. 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** 1.1.

TABLE 1.1: 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.

The oldest seafloor is near the edges of continents or deep sea trenches and is less than 180 million years old (**Figure** 1.11). Since the oldest ocean crust is so much younger than the oldest continental crust, scientists realized that something was happening to the older seafloor.

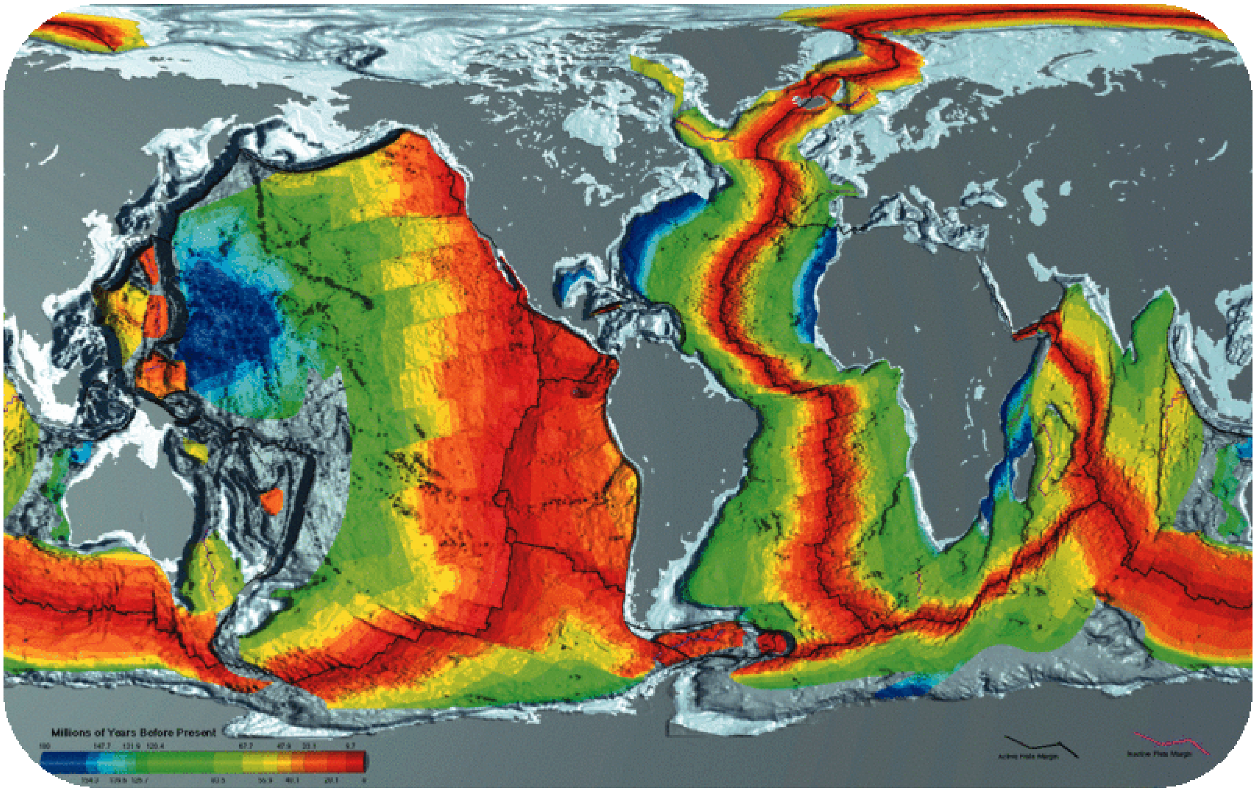


FIGURE 1.11
Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

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.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186141

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.

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?

1.5 Radiometric Dating

Learning Objectives

- 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** 1.12).

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.

FIGURE 1.12
Carbon isotopes from the black material in these cave paintings places their creating at about 26,000 to 27,000 years BP (before present).

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.

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** 1.13). 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.

FIGURE 1.13

Zircon crystal.

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.

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

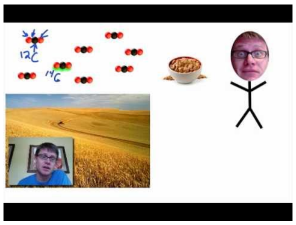
- Radiocarbon is useful for relatively young, carbon-based materials; other longer-lived isotopes are good for older rocks and minerals.
- Different isotope pairs are useful for certain materials of certain ages.
- Radiometric dating cannot be used if parent or daughter are not measurable or if one or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

Review

1. How would you determine which isotope pair to use for a particular material?
2. How does potassium-argon dating work and on what materials does it work best on?
3. What types of rocks are best for radiometric dating and why?

Explore More

Use this resource to answer the questions that follow.



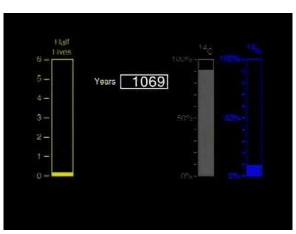
MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178320

1. What is radiocarbon dating?
2. What are the three isotopes of carbon and how many protons and neutrons do they each have? Which isotope of carbon is not stable?
3. How does carbon-14 form?
4. Why is carbon-14 used for radiocarbon dating?
5. How does carbon get into a living thing? How does carbon-14 get into a living thing?
6. How much carbon-14 is in your body when you are alive? What happens to the carbon-14 in your body after you die?
7. What is the half life of carbon-14?
8. What's the greatest age that a thing can be to be able to be dated by carbon-14?
9. How do we know that carbon-14 dating is accurate?
10. Why can't you use radiocarbon dating on an object from 1965?

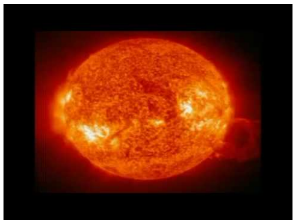
Resources



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178318



MEDIA

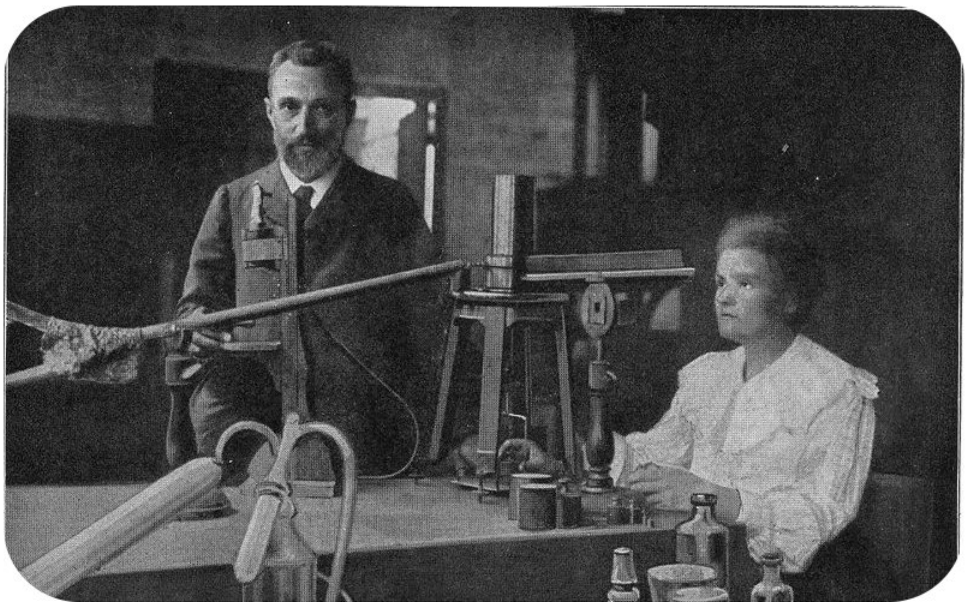
Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/177418

1.6 Radioactive Decay as a Measure of Age

Learning Objectives

- Radioactive decay gives a way to determine the age of some types of rocks.



Why did this couple win the Nobel Prize?

Pierre and Marie Curie, a husband and wife team of physicists, discovered the spontaneous emission of particles from certain elements. They called this phenomenon "radioactivity." Together they won three Nobel prizes, and the element curium was named in their honor.

Radioactive Decay

Radioactivity is the tendency of certain atoms to decay into lighter atoms, a process that emits energy. Radioactivity also provides a way to find the absolute age of a rock. First, we need to know about radioactive decay.

Radioactive Isotopes

Some isotopes are radioactive; **radioactive isotopes** are unstable and spontaneously change by gaining or losing particles. Two types of radioactive decay are relevant to dating Earth materials (**Table** 1.2):

TABLE 1.2: Types of Radioactive Decay

Particle	Composition	Effect on Nucleus
Alpha	2 protons, 2 neutrons	The nucleus contains two fewer protons and two fewer neutrons.

TABLE 1.2: (continued)

Particle	Composition	Effect on Nucleus
Beta	1 electron	One neutron decays to form a proton and an electron. The electron is emitted.

The radioactive decay of a **parent isotope** (the original element) leads to the formation of stable **daughter product**, also known as daughter isotope. As time passes, the number of parent isotopes decreases and the number of daughter isotopes increases (**Figure** 1.14).

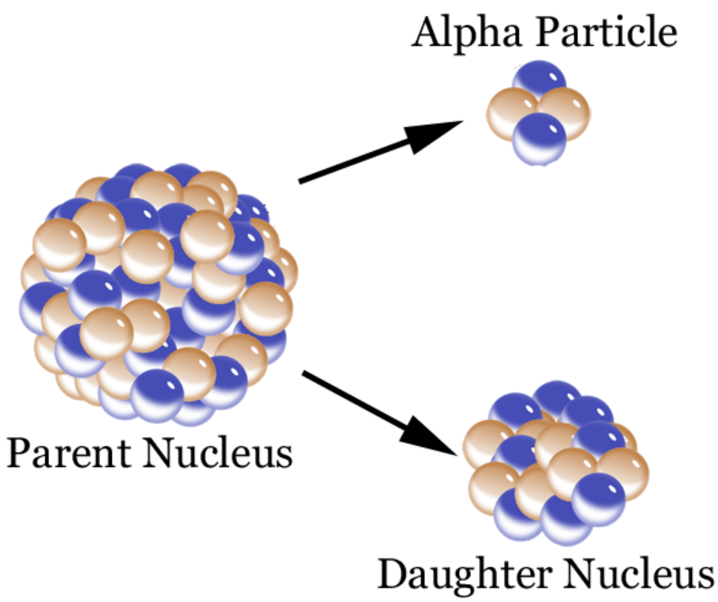


FIGURE 1.14
A parent emits an alpha particle to create a daughter.

Half-Lives

Radioactive materials decay at known rates, measured as a unit called **half-life**. The half-life of a radioactive substance is the amount of time it takes for half of the parent atoms to decay. This is how the material decays over time (see **Table** 1.3).

TABLE 1.3: Radioactive Decay

No. of half lives passed	Percent parent remaining	Percent daughter produced
0	100	0
1	50	50
2	25	75
3	12.5	87.5
4	6.25	93.75
5	3.125	96.875
6	1.563	98.437
7	0.781	99.219
8	0.391	99.609

Pretend you find a rock with 3.125% parent atoms and 96.875% daughter atoms. How many half lives have passed? If the half-life of the parent isotope is 1 year, then how old is the rock? The decay of radioactive materials can be shown with a graph (**Figure** 1.15).

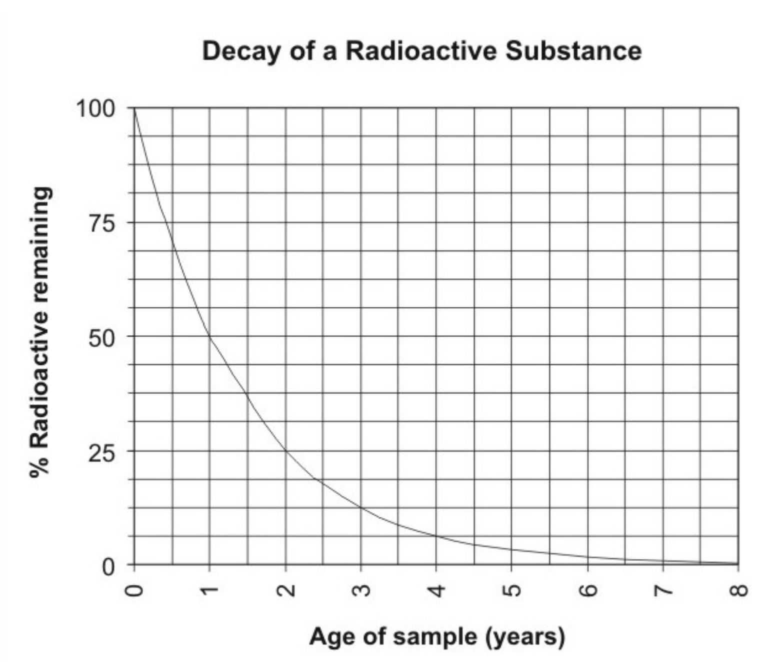
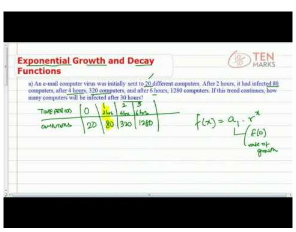


FIGURE 1.15
Decay of an imaginary radioactive substance with a half-life of one year.

Notice how it doesn't take too many half lives before there is very little parent remaining and most of the isotopes are daughter isotopes. This limits how many half lives can pass before a radioactive element is no longer useful for dating materials. Fortunately, different isotopes have very different half lives.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/1512

Summary

- A half life is the time it takes for half of the parent isotopes of an element to change to daughter isotopes.
- With alpha decay, the nucleus loses two protons and two neutrons; with beta decay only one electron is lost.
- Radiometric decay is exponential.

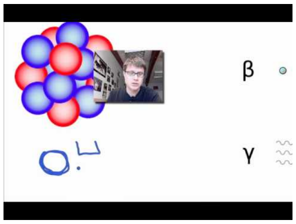
Review

1. Describe the two types of radioactive decay that are relevant to dating earth materials.

2. For how many half lives is a set of parent and daughter isotopes useful as a system of dating?
3. What does it mean that radioactive decay is exponential?

Explore More

Use this resource to answer the questions that follow.



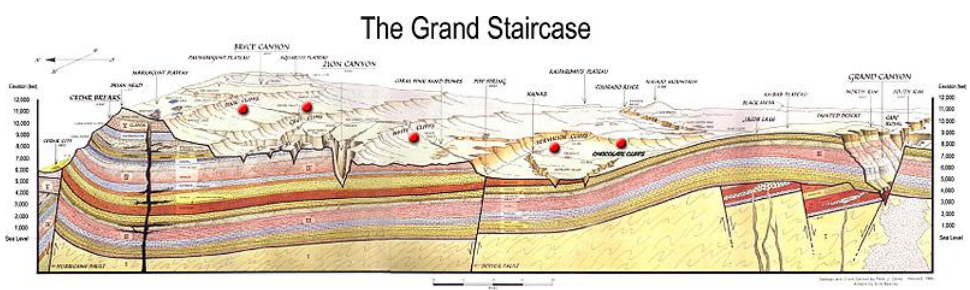
MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/171292

1. What is radiation?
2. How is radiation detected?
3. What happens to the ratio between protons and neutrons between smaller atoms and larger atoms?
4. Why does a large nucleus lose neutrons?
5. What is alpha decay and what charge and mass does it have?
6. What is beta decay and what charge and mass does it have?
7. What is gamma radiation and what charge and mass does it have?
8. What type of radiation does U-238 undergo? What does it lose?
9. Why does U-238 become Th-234?
10. Why does Cs-137 become Ba-137?
11. Why does Na-11 become Ne-12?

1.7 Correlation Using Relative Ages

Learning Objectives

- Rock units can be correlated over vast distances if they are distinctive, or contain index fossils or a key bed.



What is rock matching?

If we want to understand the geological history of a location, we need to look at the rocks in that location. But if we want to understand a region, we need to correlate the rocks between different locations so that we can meld the individual histories of the different locations into one regional history.

Matching Up Rock Layers

Superposition and cross-cutting are helpful when rocks are touching one another and lateral continuity helps match up rock layers that are nearby. To match up rocks that are further apart we need the process of **correlation**. How do geologists correlate rock layers that are separated by greater distances? There are three kinds of clues:

Distinctive Rock Formations

1. Distinctive rock formations may be recognizable across large regions (**Figure** 1.16).

Index Fossils

2. Two separated rock units with the same index fossil are of very similar age. What traits do you think an index fossil should have? To become an index fossil the organism must have (1) been widespread so that it is useful for identifying rock layers over large areas and (2) existed for a relatively brief period of time so that the approximate age of the rock layer is immediately known.

Many fossils may qualify as index fossils (**Figure** below). Ammonites, trilobites, and graptolites are often used as index fossils. **Microfossils**, which are fossils of microscopic organisms, are also useful index fossils. Fossils

FIGURE 1.16
The famous White Cliffs of Dover in southwest England can be matched to similar white cliffs in Denmark and Germany.

of animals that drifted in the upper layers of the ocean are particularly useful as index fossils, since they may be distributed over very large areas.

A biostratigraphic unit, or **biozone**, is a geological rock layer that is defined by a single index fossil or a fossil assemblage. A biozone can also be used to identify rock layers across distances.

Key Beds

3. A **key bed** can be used like an index fossil since a key bed is a distinctive layer of rock that can be recognized across a large area. A volcanic ash unit could be a good key bed. One famous key bed is the clay layer at the boundary between the Cretaceous Period and the Tertiary Period, the time that the dinosaurs went extinct (**Figure** 1.17). This widespread thin clay contains a high concentration of iridium, an element that is rare on Earth but common in asteroids. In 1980, the father-son team of Luis and Walter Alvarez proposed that a huge asteroid struck Earth 66 million years ago and caused the mass extinction.

Summary

- A single rock unit contains the story of the geology of that location. To understand the geology of a region, scientists use correlation.
- To correlate rock units, something distinctive must be present in each. This can include an index fossil, a unique rock type, a key bed, or a unique sequence of rocks.
- A key bed can be global. An example is the iridium layer that was deposited at the time of the Cretaceous-Tertiary extinctions.

FIGURE 1.17
The white clay is a key bed that marks the Cretaceous-Tertiary Boundary.

Review

1. What features must the iridium layer that dates to around 66 million years ago have to be a key bed?
2. Why are microfossils especially useful as index fossils?
3. What is the process of correlation?

Explore More

Use the resource below to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178313

1. What does the rock that forms the hoodoos of Bryce Canyon tell geologists about the environment at the time the sediments were deposited?
2. Why are the rocks at Bryce Canyon orange?
3. What happened when the Colorado Plateau rose?
4. How were the hoodoos created for the most part?
5. What is the rock that creates the white cliffs at Zion? Why are the sands at angles?
6. When was that portion of Utah a giant sand dune? Why are there dunes stacked on top of dunes?

1.8 References

1. Courtesy of the US Geological Survey, User:Osvaldocangaspadilla/Wikimedia Commons. Fossil remains of organisms on South America and Africa . Public Domain
2. Appalachian mountain image copyright Geir Olav Lyngfjell, 2014 and eastern Greenland mountain image copyright TTstudio, 2014. The Appalachian Mountains are similar to the eastern Greenland mountain ranges . Used under licenses from Shutterstock.com
3. Image copyright Vitaly Raduntsev, 2014. Magnetite crystals indicate the location of the magnetic north pole when they formed . Used under license from Shutterstock.com
4. Courtesy of the National Oceanic and Atmospheric Administration. Location of the Earth's current north ma gnetic pole . Public Domain
5. Sam McCabe. The apparent path traveled by the location of the north magnetic north pole . CC BY-NC 3.0
6. Christopher Auyeung. The apparent North Pole for Europe and North America merge if the continents drift . CC BY-NC 3.0
7. Courtesy of P. Auster, NOAA. Alvin submersible deployed from the stern of the Atlantis . Public Domain
8. Courtesy of National Oceanic and Atmospheric Administration. A modern seafloor map of the Atlantic Oc ean . Public Domain
9. Courtesy of the US Navy. The continental margin includes the continental shelf, slope, and rise . Public Domain
10. Courtesy of US Geological Survey, redrawn by CK-12 Foundation. Diagram of magnetic polarity changes in the seafloor . Public Domain
11. Courtesy of National Oceanic and Atmospheric Administration. http://commons.wikimedia.org/wiki/File:E arth_seafloor_crust_age_1996.gif . Public Domain
12. HTO. Carbon 14 dating can tell us the age of these cave paintings . Public Domain
13. Stephanie Clifford. Zircon is used for uranium-lead dating . CC BY 2.0
14. Kurt Rosenkrantz and Sam McCabe. Diagram of alpha decay . CC BY-NC 3.0
15. Kurt Rosenkrantz. Graph of the decay of an imaginary radioactive substance with a half-life of one year . CC BY-NC 3.0
16. Image copyright syringa, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
17. Courtesy of the US Geological Survey. The white clay is a key bed that marks the Cretaceous-Tertiary Bound ary . Public Domain

CHAPTER 2 ESS2-1

Chapter Outline

2.1 Geological Stresses

Learning Objectives

- 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** 2.1). Compression is the most common stress at convergent plate boundaries.

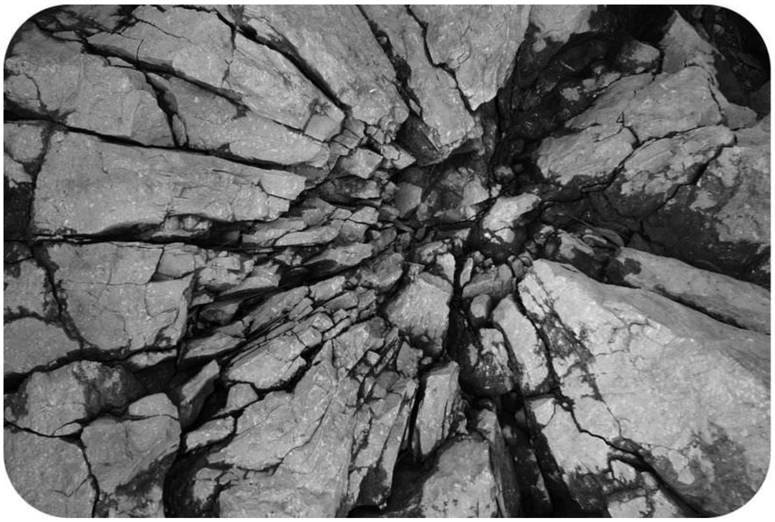


FIGURE 2.1
Stress caused these rocks to fracture.

- 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** 2.2). Shear stress is the most common stress at transform plate boundaries.

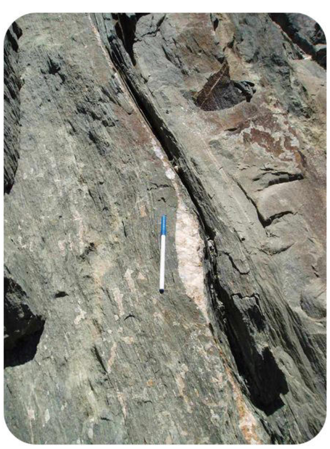


FIGURE 2.2
Shearing in rocks. The white quartz vein has been elongated by shear.

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** 2.3):

- **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.

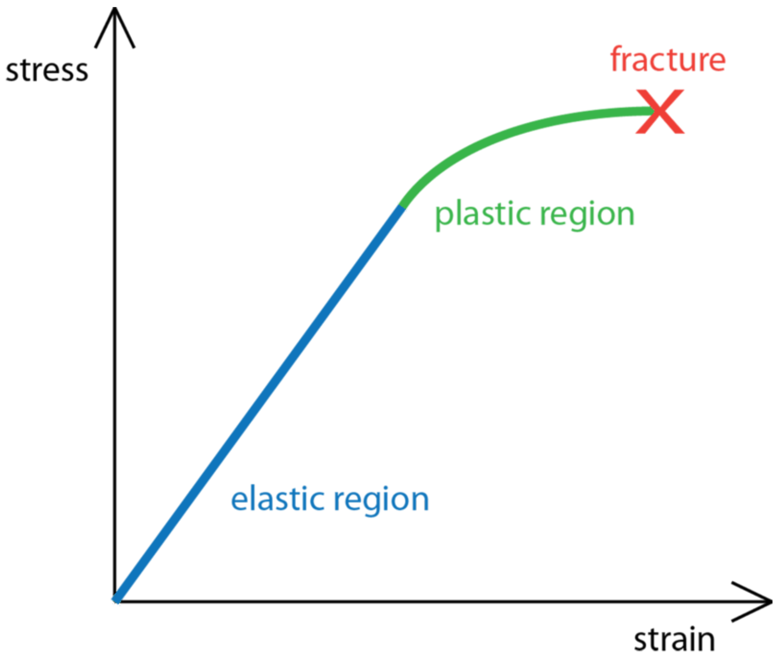
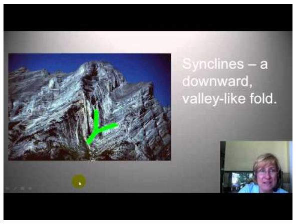


FIGURE 2.3
With increasing stress, the rock undergoes: (1) elastic deformation, (2) plastic deformation, and (3) fracture.

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.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186167

Summary

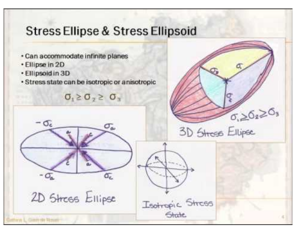
- Stress is the force applied to an object. Stresses can be confining, compression, tension, or shear.
- Rocks under stress may show strain or deformation. Deformation can be elastic or plastic, or the rock may fracture.
- Rocks respond to stress differently under different conditions.

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?

Explore More

Use this resource to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/177995

1. What is stress defined as?
2. What are body forces and what are they proportional to?
3. What are surface forces?
4. Why does stress need to be studied in vector components?
5. In what direction do the forces go in normal stress? What about in shear stress?
6. What is strain?

2.2 Faults

Learning Objectives

- 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** 2.4).

FIGURE 2.4
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** 2.5). Stresses along faults cause rocks to break and move suddenly. The energy released is an earthquake.

FIGURE 2.5
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** 2.6).

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.

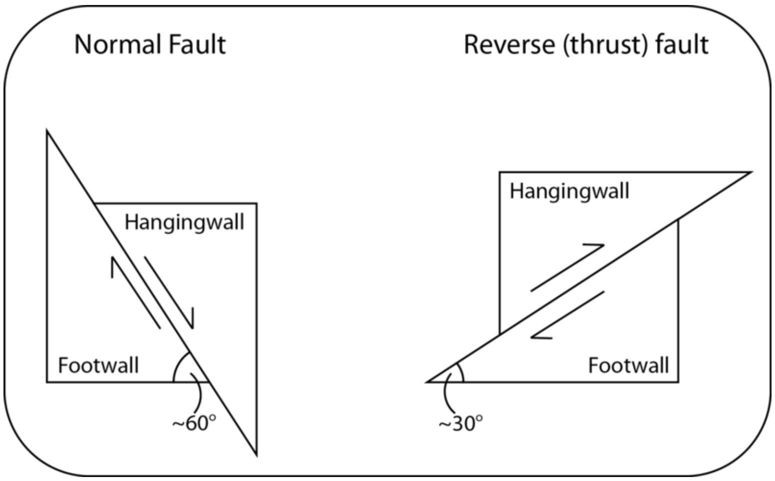


FIGURE 2.6
This diagram illustrates the two types of dip-slip faults: normal faults and reverse faults. Imagine miners extracting a resource along a fault. The hanging wall is where miners would have hung their lanterns. The footwall is where they would have walked.

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** 2.7).

FIGURE 2.7
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** 2.8).

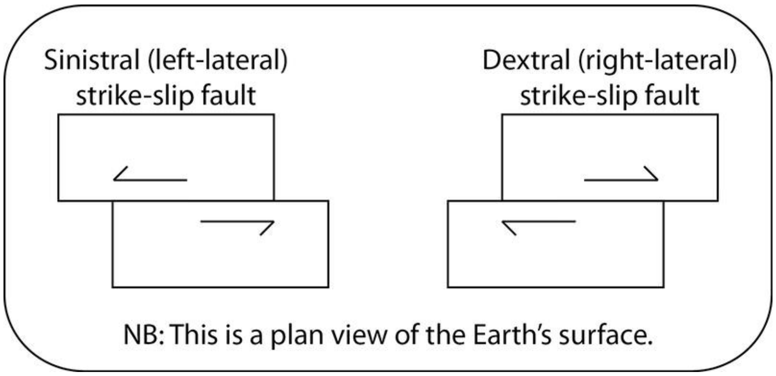
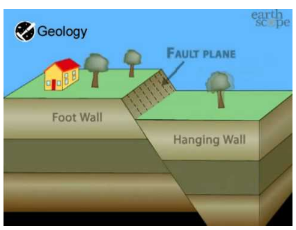


FIGURE 2.8
Strike-slip faults.

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). People sometimes say that California will fall into the ocean someday, which is not true.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/176336

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.

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?

2.3 Mountain Building

Learning Objectives

- 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** 2.9). 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.

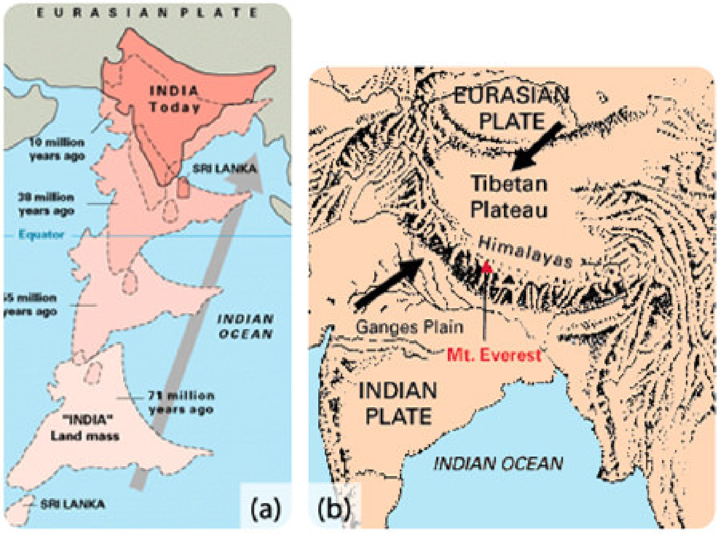


FIGURE 2.9
(a) The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. (b) The crumpling of the Indian and Eurasian plates of continental crust creates the Himalayas.

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** 2.10), 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 2.10
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** 2.11). 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.

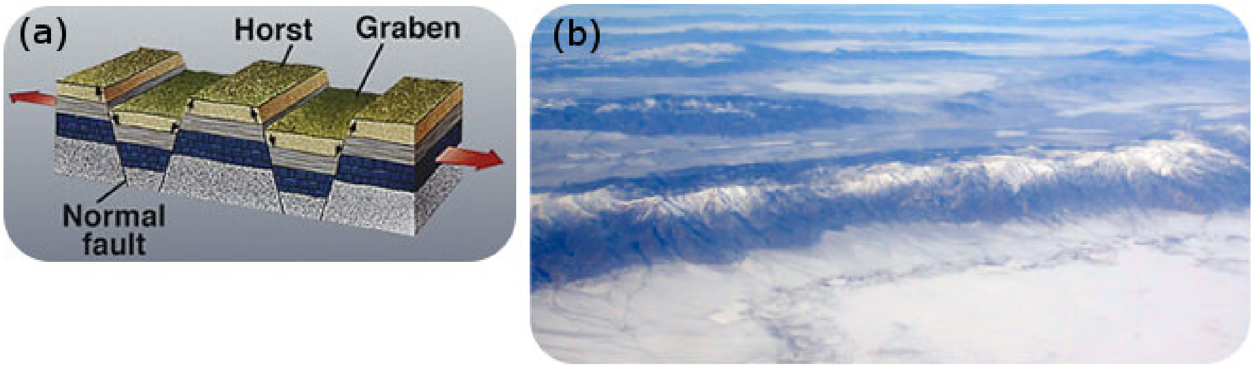
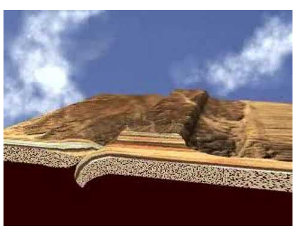


FIGURE 2.11
(a) Horsts and grabens. (b) Mountains in Nevada are of classic basin-and-range form.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186171



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186173

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.

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?

2.4 Volcanoes at Plate Boundaries

Learning Objectives

- Describe volcanic activity at convergent and divergent plate boundaries and explain why it occurs.

Climb a volcano... are you mad?

Volcanoes are fun (and difficult) to climb. Climbing in the Cascades ranges in difficulty from a non-technical hike, like on South Sister, to a technical climb on Mount Baker in which an ice axe, crampons, and experience are needed.

Convergent Plate Boundaries

Converging plates can be oceanic, continental, or one of each. If both are continental they will smash together and form a mountain range. If at least one is oceanic, it will subduct. A subducting plate creates volcanoes.

In the chapter Plate Tectonics we moved up western North America to visit the different types of plate boundaries there. Locations with converging in which at least one plate is oceanic at the boundary have volcanoes.

Melting

Melting at convergent plate boundaries has many causes. The subducting plate heats up as it sinks into the mantle. Also, water is mixed in with the sediments lying on top of the subducting plate. As the sediments subduct, the water rises into the overlying mantle material and lowers its melting point. Melting in the mantle above the subducting plate leads to volcanoes within an island or continental arc.

Pacific Rim

Volcanoes at convergent plate boundaries are found all along the Pacific Ocean basin, primarily at the edges of the Pacific, Cocos, and Nazca plates. Trenches mark subduction zones, although only the Aleutian Trench and the Java Trench appear on the map in the previous concept, "Volcano Characteristics."

The Cascades are a chain of volcanoes at a convergent boundary where an oceanic plate is subducting beneath a continental plate. Specifically the volcanoes are the result of subduction of the Juan de Fuca, Gorda, and Explorer Plates beneath North America. The volcanoes are located just above where the subducting plate is at the right depth in the mantle for there to be melting (**Figure** 2.12).

The Cascades have been active for 27 million years, although the current peaks are no more than 2 million years old. The volcanoes are far enough north and are in a region where storms are common, so many are covered by glaciers.

Divergent Plate Boundaries

At divergent plate boundaries hot mantle rock rises into the space where the plates are moving apart. As the hot mantle rock convects upward it rises higher in the mantle. The rock is under lower pressure; this lowers the melting temperature of the rock and so it melts. Lava erupts through long cracks in the ground, or **fissures.**

Mid-Ocean Ridges

Volcanoes erupt at mid-ocean ridges, such as the Mid-Atlantic ridge, where seafloor spreading creates new seafloor in the rift valleys. Where a hotspot is located along the ridge, such as at Iceland, volcanoes grow high enough to create islands (**Figure** 2.14).

Continental Rifting

Eruptions are found at divergent plate boundaries as continents break apart. The volcanoes in **Figure** 2.15 are in the East African Rift between the African and Arabian plates. Remember from the chapter Plate Tectonics that Baja California is being broken apart from mainland Mexico as another example of continental rifting.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186291

FIGURE 2.12
The Cascade Range is formed by volcanoes created from subduction of oceanic crust beneath the North American continent.

Summary

- Melting is common at convergent plate boundaries.
- Convergent plate boundaries line the Pacific Ocean basin so that volcanic arcs line the region.
- Melting at divergent plate boundaries is due to pressure release.
- At mid-ocean ridges seafloor is pulled apart and new seafloor is created.

Review

1. What causes melting at convergent plate boundaries?
2. Why are there so many volcanoes around the Pacific Ocean basin?
3. What causes melting at divergent plate boundaries?

FIGURE 2.13
Mt. Baker, Washington.

FIGURE 2.14
A volcanic eruption at Surtsey, a small island near Iceland.

4. How does a rifting within a continent lead to seafloor spreading?

Explore More

Use this resource (watch up to 11:02) to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/164117

FIGURE 2.15
Mount Gahinga in the East African Rift valley.

1. What percent of volcanoes and earthquakes occur on the Pacific Ring of Fire?
2. How long is the arc of volcanoes along the Pacific Rim?
3. How has Augustine built up so high? Does it have high or low silica?
4. What type of volcanoes are found along the ring of fire? What happens to the gas in the magma?
5. what kills so many people?
6. What does water do in hot rock below the surface?
7. What does carbon-12 indicate?
8. What process brings the sediments and water into the mantle?

2.5 Volcanoes at Hotspots

Learning Objectives

- 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

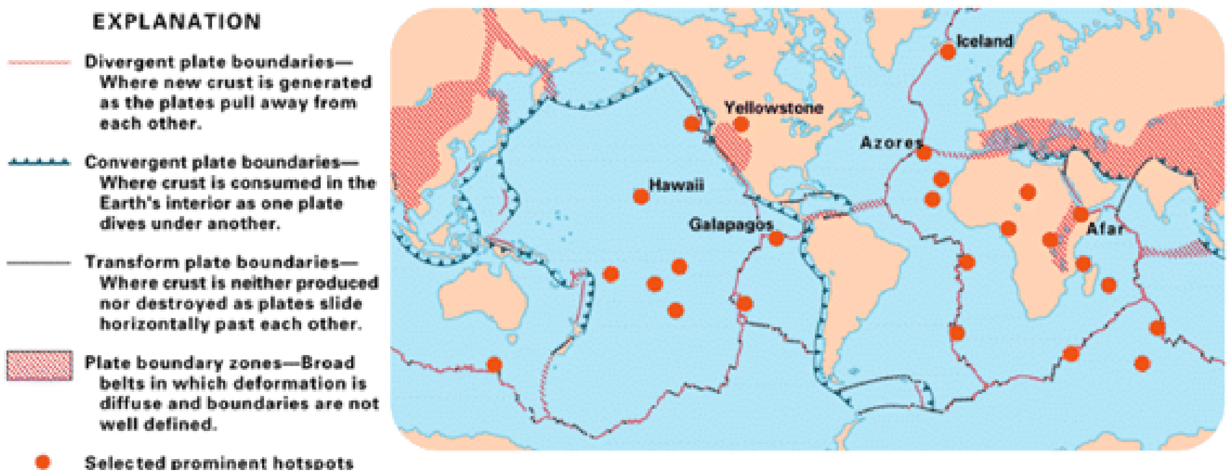


FIGURE 2.16
Prominent hotspots of the world.

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.

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** 2.17).

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.

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.

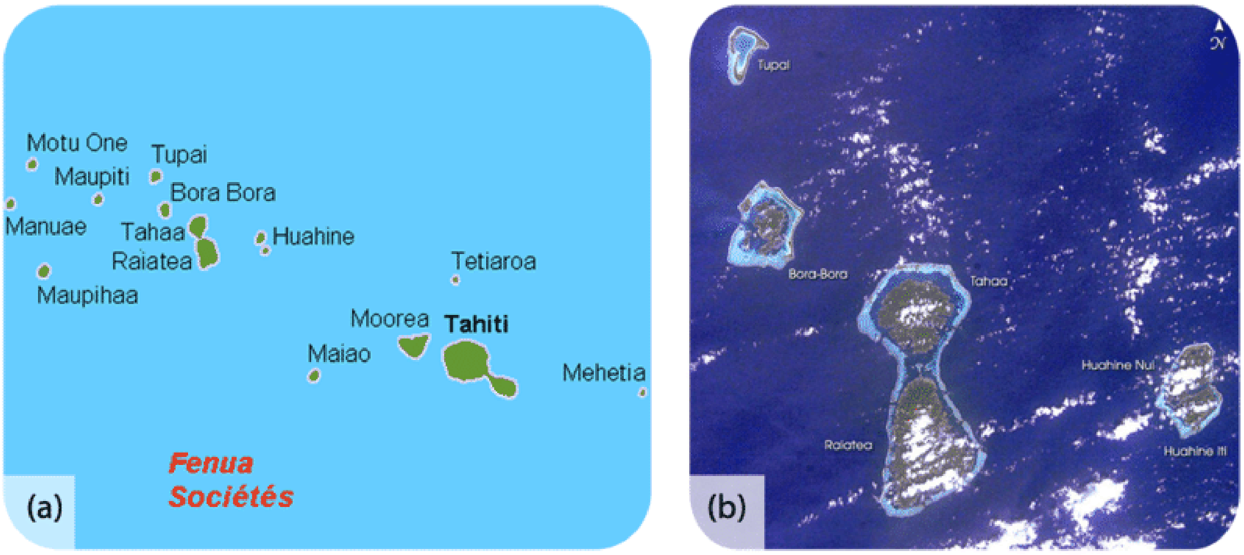
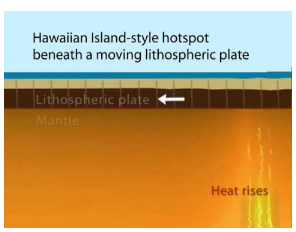


FIGURE 2.17

(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.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186293

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.

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?

Explore More

Use the resource below to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178033

1. How far is Hawaii from the nearest convergent plate boundary?
2. How does a hotspot get through the Pacific plate?
3. How do scientists know that the hotspot doesn't move?
4. Why does an older volcano cease volcanic activity?
5. What has happened to Oahu? How much was lost?

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178031

2.6 Effusive Eruptions

Learning Objectives

- Describe the causes and effects of effusive volcanic eruptions.

Is Stromboli just a rolled-up pizza?

For most people a stromboli is a rolled sandwich of dough, cheeses, and meats. For volcanologists, Stromboli is a volcano for which a type of eruption was named. Strombolian eruptions spew lava into the air but do not explode as massively as in the plinian eruptions in the previous concept. Still, the power of a volcano is easily seen in this eruption on Mt. Stromboli in Italy.

Effusive Eruptions

Mafic magma creates gentler **effusive eruptions**. Although the pressure builds enough for the magma to erupt, it does not erupt with the same explosive force as felsic magma. Magma pushes toward the surface through fissures. Eventually, the magma reaches the surface and erupts through a vent (**Figure** 2.18). Effusive eruptions are common in Hawaii, where lavas are mafic.

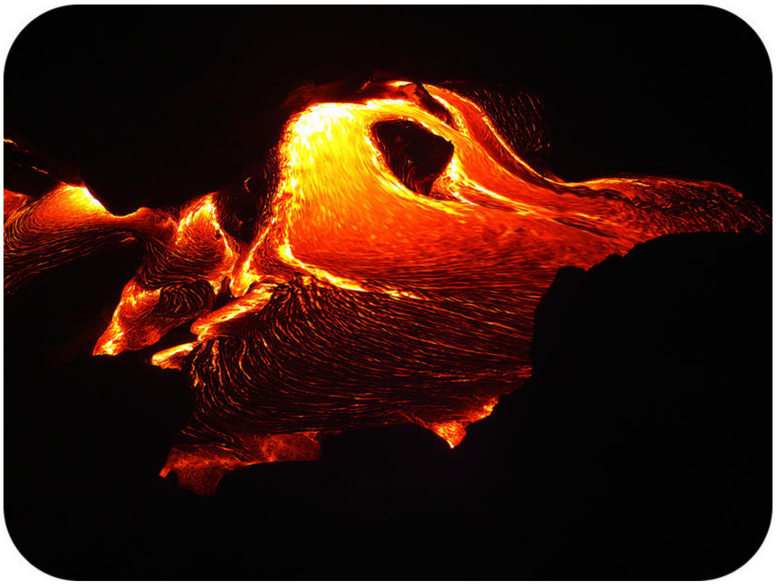


FIGURE 2.18
In effusive eruptions, lava flows readily, producing rivers of molten rock.

- A Quicktime movie with thermal camera of a lava stream within the vent of a Hawaiian volcano is seen here: http://hvo.wr.usgs.gov/kilauea/update/archive/2009/Nov/OverflightFLIR_13Jan2010.mov .

Types of Lava

Low-viscosity lava flows down mountainsides. Differences in composition and where the lavas erupt result in three types of lava flow coming from effusive eruptions. A'a lava forms a thick and brittle crust that is torn into rough and jagged pieces. A'a lava can spread over large areas as the lava continues to flow underneath the crust's surface. Pāhoehoe lava forms lava tubes where fluid lava flows through the outer cooled rock crust. Pāhoehoe lava is less viscous than a'a lava, so its surface looks is smooth and ropy. Mafic lava that erupts underwater creates pillow lava. The lava cools very quickly, forming roughly spherical rocks. Pillow lava is common at mid-ocean ridges (**Figure** 2.19).

Effusive Eruptions Damage

People can usually be evacuated before an effusive eruption, so they are much less deadly. Although effusive eruptions rarely kill anyone, they can be destructive. Even when people know that a lava flow is approaching, there is not much anyone can do to stop it from destroying a building or road (**Figure** 2.20).

Summary

- Mafic magma creates effusive eruptions. The pressure builds but the lava does not explode so violently from the vent.

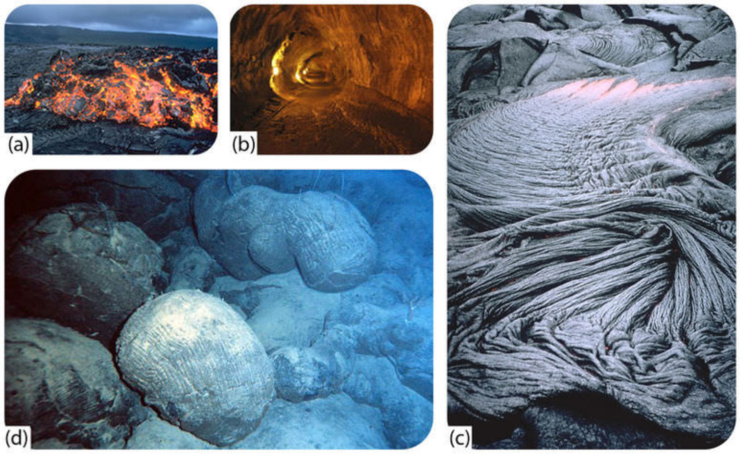


FIGURE 2.19
(a) A'a lava spread over large areas. (b) Pāhoehoe lava tubes where at the Thurston Lava Tube in Hawai'i Volcanoes National Park. (c) Pāhoehoe lava is less viscous than a'a lava so its surface looks is smooth and ropy. (d) Pillow lava.

FIGURE 2.20
A road is overrun by an eruption at Kilauea volcano in Hawaii.

- Effusive eruptions cause damage but usually people can be evacuated, so there are few or no fatalities.
- Mafic magma cools into different types of flows like a'a, pāhoehoe, and pillow lava.

Review

1. Why do mafic lavas flow rather than explode?
2. Compare and contrast a'a and pāhoehoe lavas.
3. How do pillow lavas form?

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178038

1. What are you viewing early in the video?
2. What is the source of the thunder-like cracking and booming?
3. What is causing the rise in the lava lake?
4. How does a fissure eruption differ from a lava lake eruption?
5. How does the eruption in this video differ from the eruption in the Mount St. Helens video in the previous concept?

Resources

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178036

2.7 Explosive Eruptions

Learning Objectives

- Describe the causes and effects of explosive volcanic eruptions.

Why do we still talk about Pompeii, 79 AD?

Nearly 2,000 years later, the explosive eruption of Mt. Vesuvius remains one of the most talked about eruptions in history. It began with a column of ash that blanketed the area, which was followed by fast-moving, dense, and scorching-hot pyroclastic flows. People suffocated or burnt, and structures in two thriving Roman cities were destroyed. Remains of some of the dead can be seen at Pompeii, where people were entombed in scorching ash. The eruption type was named plinian, after Pliny the Younger, who watched from offshore.

Explosive Eruptions

A large **explosive eruption** creates even more devastation than the force of the atom bomb dropped on Nagasaki at the end of World War II, in which more than 40,000 people died. A large explosive volcanic eruption is 10,000 times as powerful. Explosive eruptions are found at the convergent plate boundaries that line parts of western North America, resulting in the Cascades in the Pacific Northwest and the Aleutians in Alaska.

Causes of the Explosion

Explosive eruptions are caused by gas-rich, felsic magmas that churn within the magma chamber. When the pressure becomes too great the magma breaks through the rock above the chamber and explodes, just like when a cork is released from a bottle of champagne. Magma, rock, and ash burst upward in an enormous explosion (**Figure** 2.21).

FIGURE 2.21
Ash and gases create a mushroom cloud above Mt. Redoubt in Alaska, 1989. The cloud reached 45,000 feet and caught a Boeing 747 in its plume.

Pyroclastic Material

The erupted rock fragments are called **tephra**. Ash and gas also explode from the volcano. Scorching hot tephra, ash, and gas may speed down the volcano's slopes at 700 km/h (450 mph) as a **pyroclastic flow**. Pyroclastic means fire rock (**Figure** 2.22).

FIGURE 2.22
Left: An explosive eruption from the Mayon Volcano in the Philippines in 1984. Ash flies upward into the sky and pyroclastic flows pour down the mountainside. Right: The end of a pyroclastic flow at Mount St. Helens.

Pyroclastic flows knock down everything in their path. The temperature inside a pyroclastic flow may be as high as 1,000°C (1,800°F).

FIGURE 2.23
Blowdown of trees near Mount St. Helens shows the direction of the blast and pyroclastic flow.

Cascades Volcanoes

Prior to the Mount St. Helens eruption in 1980, the Lassen Peak eruption on May 22, 1915, was the most recent Cascades eruption. A column of ash and gas shot 30,000 feet into the air. This triggered a high-speed pyroclastic flow, which melted snow and created a volcanic mudflow known as a **lahar**. Lassen Peak currently has geothermal activity and could erupt explosively again. Mt. Shasta, the other active volcano in California, erupts every 600 to 800 years. An eruption would most likely create a large pyroclastic flow, and probably a lahar. Of course, Mt. Shasta could explode and collapse like Mt. Mazama in Oregon (**Figure** 2.24).

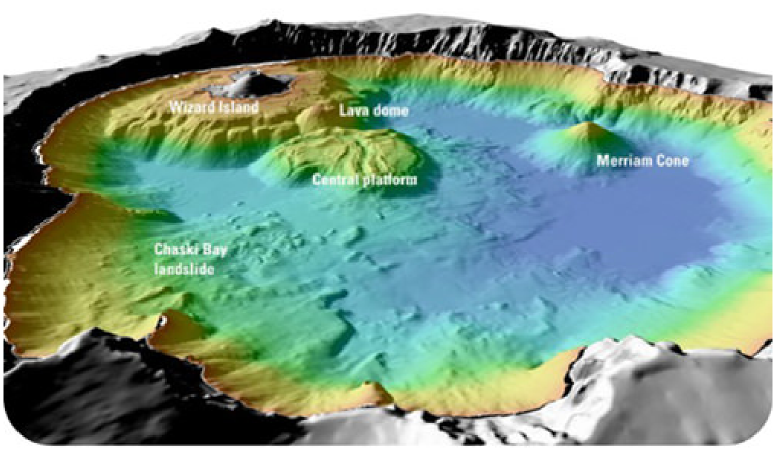


FIGURE 2.24
Crater Lake fills the caldera of the collapsed Mt. Mazama, which erupted with 42 times more power than Mount St. Helens in 1980. The bathymetry of the lake shows volcanic features such as cinder cones.

Volcanic Gases

Volcanic gases can form poisonous and invisible clouds in the atmosphere. These gases may contribute to environmental problems such as acid rain and ozone destruction. Particles of dust and ash may stay in the atmosphere for years, disrupting weather patterns and blocking sunlight (**Figure** 2.25).

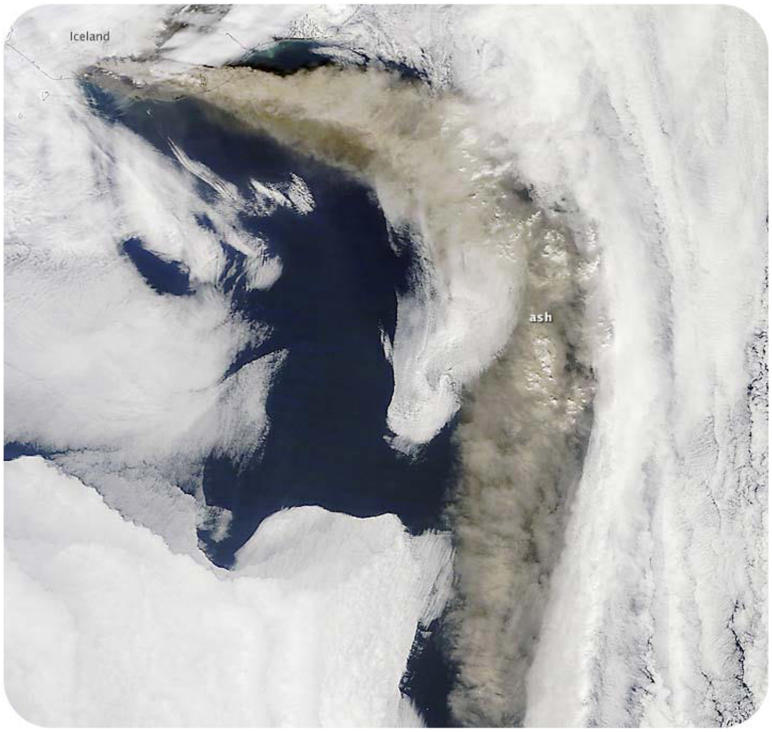


FIGURE 2.25
The ash plume from Eyjafjallajökull volcano in Iceland disrupted air travel across Europe for six days in April 2010.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186297

Summary

- Felsic magmas erupt explosively, creating pyroclastic eruptions.
- Pyroclastic eruption types include tephra, ash, and lahars.
- Mt. Mazama blew its top off and then collapsed, creating Crater Lake in Oregon.

Review

1. Why do convergent plate boundaries have explosive eruptions?
2. Why do felsic magmas erupt explosively?
3. How do volcanic gases affect the atmosphere?

2.8 Principle of Horizontality

Learning Objectives

- Identify rules for the formation and deformation of sedimentary rock.
- Explain how sedimentary rock helps scientists study geological history.

Why does the Grand Canyon resemble these cakes?

If you go to the Grand Canyon, you'll see a layer cake of geological formations. Some people call this "layer cake geology." Just like the cake, the bottom layer is put down first and then subsequent layers moving upward. If a layer is not horizontal it must have been deformed. We'll learn about deformation in the next several concepts.

Sedimentary Rock Rules

Sedimentary rocks follow certain rules.

1. Sedimentary rocks are formed with the oldest layers on the bottom and the youngest on top.
2. Sediments are deposited horizontally, so sedimentary rock layers are originally horizontal, as are some volcanic rocks, such as ash falls.
3. Sedimentary rock layers that are not horizontal are deformed.

Since sedimentary rocks follow these rules, they are useful for seeing the effects of stress on rocks. Sedimentary rocks that are not horizontal must have been deformed.

You can trace the deformation a rock has experienced by seeing how it differs from its original horizontal, oldest-on-bottom position. This deformation produces geologic structures such as folds, joints, and faults that are caused by stresses.

Geologic History

You're standing in the Grand Canyon and you see rocks like those in the **Figure** 2.26. Using the rules listed above, try to figure out the geologic history of the geologic column. The Grand Canyon is full mostly of sedimentary rocks, which are important for deciphering the geologic history of a region.

In the Grand Canyon, the rock layers are exposed like a layer cake. Each layer is made of sediments that were deposited in a particular environment - perhaps a lake bed, shallow offshore region, or a sand dune.

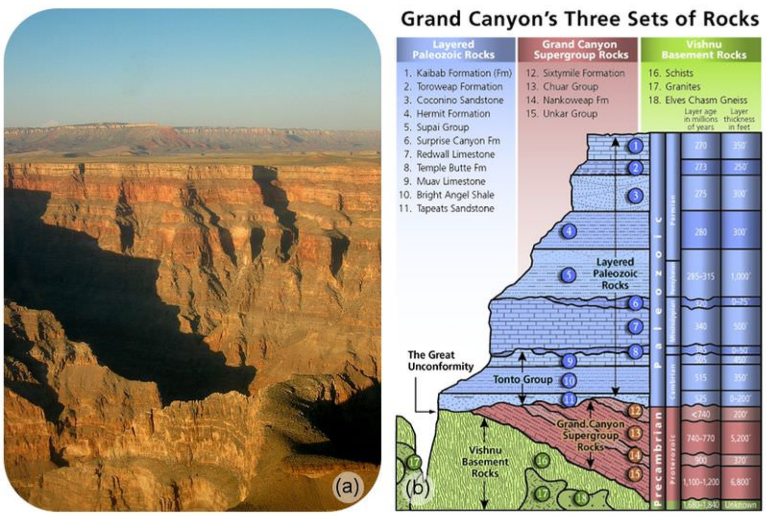


FIGURE 2.26

(a) The rocks of the Grand Canyon are like a layer cake. (b) A geologic column showing the rocks of the Grand Canyon.

In this geologic column of the Grand Canyon, the sedimentary rocks of groups 3 through 6 are still horizontal. Group 2 rocks have been tilted. Group 1 rocks are not sedimentary. The oldest layers are on the bottom and youngest are on the top.

The ways geologists figure out the geological history of an area will be explored more in the chapter Earth History.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186169

Summary

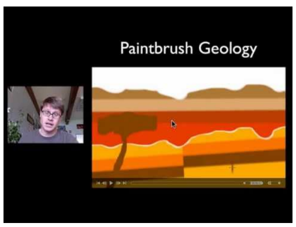
- Sedimentary rocks are laid down horizontally.
- Rocks are laid down from oldest to youngest.
- Sedimentary rocks that are not horizontal have been deformed.
- Sedimentary rocks are very useful for deciphering the geological history of an area.

Review

1. In the Grand Canyon section, what do you think happened to the rocks between layers 12 and 11?
2. For what reason are the rocks 16, 17 and 18 not layered?
3. What are the oldest rocks in the Grand Canyon and what type are they? What are the youngest rocks and what type are they?

Explore More

Use this resource to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/1430

1. What is the law of superposition?
2. How are the sediments laid down?
3. How can you determine the oldest rock?
4. What can happen to disturb the layers?
5. What does erosion do?
6. What is an intrusion?

2.9 Folds

Learning Objectives

- 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** 2.27 for an example).

FIGURE 2.27
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** 2.28). 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** 2.29).

When rocks bend downward in a circular structure, that structure is called a **basin** (**Figure** 2.30). If the rocks are exposed at the surface, where are the oldest rocks located?

FIGURE 2.28
Anticlines are formations that have folded rocks upward.

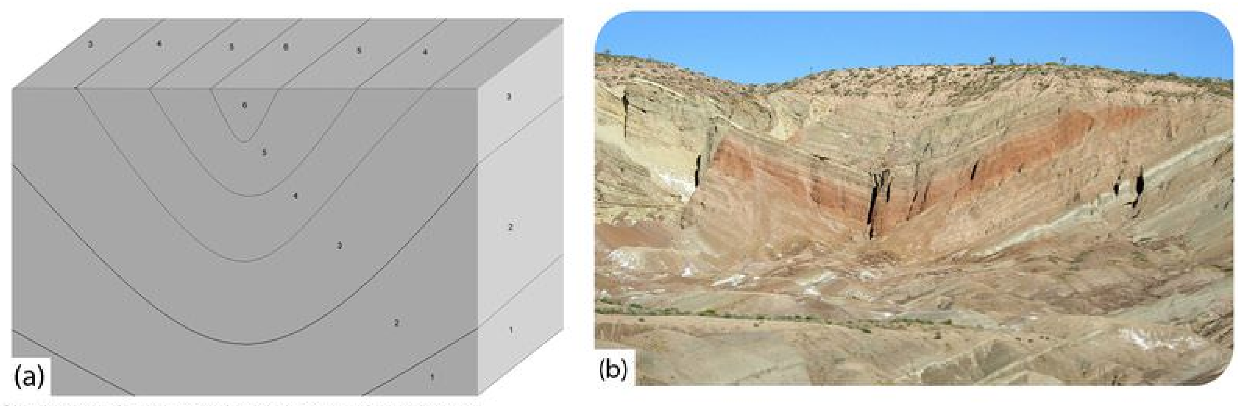


FIGURE 2.29
(a) Schematic of a syncline. (b) This syncline is in Rainbow Basin, California.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/179835

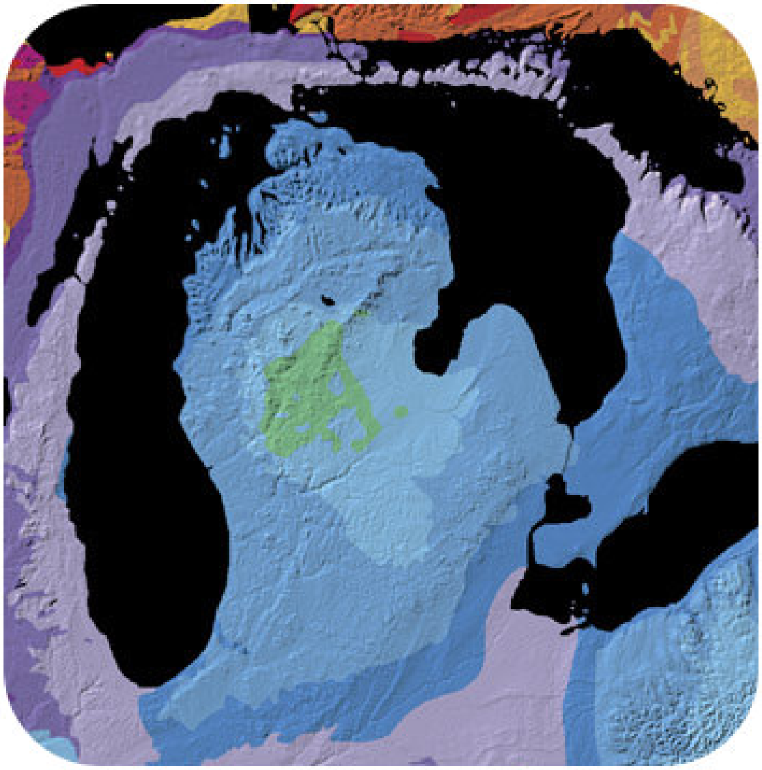


FIGURE 2.30

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 2.31

Some folding can be fairly complicated. What do you see in the photo above?

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.
- In a syncline, rocks arch downward. A three-dimensional syncline is a basin.

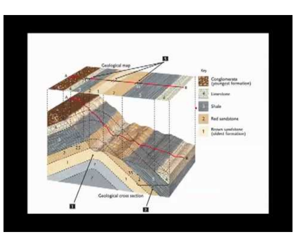
Review

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?

Explore More

Use this resource to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/1410

1. What causes folds?

2. What are the folds called?
3. What is dip? What is it measured from?
4. What is 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 on how a rock layer looks on a map.

2.10 Divergent Plate Boundaries

Learning Objectives

- 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** 2.32 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** 2.33).

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

FIGURE 2.32
This map shows the three major plate boundaries in or near California.

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.

Baja California

Baja California is a state in Mexico just south of California. In the **Figure** 2.34, 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** 2.35.

Can you relate what is happening at this plate boundary to what happened when Pangaea broke apart?

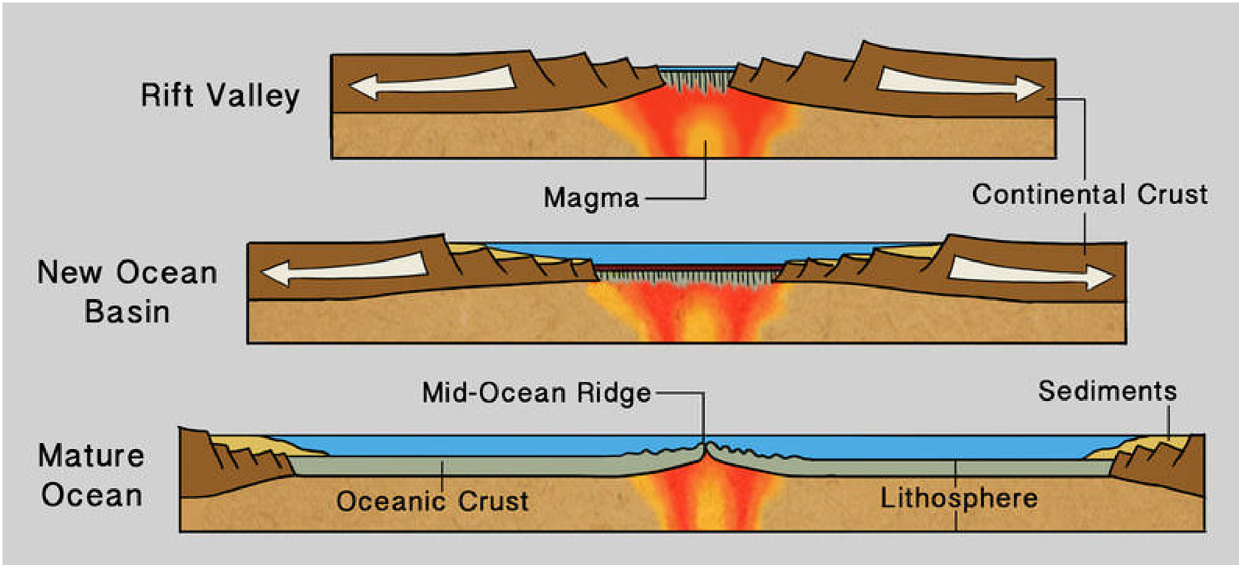


FIGURE 2.33

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.

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.

Review

1. How is a divergent plate boundary on land different from one in the ocean?
2. What is happening to the Baja California peninsula?
3. How did continental rifting play into the breakup of Pangaea?

FIGURE 2.34

Baja California is rifting apart from mainland Mexico, as seen in this satellite image.

FIGURE 2.35

Volcanism in Baja California is evidence of rifting.

2.11 Weathering and Erosion

Learning Objectives

- 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** 2.36). What forces of weathering wear down that road, or rocks or mountains over time?

FIGURE 2.36
A once smooth road surface has cracks and fractures, plus a large pothole.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186338

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.

Review

1. What is weathering?
2. How is weathering different from erosion?
3. Why does weathering take so much time?

2.12 Influences on Weathering

Learning Objectives

- 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:

FIGURE 2.37
The Shiprock formation in northwest New Mexico is the central plug of resistant lava from which the surrounding rock weathered and eroded away.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/4779

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^oC 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** 2.38). 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.

FIGURE 2.38
Wet, warm tropical areas have the most weathering.

Summary

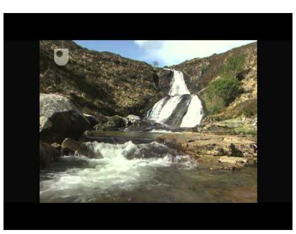
- Different materials weather at different rates and intensities under the same conditions.
- Different climate conditions cause the same materials to weather different intensities.

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 the aluminum resource bauxite form?

Explore More

Use this resource to answer the questions that follow.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/4780

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. Why do the dikes on the hillside stick out of the hill?
4. What two processes shape the landscape of the island?
5. What are the primary sources of weathering on Skye?
6. How is scree produced?

7. How does weathering affect granite?
8. What is responsible for the topography of the island?
9. Which rocks are more resistant to weathering? How does that affect the topography?

2.13 Landforms from Stream Erosion and Deposition

Learning Objectives

- 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** 2.39). 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 2.39
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.

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** 2.40).

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

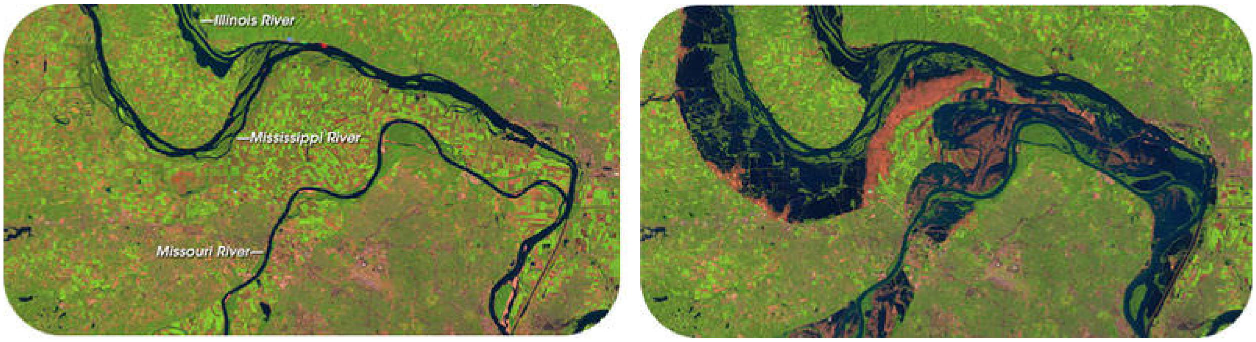


FIGURE 2.40
The Mississippi River floodplain at normal flow and during flood.

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** 2.41).

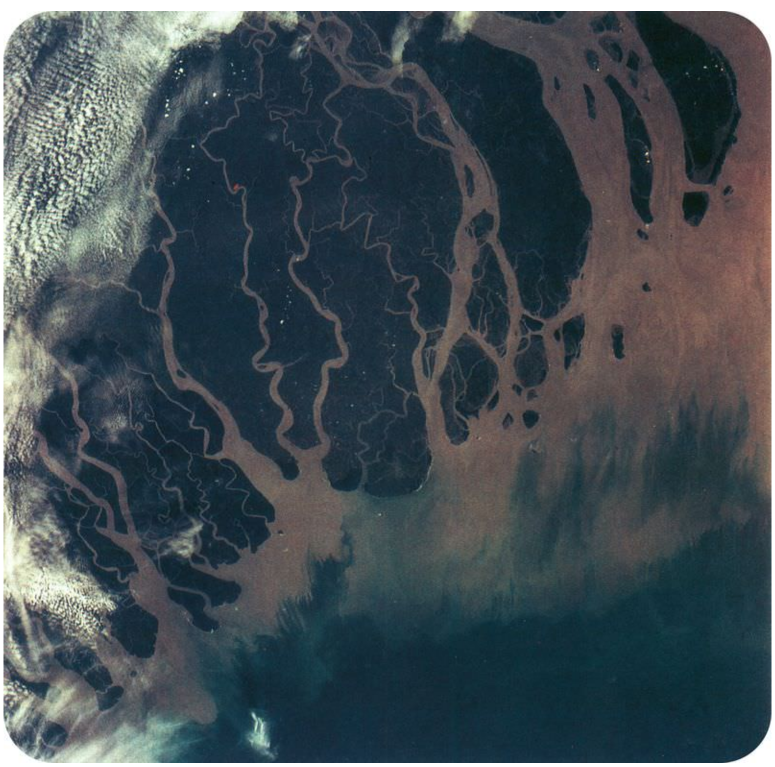


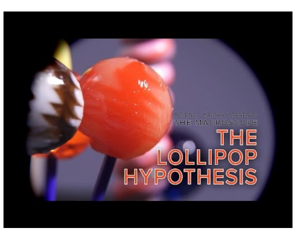
FIGURE 2.41
The Ganges River forms an enormous delta in Bangladesh.

If a stream falls down a steep slope onto a broad flat valley, an **alluvial fan** develops (**Figure** 2.42). Alluvial fans generally form in arid regions.

FIGURE 2.42
A series of alluvial fans spread out from mountains along the Badwater Basin in Death Valley, California.

Science Friday: The Lollipop Hypothesis

Ever wondered how many licks it takes to reach the center of a lollipop? Mathematicians at NYU's applied mathematics lab have designed experiments to determine this. Find out in this video by Science Friday.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/191876

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.

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.

Explore More

Use the resource below to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/4784

1. What is laminar flow?
2. What is turbulent flow?
3. Where along the river in Yellowstone is there laminar flow and where is there turbulent flow? Why?
4. What is jet flow? Where does jet flow occur?
5. What is water velocity?
6. What factors can influence the stream velocity?

2.14 References

1. Giulio Callegaro. Stress caused these rocks to fracture . CC BY 2.0
2. Roland Gotthard. Rock that has undergone shearing . Public Domain
3. Jodi So. Graph of stress, going from elastic deformation to plastic deformation to fracture . CC BY-NC 3.0
4. Flickr:Tscherno. Joints in rocks at Joshua Tree National Park, in California . CC BY 2.0
5. Roy Luck. A fault cutting across bedded rocks . CC BY 2.0
6. Jodi So. Diagram of a reverse and normal fault . CC BY-NC 3.0
7. Courtesy of the National Park Service. Chief Mountain in Montana formed due to a thrust fault . Public Domain
8. Jodi So. Diagram of a strike-slip fault . CC BY-NC 3.0
9. Courtesy of the US Geological Survey. The Himalaya Mountains rise as India rams into Eurasia . Public Domain
10. Courtesy of NASA. The Andes Mountains formed due to oceanic plate subduction . Public Domain
11. (a) Courtesy of the US Geological Survey; (b) Miguel Vieira. Diagram and picture of basin-and-range . (a) Public Domain; (b) CC BY 2.0
12. Courtesy of NASA, modified by User:Black Tusk/Wikimedia Commons. Map of volcanoes on the Cascade Range . Public Domain
13. Curt Smith. Picture of Mt. Baker in Washington . CC BY 2.0
14. Courtesy of the U.S. National Oceanic and Atmospheric Administration. A volcanic eruption at Surtsey, a sm all island near Iceland . Public Domain
15. Image copyright PRILL, 2013. Mount Gahinga in the East African Rift valley . Used under license from Shutterstock.com
16. Courtesy of US Geological Survey. Map of hotspots around the world . Public Domain
17. (a) Holger Behr (User:Hobe/Wikimedia Commons); (b) Courtesy of Johnson Space Center/NASA's Earth Observatory. Map of the Society Islands . Public Domain
18. Paul Bica. In effusive eruptions, lava flows readily, producing rivers of molten rock . CC BY 2.0
19. (a) Courtesy of US Geological Survey; (b) Michael Oswald; (c) Courtesy of TN Mattox/US Geological Survey; (d) Courtesy of OAR/National Undersea Research Program. Pictures of A'a, pahoehoe, and pillo w lava . Public Domain
20. Courtesy of the US Geological Survey. Road covered by lava from an eruption at Kilauea in Hawaii . Public Domain
21. Courtesy of the US Geological Survey. Eruption of Mt. Redoubt in Alaska in 1989 . Public Domain
22. Left: Courtesy of CG Newhall/US Geological Survey; Right: Courtesy of DA Swanson/US Geological Survey. Erupting volcano and pyroclastic flow aftermath . Public Domain
23. Courtesy of Lyn Topinka/US Geological Survey. Trees knocked down by Mount St. Helens eruption . Public Domain
24. Courtesy of the US Geological Survey. Crater Lake fills the caldera of the collapsed Mt. Mazama . Public Domain
25. Courtesy of Jeff Schmaltz/NASA's Earth Observatory. Satellite photo of the ash plume from the eruption of the Eyjafjallajökull volcano in Iceland . Public Domain
26. (a) Kyle Simourd; (b) Courtesy of the US Department of the Interior. Graph showing the ages of the layers of the Grand Canyon . (a) CC BY 2.0; (b) Public Domain
27. Image copyright Scott Prokop, 2014. Picture of a monocline . Used under license from Shutterstock.com
28. Flickr:woosh2007. Picture of an anticline . CC BY 2.0
29. (A) User:Jonathan3784/Wikipedia; (B) Mark A. Wilson (User:Wilson44691/Wikipedia). Picture of a synclin e . Public Domain

30. Courtesy of Nation Atlas of the United States. Map of the Michigan Basin . Public Domain
31. Image copyright Darren J. Bradley, 2013. Folding in rock . Used under license from Shutterstock.com
32. Courtesy of US Geological Survey, modified by CK-12 Foundation. Map showing three major plate boundaries around California . Public Domain
33. Laura Guerin. Plate divergence creates a rift valley or a new ocean basin . CC BY-NC 3.0
34. Courtesy of NASA. Baja California is rifting apart from Mainland Mexico . Public Domain
35. Courtesy of NASA. Volcanism in Baja California is evidence of rifting . Public Domain
36. Miguel Tremblay. Weathering leads to potholes in roads . Public Domain
37. bowie snodgrass. The Shiprock formation in New Mexico formed after the surrounding rock eroded away . CC BY 2.0
38. Flickr:finchlake2000. Wet, warm tropical areas have the most weathering . CC BY 2.0
39. Ken Bosma. The Amazon River appears brown when carrying a large sediment load . CC BY 2.0
40. Courtesy of Jesse Allen/NASA's Earth Observatory. The Mississippi River floodplain at normal flow and during flood . Public Domain
41. Courtesy of NASA. The Ganges River delta in Bangladesh . Public Domain
42. Courtesy of National Park Service. A series of alluvial fans in Death Valley . Public Domain

CHAPTER 3 ESS2-3

Chapter Outline

3.1 Earth's Interior Material

Learning Objectives

- Explain how information provided by study of density, magnetism, and rocks provide clues about Earth's interior.

In , what did they find?

Jules Verne published *A Journey to the Center of the Earth* in 1864 with very little idea of what was below the surface. Unfortunately, there are no volcanic tubes in which to travel deep within the planet, as Verne had imagined. But scientists have learned a lot about Earth's interior using seismic waves, rocks, and calculations of Earth's density and magnetism.

Other Clues About Earth's Interior

1. Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal.
2. Since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic.
3. **Meteorites** are the remains of the material that formed the early solar system and are thought to be similar to material in Earth's interior (**Figure** 3.1).

FIGURE 3.1
This meteorite contains silica minerals and iron-nickel. The material is like the boundary between Earth's core and mantle. The meteorite is 4.2 billion years old.

Summary

- Earth's density indicates that it must contain a significant amount of metal.
- Since Earth has a magnetic field, there must be metal inside.
- Meteorites formed elsewhere in the solar system but by similar processes indicate something about Earth's interior.

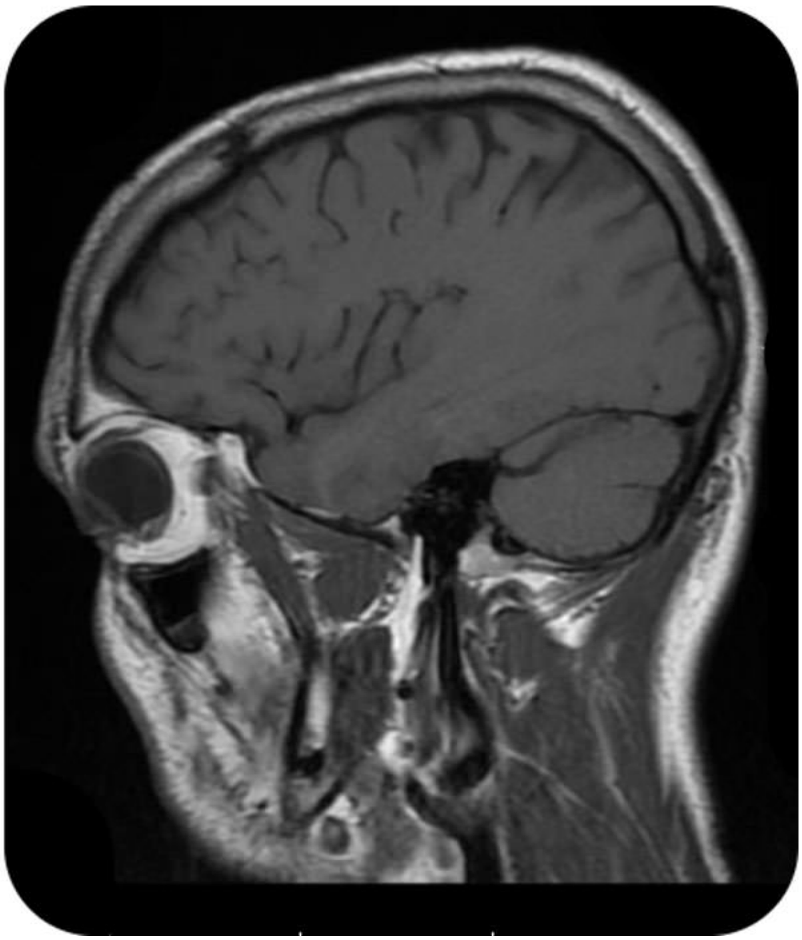
Review

1. Scientists know that Earth's interior contains metal, but how do they know it's in the core?
2. How does the meteorite in the **Figure** 3.1 give clues as to what is found in Earth's interior?
3. If a planet in our solar system has a magnetic field, what do we know about it?

3.2 Seismic Waves

Learning Objectives

- 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** 3.2.

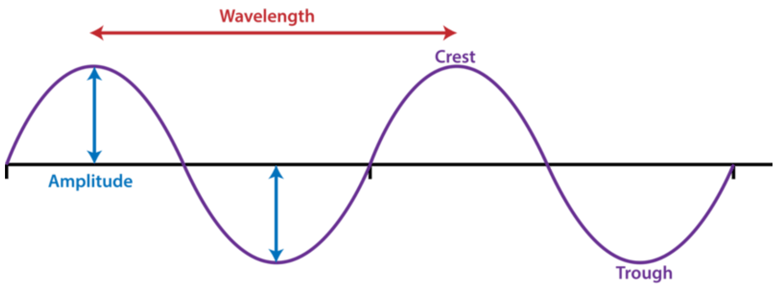


FIGURE 3.2
The crest, trough, and amplitude are illustrated in this diagram.

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** 3.3). 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.

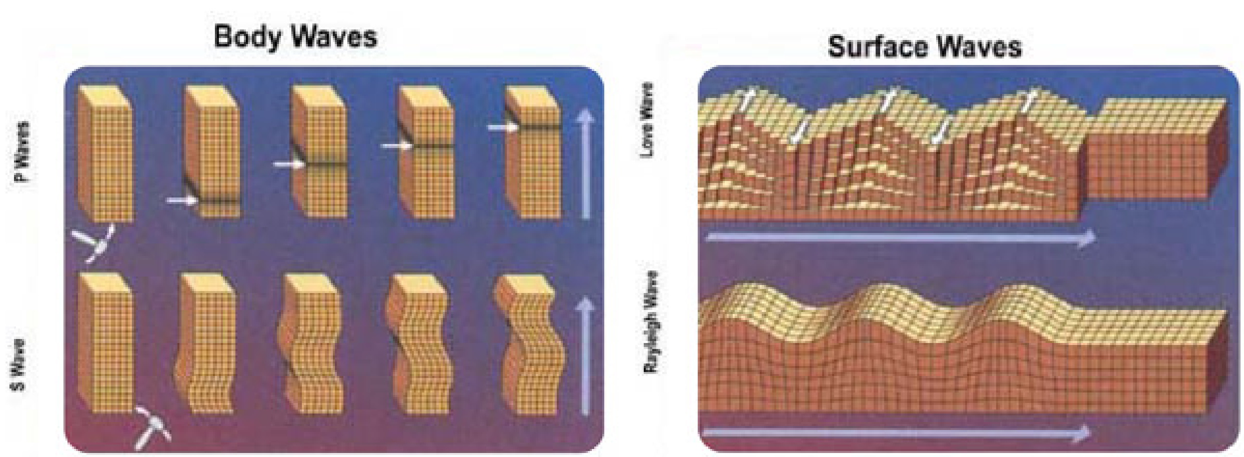


FIGURE 3.3

- **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.

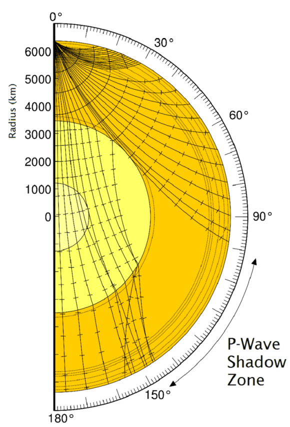


FIGURE 3.4
How P-waves travel through Earth's interior.

- **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** 3.5).

- 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.

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.

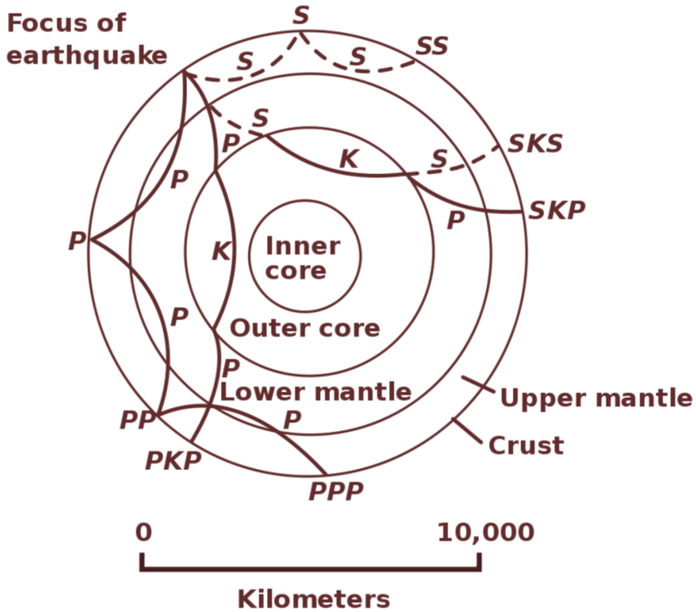


FIGURE 3.5

Letters describe the path of an individual P-wave or S-wave. Waves traveling through the core take on the letter K.

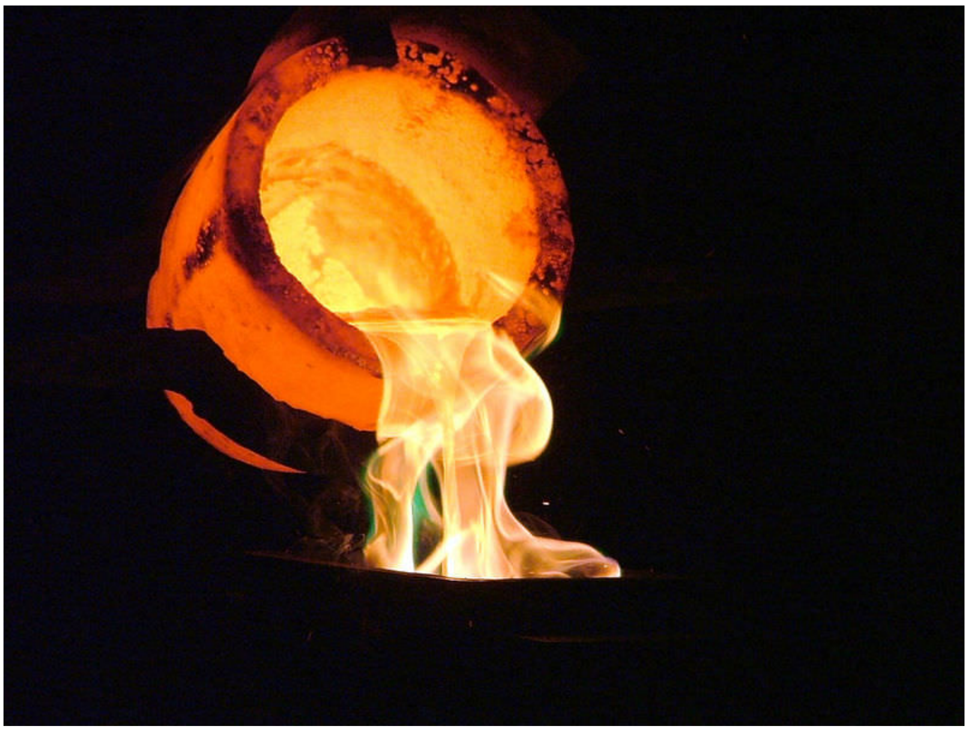
Review

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?

3.3 Earth's Core

Learning Objectives

- 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** 3.6).

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:

FIGURE 3.6
An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

1. S-waves do not go through the outer core.
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.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186098

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.

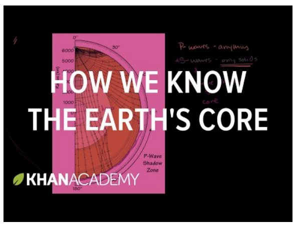
Review

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. Why is the outer core so hot?

Explore More

Use this resource to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/1474

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?

3.4 Earth's Crust

Learning Objectives

- Describe the characteristics of Earth's two types of crust, oceanic and continental.

How does a loaf of bread resemble Earth?

A loaf of homemade bread could almost resemble Earth. The raised parts of the crust are the continents and the depressed parts are the oceans. The inside is gooier than the brittle exterior, but it's still solid. How is a loaf of bread not like Earth?

Crust

Earth's outer surface is its crust, a cold, thin, brittle outer shell made of rock. The crust is very thin relative to the radius of the planet. There are two very different types of crust, each with its own distinctive physical and chemical properties, which are summarized in **Table** 3.1.

TABLE 3.1: Oceanic and Continental Crust

Crust	Thickness	Density	Composition	Rock types
Oceanic	5-12 km (3-8 mi)	3.0 g/cm^3	Mafic	Basalt and gabbro
Continental	Avg. 35 km (22 mi)	2.7 g/cm^3	Felsic	All types

Oceanic Crust

Oceanic crust is composed of mafic magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro (**Figure** 3.7).

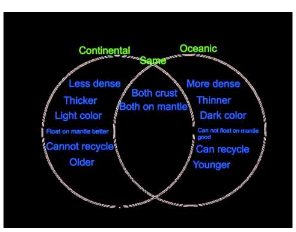
FIGURE 3.7
Gabbro from ocean crust. The gabbro is deformed because of intense faulting at the eruption site.

Sediments, primarily mud and the shells of tiny sea creatures, coat the seafloor. Sediment is thickest near the shore, where it comes off the continents in rivers and on wind currents.

The oceanic crust is relatively thin and lies above the mantle. The cross section of oceanic crust in the **Figure** 3.8 shows the layers that grade from sediments at the top to extrusive basalt lava, to the sheeted dikes that feed lava to the surface, to deeper intrusive gabbro, and finally to the mantle.

Continental Crust

Continental crust is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic rocks of the oceanic crust (**Figure** 3.9). Because it is thick and has relatively low density, continental crust rises higher on the mantle than oceanic crust, which sinks into the mantle to form basins. When filled with water, these basins form the planet's oceans.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186100

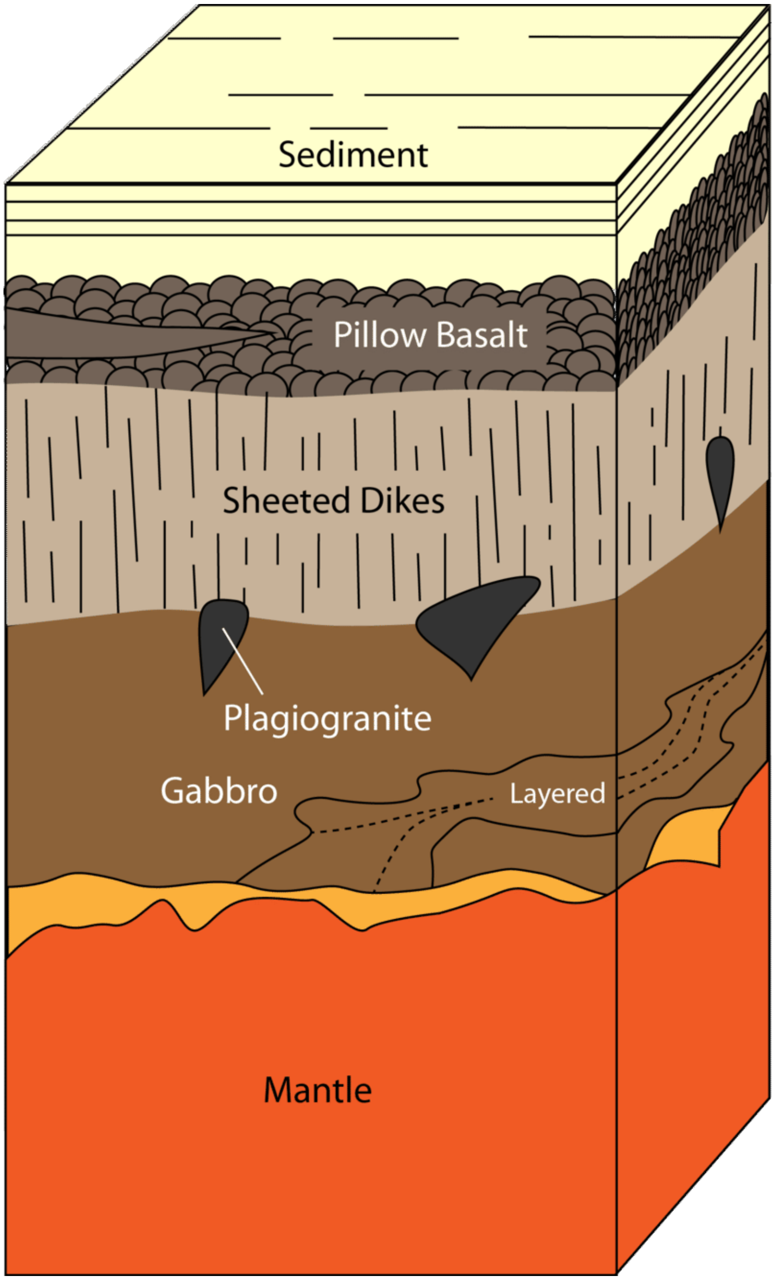


FIGURE 3.8
A cross-section of oceanic crust.

Summary

- Oceanic crust is thinner and denser than continental crust.
- Oceanic crust is more mafic, continental crust is more felsic.
- Crust is very thin relative to Earth's radius.

Review

1. Describe the properties of oceanic crust.
2. Describe the properties of continental crust.
3. What type of rock makes up each of the types of crust?

FIGURE 3.9
This granite from Missouri is more than 1 billion years old.

3.5 Earth's Mantle

Learning Objectives

- Describe Earth's mantle and explain its relationship to conduction and convection.

What is a diamond delivery system?

Some events happened when Earth was younger and hotter that do not happen any more. **Kimberlite pipes** shot up from deep in the mantle. These pipes are the most important source of diamonds, which form at very high pressure. Most kimberlites surfaced long ago.

Mantle

The two most important things about the mantle are: (1) it is made of solid rock, and (2) it is hot.

Solid Rock

Scientists know that the mantle is made of rock based on evidence from seismic waves, heat flow, and meteorites. The properties fit the ultramafic rock **peridotite**, which is made of the iron- and magnesium-rich silicate minerals (**Figure** 3.10). Peridotite is rarely found at Earth's surface.

Heat Flow

Scientists know that the mantle is extremely hot because of the heat flowing outward from it and because of its physical properties.

FIGURE 3.10
Peridotite is formed of crystals of olivine (green) and pyroxene (black).

Heat flows in two different ways within the Earth:

1. **Conduction**: Heat is transferred through rapid collisions of atoms, which can only happen if the material is solid. Heat flows from warmer to cooler places until all are the same temperature. The mantle is hot mostly because of heat conducted from the core.
2. **Convection**: If a material is able to move, even if it moves very slowly, convection currents can form.

Convection in the mantle is the same as convection in a pot of water on a stove. Convection currents within Earth's mantle form as material near the core heats up. As the core heats the bottom layer of mantle material, particles move more rapidly, decreasing its density and causing it to rise. The rising material begins the convection current. When the warm material reaches the surface, it spreads horizontally. The material cools because it is no longer near the core. It eventually becomes cool and dense enough to sink back down into the mantle. At the bottom of the mantle, the material travels horizontally and is heated by the core. It reaches the location where warm mantle material rises, and the mantle **convection cell** is complete (**Figure** 3.11).

Summary

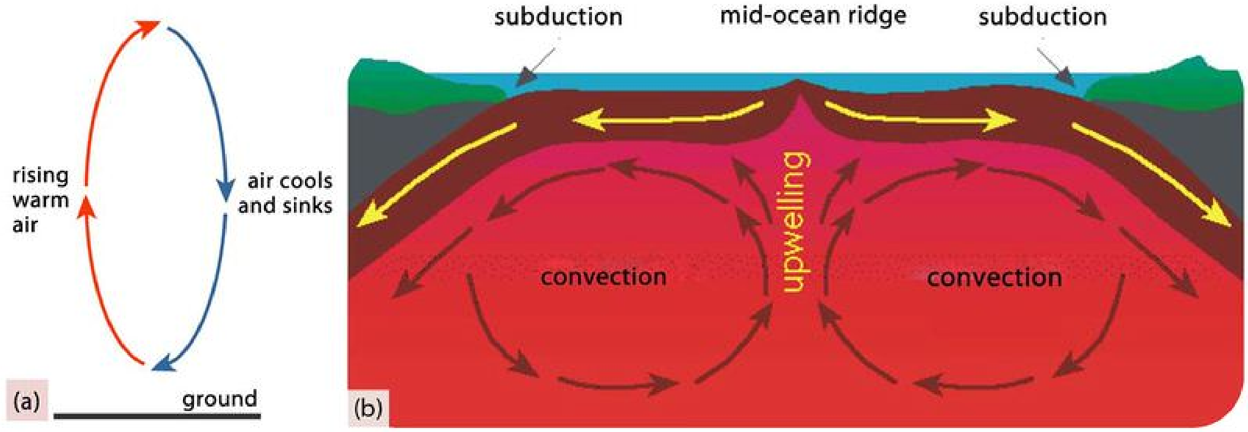
- The mantle is composed of solid peridotite.
- Conduction from the core heats the lower mantle.
- Mantle convection cells bring hot material up toward the surface and cooler material down toward the core.

Review

1. What is the composition of the mantle and how do scientists know this?
2. What is conduction?
3. How does convection work in the mantle?

Explore More

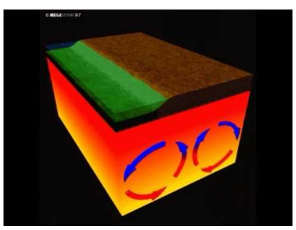
Use these resources to answer the questions that follow.



In a convection cell, warm material rises and cool material sinks. In mantle convection, the heat source is the core.

Diagram of convection within Earth's mantle.

FIGURE 3.11
Convection.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/1479

1. What incorrect statement does this video make about the asthenosphere? What is correct?
2. What causes plate movement?
3. What is convection?

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/4797

1. Why do convection currents form?
2. What happens to the denser material? What happens to the less dense material?
3. Where are convection currents found?

3.6 References

1. Steve Jurvetson. This meteorite contains silica minerals and iron-nickel, and is like the material is like the boundary between Earth's core and mantle . CC BY 2.0
2. Raymond Chou. The crest, trough, and amplitude of a wave . CC BY-NC 2.0
3. Courtesy of US Geological Survey. Pictures of body waves and surface waves . Public Domain
4. User:Lies Van Rompaey/Wikimedia Commons, based on image from the US Geological Survey. How P-waves travel through Earth's interior . Public Domain
5. Courtesy of US Geological Service. Diagram describing the path of p or s waves . Public Domain
6. Kevin Walsh. An iron meteorite is the closest thing to the Earth's core . CC BY 2.0
7. Courtesy of National Oceanic and Atmospheric Administration/University of Washington. Gabbro from ocean crust . Public Domain
8. Christopher Auyeung. A cross-section of oceanic crust . CC BY-NC 3.0
9. Courtesy of US Geological Survey. Granite from Missouri, and part of the continental crust . Public Domain
10. Image copyright Marcin Ciesielski / Sylwia Cisek, 2013. Peridotite is formed of crystals of olivine and pyroxene . Used under license from Shutterstock.com
11. Hana Zavadska. Illustration of convection within the Earth . CC BY-NC 3.0

CHAPTER 4 ESS2-7

Chapter Outline

4.1 Early Atmosphere and Oceans

Learning Objectives

- Earth's early atmosphere formed from volcanic outgassing and meteorites, and the later evolution of photosynthesis released oxygen, allowing more complex life to evolve.

Where did the first atmosphere and oceans come from?

At first, Earth did not have an atmosphere or free water since the planet was too hot for gases and water to collect. The atmosphere and oceans that we see today evolved over time. The gases came from within the planet and from far out in the solar system.

Earth's First Atmosphere

Earth's first atmosphere was made of hydrogen and helium, the gases that were common in this region of the solar system as it was forming. Most of these gases were drawn into the center of the solar nebula to form the Sun. When Earth was new and very small, the solar wind blew off atmospheric gases that collected. If gases did collect, they were vaporized by impacts, especially from the impact that brought about the formation of the Moon.

Eventually things started to settle down and gases began to collect. High heat in Earth's early days meant that there were constant volcanic eruptions, which released gases from the mantle into the atmosphere (see opening image). Just as today, volcanic **outgassing** was a source of water vapor, carbon dioxide, small amounts of nitrogen, and other gases.

Scientists have calculated that the amount of gas that collected to form the early atmosphere could not have come entirely from volcanic eruptions. Frequent impacts by asteroids and comets brought in gases and ices, including water, carbon dioxide, methane, ammonia, nitrogen, and other volatiles from elsewhere in the solar system (**Figure** 4.1).

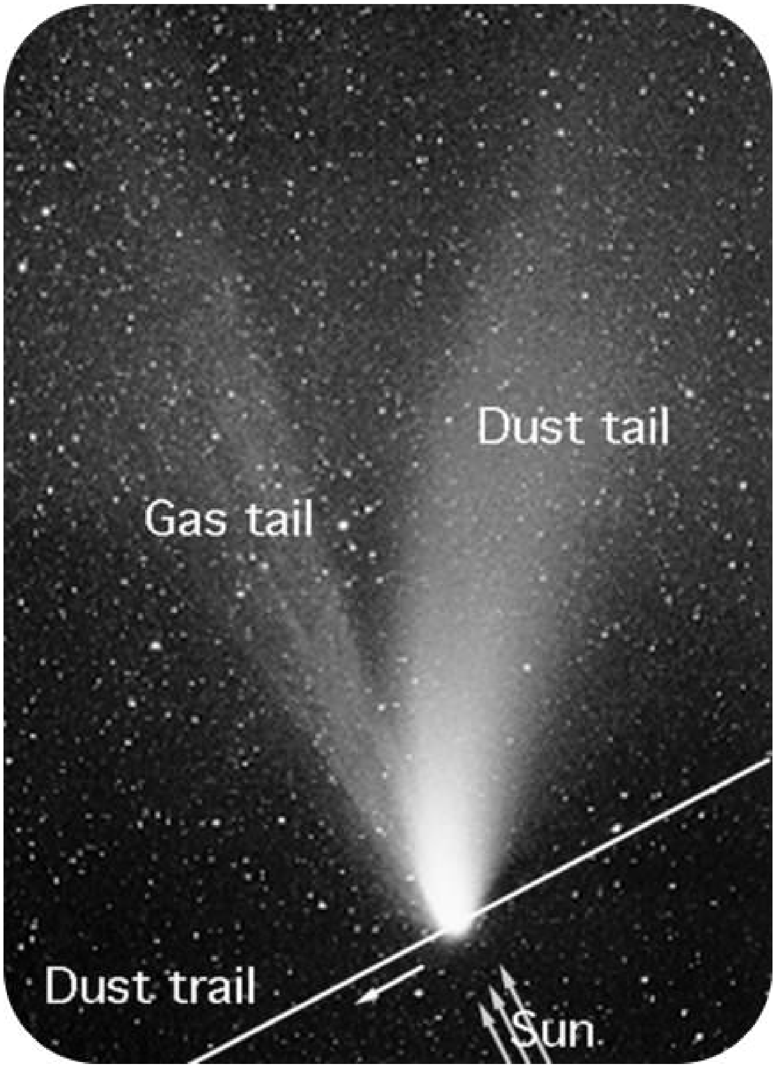


FIGURE 4.1
The gases that create a comet's tail can become part of the atmosphere of a planet.

Calculations also show that asteroids and comets cannot be responsible for all of the gases of the early atmosphere, so both impacts and outgassing were needed.

Earth's Second Atmosphere

The second atmosphere, which was the first to stay with the planet, formed from volcanic outgassing and comet ices. This atmosphere had lots of water vapor, carbon dioxide, nitrogen, and methane but almost no oxygen. Why was there so little oxygen? Plants produce oxygen when they photosynthesize but life had not yet begun or had not yet developed photosynthesis. In the early atmosphere, oxygen only appeared when sunlight split water molecules into hydrogen and oxygen and the oxygen accumulated in the atmosphere.

Without oxygen, life was restricted to tiny simple organisms. Why is oxygen essential for most life on Earth?

1. Oxygen is needed to make ozone, a molecule made of three oxygen ions, O_3. Ozone collects in the atmospheric ozone layer and blocks harmful ultraviolet radiation from the Sun. Without an ozone layer, life in the early Earth was almost impossible.

2. Animals need oxygen to breathe. No animals would have been able to breathe in Earth's early atmosphere.

Early Oceans

The early atmosphere was rich in water vapor from volcanic eruptions and comets. When Earth was cool enough, water vapor condensed and rain began to fall. The water cycle began. Over millions of years enough precipitation collected that the first oceans could have formed as early as 4.2 to 4.4 billion years ago. Dissolved minerals carried by stream runoff made the early oceans salty. What geological evidence could there be for the presence of an early ocean? Marine sedimentary rocks can be dated back about 4 billion years.

By the Archean, the planet was covered with oceans and the atmosphere was full of water vapor, carbon dioxide, nitrogen, and smaller amounts of other gases.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186686

Earth's Third Atmosphere

When photosynthesis evolved and spread around the planet, oxygen was released in abundance. The addition of oxygen is what created Earth's third atmosphere. This event, which occurred about 2.5 billion years ago, is sometimes called the oxygen catastrophe because so many organisms died. Although entire species died out and went extinct, this event is also called the Great Oxygenation Event because it was a great opportunity. The organisms that survived developed a use for oxygen through **cellular respiration**, the process by which cells can obtain energy from organic molecules. This opened up many opportunities for organisms to evolve to fill different niches and many new types of organisms first appeared on Earth.

Banded-Iron Formations

What evidence do scientists have that large quantities of oxygen entered the atmosphere? The iron contained in the rocks combined with the oxygen to form reddish iron oxides. By the beginning of the Proterozoic, banded-iron formations (BIFs) were forming. Banded-iron formations display alternating bands of iron oxide and iron-poor chert that probably represent a seasonal cycle of an aerobic and an anaerobic environment.

The oldest BIFs are 3.7 billion years old, but they are very common during the Great Oxygenation Event 2.4 billion years ago (**Figure** 4.2). By 1.8 billion years ago, the amount of BIF declined. In recent times, the iron in these formations has been mined, and that explains the location of the auto industry in the upper Midwest.

UV Protection

With more oxygen in the atmosphere, ultraviolet radiation could create ozone. With the formation of an ozone layer to protect the surface of the Earth from UV radiation, more complex life forms could evolve.

FIGURE 4.2
Banded-iron formation.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186688

Summary

- Earth's first atmosphere came from outgassing from the planet's interior and from asteroids and comets from elsewhere in the solar system.
- Earth's first and second atmosphere did not contain oxygen so there was no ozone layer to protect life from ultraviolet radiation and no oxygen for animals to breathe.
- Earth's third atmosphere contained oxygen that is a by-product of photosynthesis, allowing the evolution of animals and the formation of an ozone layer.

Review

1. What were the first gases to collect in Earth's atmosphere? Where did they come from and where did they go?
2. What was the source of gases in Earth's first atmosphere that collected? What were those gases?
3. When did oxygen enter the atmosphere in abundance? Where did it come from? What was the effect on life on Earth?
4. What are banded-iron formations and why are they important to Earth historians?

4.2 First Cells

Learning Objectives

- Define LUCA.
- Summarize the characteristics of the first cells.
- Describe the oxygen catastrophe.

How do you make complex cells?

You start with simple ones. The first cells were most likely primitive prokaryotic-like cells, even more simplistic than these *E. coli* bacteria. The first cells were probably no more than organic compounds, such as a simplistic RNA, surrounded by a membrane. Was it a phospholipid bilayer membrane? Probably not — it was likely a simplistic membrane able to separate the inside from the outside. Over time, as other organic compounds such as DNA and proteins developed, cells also evolved into more complex structures. Once a cell was able to be stable, reproduce itself, and pass its genetic information to the next generation, then there was life.

The First Cells

What was needed for the first cell? Some sort of membrane surrounding organic molecules? Probably.

How organic molecules such as RNA developed into cells is not known for certain. Scientists speculate that lipid membranes grew around the organic molecules. The membranes prevented the molecules from reacting with other molecules, so they did not form new compounds. In this way, the organic molecules persisted, and the first cells may have formed. **Figure** 4.3 shows a model of the hypothetical first cell. Were these first cells the first living organisms?

Were they able to live and reproduce while passing their genetic information to the next generation? If so, then yes, these first cells could be considered the first living organisms.

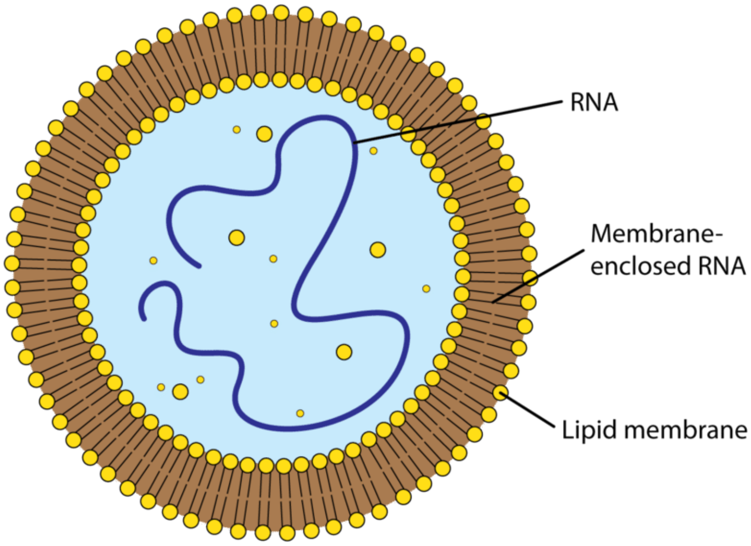


FIGURE 4.3

Hypothetical First Cell. The earliest cells may have consisted of little more than RNA inside a lipid membrane.

LUCA

No doubt there were many early cells of this type. However, scientists think that only one early cell (or group of cells) eventually gave rise to all subsequent life on Earth. That one cell is called the **Last Universal Common Ancestor (LUCA).** It probably existed around 3.5 billion years ago. LUCA was one of the earliest **prokaryotic cells**. It would have lacked a nucleus and other membrane-bound organelles.

Photosynthesis and Cellular Respiration

The earliest cells were probably **heterotrophs**. Most likely they got their energy from other molecules in the organic "soup." However, by about 3 billion years ago, a new way of obtaining energy evolved. This new way was **photosynthesis**. Through photosynthesis, organisms could use sunlight to make food from carbon dioxide and water. These organisms were the first **autotrophs**. They provided food for themselves and for other organisms that began to consume them.

After photosynthesis evolved, oxygen started to accumulate in the atmosphere. This has been dubbed the "oxygen catastrophe." Why? Oxygen was toxic to most early cells because they had evolved in its absence. As a result, many of them died out. The few that survived evolved a new way to take advantage of the oxygen. This second major innovation was **cellular respiration**. It allowed cells to use oxygen to obtain more energy from organic molecules.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/184918

Summary

- The first cells consisted of little more than an organic molecule such as RNA inside a lipid membrane.
- One cell (or group of cells), called the last universal common ancestor (LUCA), gave rise to all subsequent life on Earth.
- Photosynthesis evolved by 3 billion years ago and released oxygen into the atmosphere.
- Cellular respiration evolved after that to make use of the oxygen.

Review

1. What was LUCA? What were its characteristics?
2. Which evolved first, autotrophs or heterotrophs? Why?
3. Why could cellular respiration evolve only after photosynthesis had evolved?

4.3 History of Life

Learning Objectives

- Define fossil.
- Describe the fossil record.
- Compare relative dating to absolute dating.
- Describe the role of molecular clocks.
- Summarize the geologic time scale.

How do we learn about the past?

We study the remains of things that existed many years ago. The Ruins of Pompeii have given archeologists, historians, and other scholars a tremendous amount of information about life two thousand years ago. This section discusses studying things that are many thousands of years older than these remains.

Earth in a Day

It's hard to grasp the vast amounts of time since Earth formed and life first appeared on its surface. It may help to think of Earth's history as a 24-hour day, as shown in **Figure** 4.4. Humans would have appeared only during the last minute of that day. If we are such newcomers on planet Earth, how do we know about the vast period of time that went before us? How have we learned about the distant past?

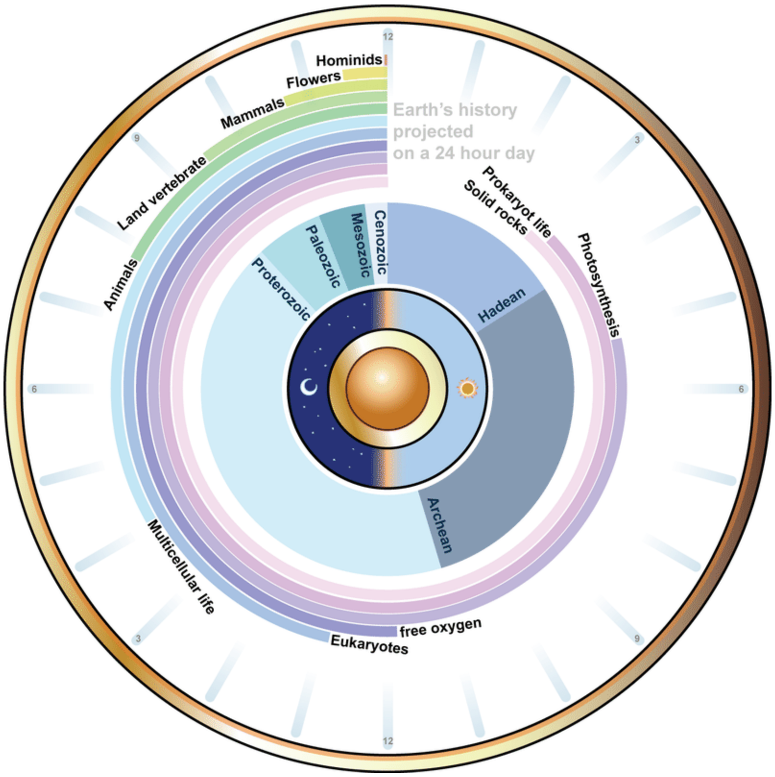


FIGURE 4.4
History of Earth in a Day. In this model of Earth's history, the planet formed at midnight. What time was it when the first prokaryotes evolved?

Learning About the Past

Much of what we know about the history of life on Earth is based on the fossil record. Detailed knowledge of modern organisms also helps us understand how life evolved.

The Fossil Record

Fossils are the preserved remains or traces of organisms that lived in the past. The soft parts of organisms almost always decompose quickly after death. On occasion, the hard parts—mainly bones, teeth, or shells—remain long enough to mineralize and form fossils. An example of a complete fossil skeleton is shown in **Figure** 4.5. The **fossil record** is the record of life that unfolded over four billion years and pieced back together through the analysis of fossils.

To be preserved as fossils, remains must be covered quickly by sediments or preserved in some other way. For example, they may be frozen in glaciers or trapped in tree resin, like the frog in **Figure** 4.6. Sometimes traces of organisms—such as footprints or burrows—are preserved (see the fossil footprints in **Figure** 4.6). The conditions required for fossils to form rarely occur. Therefore, the chance of an organism being preserved as a fossil is very low.

In order for fossils to "tell" us the story of life, they must be dated. Then they can help scientists reconstruct how life changed over time. Fossils can be dated in two different ways: relative dating and absolute dating. Both are described below.

- **Relative dating** determines which of two fossils is older or younger than the other, but not their age in years. Relative dating is based on the positions of fossils in rock layers. Lower layers were laid down earlier, so they are assumed to contain older fossils. This is illustrated in **Figure** 4.7.

FIGURE 4.5
Extinct Lion Fossil. This fossilized skeleton represents an extinct lion species. It is rare for fossils to be so complete and well preserved as this one.

FIGURE 4.6
The photo on the left shows an ancient frog trapped in hardened tree resin, or amber. The photo on the right shows the fossil footprints of a dinosaur.

- **Absolute dating** determines about how long ago a fossil organism lived. This gives the fossil an approximate age in years. Absolute dating is often based on the amount of carbon-14 or other radioactive element that remains in a fossil.

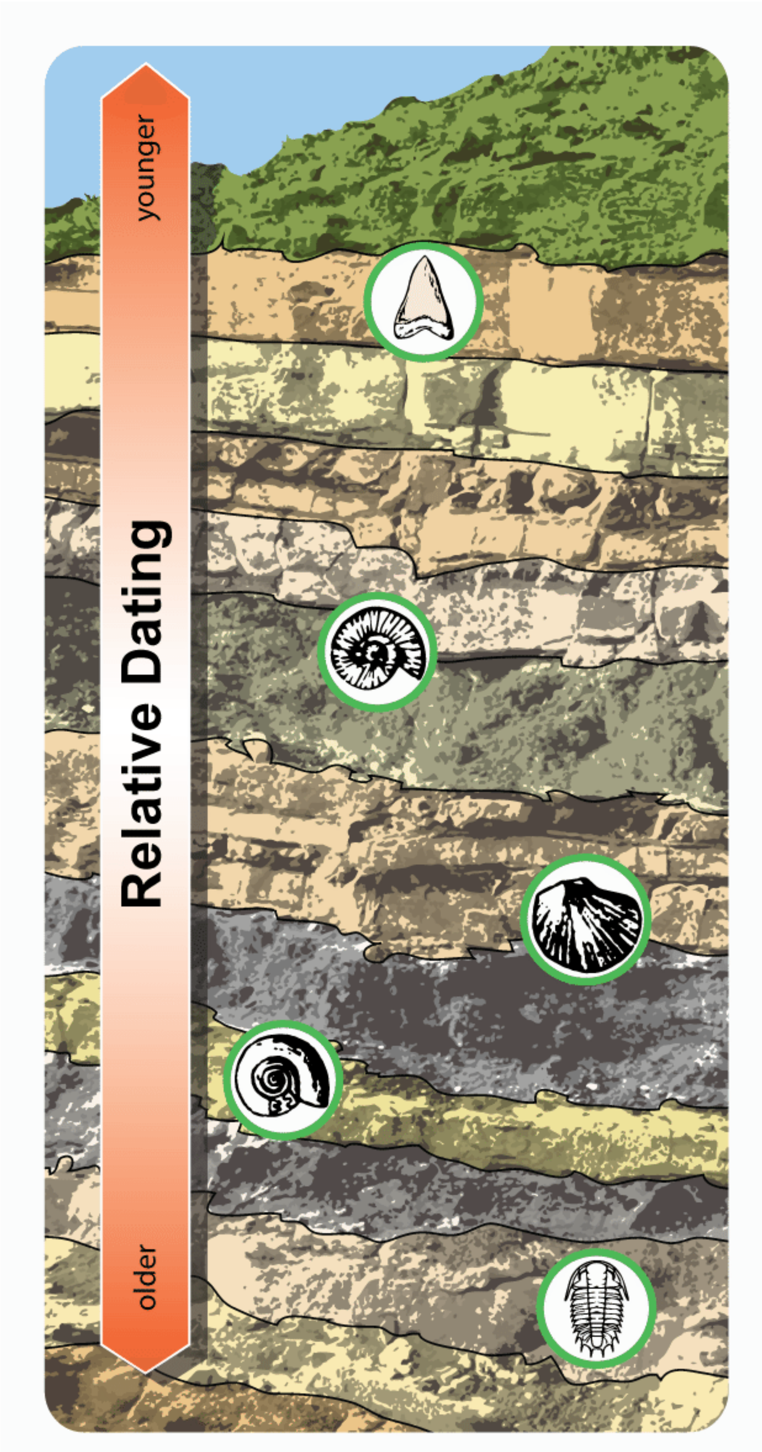
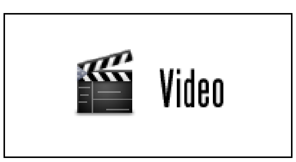


FIGURE 4.7

Relative Dating Using Rock Layers. Relative dating establishes which of two fossils is older than the other. It is based on the rock layers in which the fossils formed.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/157808

Molecular Clocks

Evidence from the fossil record can be combined with data from molecular clocks. A **molecular clock** uses DNA sequences (or the proteins they encode) to estimate relatedness among species. Molecular clocks estimate the time in geologic history when related species diverged from a common ancestor. Molecular clocks are based on the assumption that mutations accumulate through time at a steady average rate for a given region of DNA. Species that have accumulated greater differences in their DNA sequences are assumed to have diverged from their common ancestor in the more distant past. Molecular clocks based on different regions of DNA may be used together for more accuracy.

Consider the example in **Table** 4.1. The table shows how similar the DNA of several animal species is to human DNA. Based on these data, which organism do you think shared the most recent common ancestor with humans?

TABLE 4.1: Comparing DNA: Humans and Other Animals

Organism	Similarity with Human DNA (percent)
Chimpanzee	98
Mouse	85
Chicken	60
Fruit Fly	44

Geologic Time Scale

Another tool for understanding the history of Earth and its life is the **geologic time scale**, shown in **Figure** 4.8. The geologic time scale divides Earth's history into divisions (such as eons, eras, and periods) that are based on major changes in geology, climate, and the evolution of life. It organizes Earth's history and the evolution of life on the basis of important events instead of time alone. It also allows more focus to be placed on recent events, about which we know the most.

Summary

- Much of what we know about the history of life on Earth is based on the fossil record.
- Molecular clocks are used to estimate how long it has been since two species diverged from a common ancestor.
- The geologic time scale is another important tool for understanding the history of life on Earth.

Review

1. What are fossils?

2. Describe how fossils form.

3. Distinguish relative dating from absolute dating.

4. This table shows DNA sequence comparisons for some hypothetical species. Based on the data, describe evolutionary relationships between Species A and the other four species. Explain your answer.

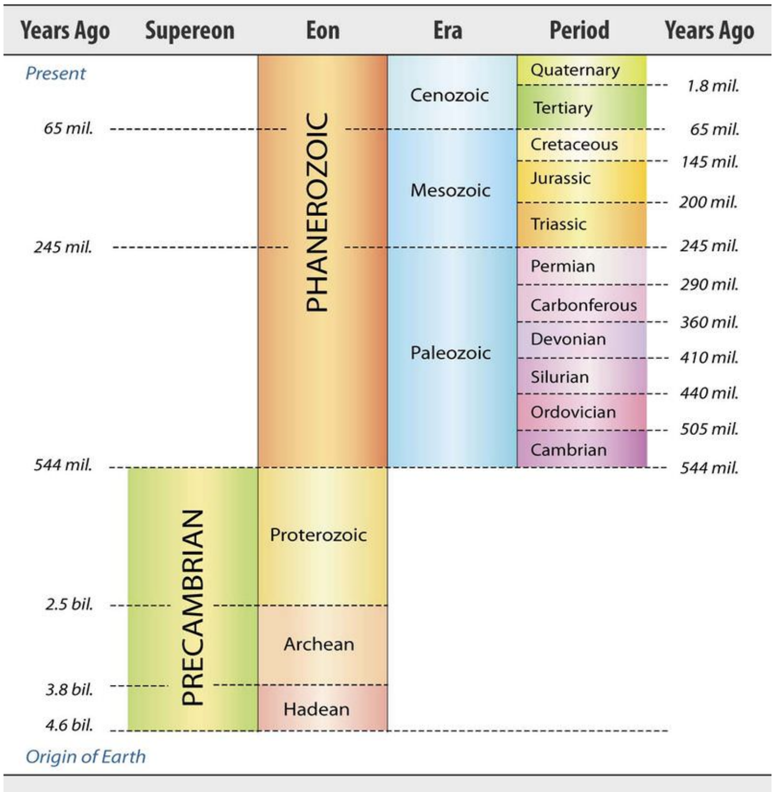


FIGURE 4.8

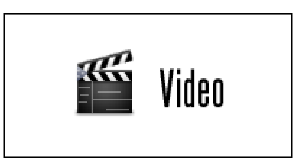
Geologic Time Scale. The geologic time scale divides Earth's history into units that reflect major changes in Earth and its life forms. During which eon did Earth form? What is the present era?

TABLE 4.2: DNA Similarities

Species	DNA Similarity with Species A
Species B	42%
Species C	85%
Species D	67%
Species E	91%

5. Describe the geologic time scale.

Resources



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/157363

4.4 History of Paleozoic Life

Learning Objectives

- The describe the diversification and extinction of life during the Paleozoic.

If you woke up and found yourself in the Paleozoic, would you recognize the planet?

Probably not. You'd see things like this bizarre soft-bodied animal. The creature had five eyes, and a long nose like a vacuum cleaner hose. This creature was found as a fossil in the Burgess shale.

Paleozoic Life

The Paleozoic saw the evolution a tremendous diversity of life throughout the seas and onto land.

Cambrian Explosion

The Cambrian began with the most rapid and far-reaching evolution of life forms ever in Earth's history. Evolving to inhabit so many different habitats resulted in a tremendous diversification of life forms. Shallow seas covered the lands, so every major marine organism group, including nearly all invertebrate animal phyla, evolved during this time. With the evolution of hard body parts, fossils are much more abundant and better preserved from this period than from the Precambrian.

The Burgess shale formation in the Rocky Mountains of British Columbia, Canada, contains an amazing diversity of middle Cambrian life forms, from about 505 million years ago. Paleontologists do not agree on whether the Burgess shale fossils can all be classified into modern groups of organisms or whether many represent lines that have gone completely extinct.

Paleozoic Evolution

Throughout the Paleozoic, seas transgressed and regressed. When continental areas were covered with shallow seas, the number and diversity of marine organisms increased. During regressions the number shrank. Arthropods, fish, amphibians and reptiles all originated in the Paleozoic.

FIGURE 4.9
Trilobites were shallow marine animals that flourished during the lower Paleozoic.

Simple plants began to colonize the land during the Ordovician, but land plants really flourished when seeds evolved during the Carboniferous (**Figure** 4.10). The abundant swamps became the coal and petroleum deposits that are the source of much of our fossil fuels today. During the later part of the Paleozoic, land animals and insects greatly increased in numbers and diversity.

Mass Extinctions

Large extinction events separate the periods of the Paleozoic. After extinctions, new life forms evolved (**Figure**). For example, after the extinction at the end of the Ordovician, fish and the first tetrapod animals appeared. Tetrapods are four legged vertebrates, but the earliest ones did not leave shallow, brackish water.

Permian Extinction

The largest mass extinction in Earth's history occurred at the end of the Permian period, about 250 million years ago. In this catastrophe, it is estimated that more than 95% of marine species on Earth went extinct. Marine species with calcium carbonate shells and skeletons suffered worst. About 70% of terrestrial vertebrate species (land animals) suffered the same fate. This was the only known mass extinction of insects.

This mass extinction appears to have taken place in three pulses, with three separate causes. Gradual environmental change, an asteroid impact, intense volcanism, or changes in the composition of the atmosphere may all have played a role.

FIGURE 4.10
A modern rainforest has many seed-bearing plants that are similar to those that were common during the Carboniferous.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/176672

Summary

- During the Cambrian explosion many more life forms evolved than at any other time in Earth's history.
- Today's fossil fuels originated in the tremendous number of plants that spread over the land during the Carboniferous.
- The major periods of the Paleozoic are separated by extinction events, the largest of which brought the end of the Paleozoic.

Review

1. Give two reasons that the Cambrian is significant for the evolution of life.
2. How did extinctions during the Paleozoic lead to changes in life forms?
3. What brought about the Permian extinction?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/1510

1. What were the first creatures to dominate the land?
2. What happened 250 million years ago?
3. What is a flood basalt eruption? What was the Siberian eruption like?
4. What happened to the Earth's temperature during this extinction? Why did this happen?
5. What occurs when the Earth's temperature raises 4-5 degrees?
6. Why didn't Peter Ward think that the Siberian Traps eruption was the sole reason for the Permian mass extinctions?
7. When and where did the extinction event begin?
8. When and where did the marine extinction phase begin?
9. What are the characteristics of the third phase of the extinction?
10. What is methane hydrate?
11. What caused the increase of carbon-12?
12. Why was it important for the Permian Mass Extinction to take place in the history of life on Earth?

4.5 Life During the Paleozoic

Learning Objectives

- Define Cambrian explosion and Permian extinction.
- Give an overview of life during the six periods of the Paleozoic Era.

What was early life like?

Prehistoric underwater life exploded with amazing new creatures during the Paleozoic Era. Evolution allowed life to take many diverse forms, eventually developing the necessary adaptations to move from the ocean onto land.

Life During the Paleozoic

The **Paleozoic Era** is literally the era of "old life." It lasted from 544 to 245 million years ago and is divided into six periods. Major events in each period of the Paleozoic Era are described in **Figure** 4.11. The era began with a spectacular burst of new life. This is called the **Cambrian explosion.** The era ended with the biggest mass extinction the world had ever seen. This is known as the **Permian extinction.**

The Paleozoic Era

The Cambrian Period: Following the Precambrian mass extinction, there was an explosion of new kinds of organisms in the Cambrian Period (544-505 million years ago). Many types of primitive animals called sponges evolved. Small ocean invertebrates called **trilobites** became abundant.

The Ordovician Period: During the next period, the Ordovician Period (505-440 million years ago), the oceans became filled with invertebrates of many types. Also during this period, the first fish evolved and plants colonized the land for the first time. But animals still remained in the water.

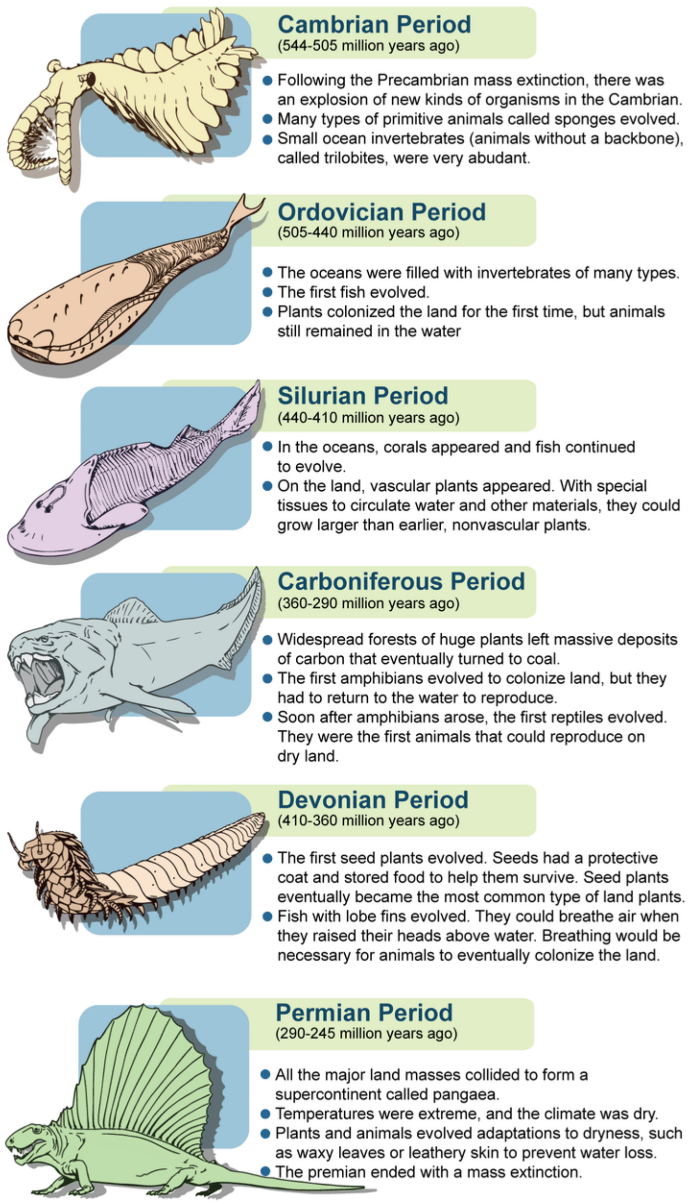


FIGURE 4.11

The Paleozoic Era includes the six periods described here.

The Silurian Period: During the Silurian Period (440-410 million years ago), corals appeared in the oceans, and fish continued to evolve. On land, vascular plants appeared. With special tissues to circulate water and other materials, these plants could grow larger than the earlier nonvascular plants.

The Devonian Period: During the Devonian Period (410-360 million years ago), the first seed plants evolved. Seeds have a protective coat and stored food to help these plants survive. Seed plants eventually became the most common type of land plants. In the oceans, fish with lobe fins evolved. They could breathe air when they raised their heads above water. Breathing would be necessary for animals to eventually colonize the land.

The Carboniferous Period: Next, during the Carboniferous Period (360-290 million years ago), widespread forests of huge plants left massive deposits of carbon that eventually turned to coal. The first amphibians evolved to move out of the water and colonize land, but they had to return to the water to reproduce. Soon after amphibians arose, the first reptiles evolved. They were the first animals that could reproduce on dry land.

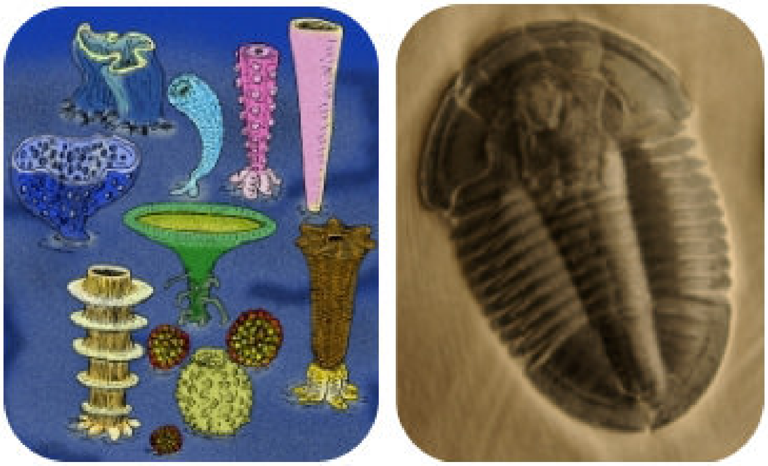


FIGURE 4.12

Two representatives of more than fifty modern animal phyla from the Cambrian explosion are reef-building sponges (left) and early arthropods known as trilobites (right). Both were abundant during the Cambrian and later became extinct; however, the phyla they represent persist to this day.

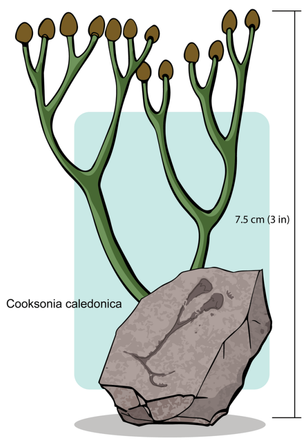


FIGURE 4.13

Cooksonia, a branching vascular plant with sporangia at the tips of each branch. *Cooksonia* fossils measure just centimeters in height and date from the Silurian period.

FIGURE 4.14

On land, club mosses, horsetails, and ferns joined primitive seed plants and early trees to form the first forests.

The Permian Period: During the Permian Period (290-245 million years ago), all the major land masses collided to form a supercontinent called **Pangaea**. Temperatures were extreme, and the climate was dry. Plants and animals evolved adaptations to dryness, such as waxy leaves or leathery skin to prevent water loss. The Permian Period ended with a mass extinction.

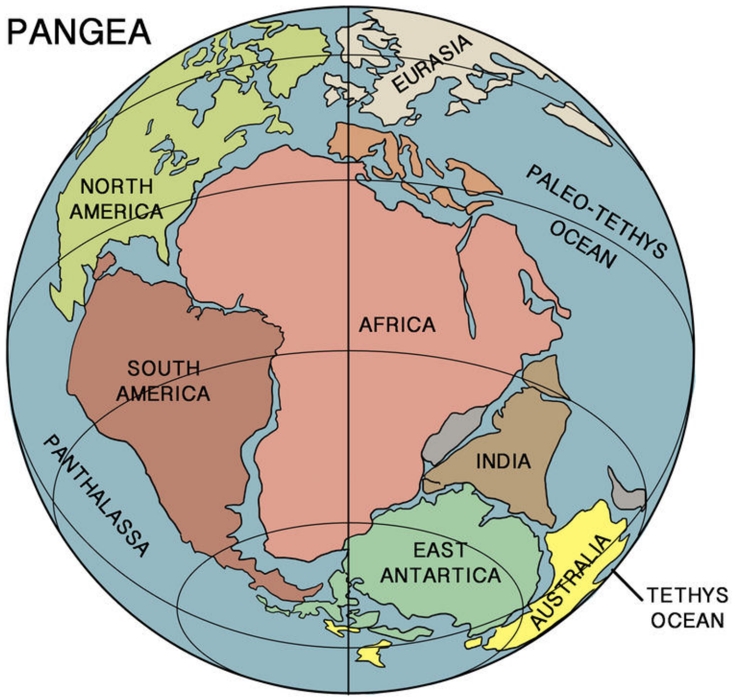


FIGURE 4.15
The supercontinent Pangaea encompassed all of today's continents in a single land mass. This configuration limited shallow coastal areas which harbor marine species, and may have contributed to the dramatic event which ended the Permian - the most massive extinction ever recorded.

In the mass extinction that ended the Permian, the majority of species went extinct. Many hypotheses have been offered to explain why this mass extinction occurred. These include huge meteorites striking Earth and enormous volcanoes spewing ashes and gases into the atmosphere. Both could have darkened the skies with dust for many months. This, in turn, would have shut down photosynthesis and cooled the planet.

Despite the great loss of life, there was light at the end of the tunnel. The Permian extinction paved the way for another burst of new life at the start of the following Mesozoic Era. This included the evolution of the dinosaurs.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/176672

Summary

- The Paleozoic Era began with the Cambrian explosion. It ended with the Permian extinction.

- During the era, invertebrate animals diversified in the oceans. Plants, amphibians, and reptiles also moved to the land.

Review

1. What was the Cambrian explosion?
2. What was the Permian extinction?
3. List important evolutionary events that occurred during the Cambrian Period.
4. List important evolutionary events that occurred during the Ordovician Period.
5. List important evolutionary events that occurred during the Carboniferous Period.
6. Describe Pangaea. When did Pangaea form?

4.6 Late Precambrian Period

Learning Objectives

- Describe geologic and climatic changes of the late Precambrian.
- Summarize life during the late Precambrian.

What did early eukaryotic life look like?

Some looked like this. This is a fossil of an ammonite. Ammonites are excellent index fossils, and it is often possible to link the rock layer in which they are found to specific geological time periods.

Multicellular Life: Setting the Stage

Nearly 80% of Earth's history passed before multicellular life evolved. Up until then, all organisms existed as single cells. Why did multicellular organisms evolve? What led up to this major step in the evolution of life? To put the evolution of multicellularity in context, let's return to what was happening on planet Earth during this part of its history.

The Late Precambrian

The **late Precambrian** is the time from about 2 billion to half a billion years ago. During this long span of time, Earth experienced many dramatic geologic and climatic changes.

- Continents drifted. They collided to form a gigantic supercontinent and then broke up again and moved apart. Continental drift changed climates worldwide and caused intense volcanic activity.
- Carbon dioxide levels in the atmosphere rose and fell. This was due to volcanic activity and other factors. When the levels were high, they created a **greenhouse effect**. More heat was trapped on Earth's surface, and the climate became warmer. When the levels were low, less heat was trapped and the planet cooled. Several times, cooling was severe enough to plunge Earth into an ice age. One ice age was so cold that snow and ice completely covered the planet. Earth during this ice age has been called **snowball Earth** (see **Figure** 4.16).

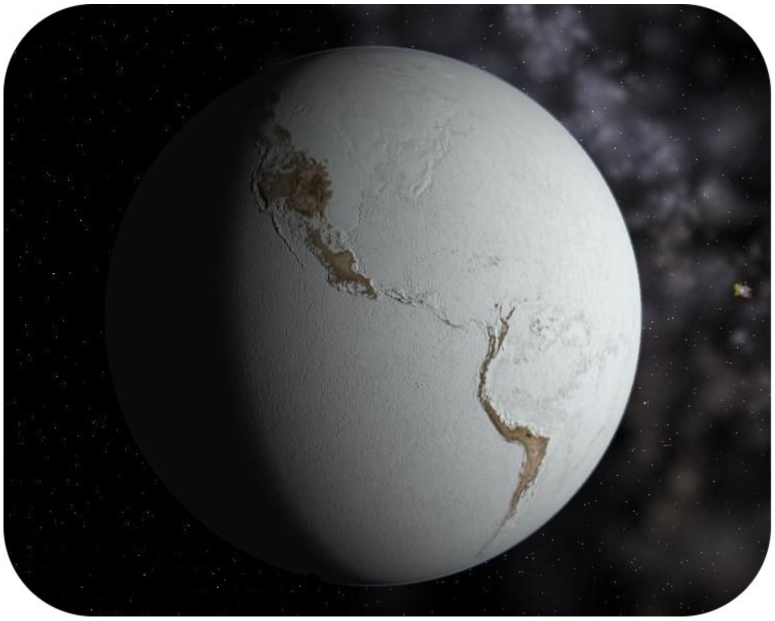


FIGURE 4.16
Snowball Earth. During the late Precambrian, Earth grew so cold that it was covered with snow and ice. Earth during this ice age has been called snowball Earth.

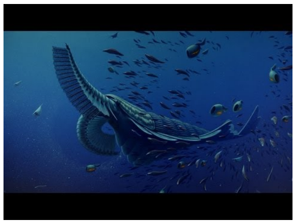
Life During the Late Precambrian

The dramatic changes of the late Precambrian had a major impact on Earth's life forms. Living things that could not adapt died out. They were replaced by organisms that evolved new adaptations. These adaptations included **sexual reproduction**, specialization of cells, and **multicellularity**.

- Sexual reproduction created much more variety among offspring. This increased the chances that at least some of them would survive when the environment changed. It also increased the speed at which evolution could occur.
- Some cells started to live together in colonies. In some colonies, cells started to specialize in doing different jobs. This made the cells more efficient as a colony than as individual cells.
- By 1 billion years ago, the first multicellular organisms had evolved. They may have developed from colonies of specialized cells. Their cells were so specialized they could no longer survive independently. However, together they were mighty. They formed an organism that was bigger, more efficient, and able to do much more than any single-celled organism ever could.

The Precambrian Extinction

At the close of the Precambrian 544 million years ago, a mass extinction occurred. In a **mass extinction**, many or even most species abruptly disappear from Earth. There have been five mass extinctions in Earth's history. Many scientists think we are currently going through a sixth mass extinction. What caused the Precambrian mass extinction? A combination of climatic and geologic events was probably responsible. No matter what the cause, the extinction paved the way for a burst of new life, called the Cambrian explosion, during the following Paleozoic Era.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/190190

Summary

- During the late Precambrian, continents drifted, carbon dioxide levels fluctuated, and climates changed. Many organisms could not survive the changes and died out.
- Other organisms evolved important new adaptations. These include sexual reproduction, cell specialization, and multicellularity.
- The Precambrian ended with a mass extinction, which paved the way for the Cambrian explosion.

Review

1. When was the late Precambrian?
2. Describe geologic and climatic changes that occurred during the late Precambrian.
3. What is a greenhouse effect?
4. What three significant evolutionary events occurred during the late Precambrian?
5. What is a mass extinction?

If you wound up in the Mesozoic, would you recognize Earth?

So if you woke up in the Paleozoic, you probably wouldn't recognize Earth. How about if you woke up in the Mesozoic? In some ways, the planet would look a lot more like it does today. Animals would fill the niches you're used to seeing animals fill. But if you looked closely, you'd see that the animals are mostly all reptiles. And some of them may be interested in having you for dinner!

Mesozoic Life

With most niches available after the mass extinction, a great diversity of organisms evolved. Mostly these niches were filled with reptiles.

Climate alternated between cool, warm, and tropical, but overall the planet was much warmer than today. These conditions were good for reptiles. Surprisingly, there was more oxygen in the Mesozoic atmosphere than there is today.

Marine Life

Tiny phytoplankton arose to become the base of the marine food web. At the beginning of the Mesozoic, Pangaea began to break apart, so more beaches and continental shelf areas were available for colonization by new species of marine organisms. Marine reptiles colonized the seas and diversified. Some became huge, filling the niches that are filled by large marine mammals today.

Terrestrial Life

On land, seed plants and trees diversified and spread widely. Ferns were common at the time of the dinosaurs (**Figure** 4.17). The earliest known fossil of a flowering plant is from the Cretaceous, 125 million years old.

Dinosaurs

Of course the most famous Mesozoic reptiles were the dinosaurs (**Figure** 4.18). Dinosaurs reigned for 160 million years and had tremendous numbers and diversity. Species of dinosaurs filled all the niches that are currently filled by mammals. Dinosaurs were plant eaters, meat eaters, bipedal, quadrupedal, endothermic (warm-blooded), exothermic (cold-blooded), enormous, small, and some could swim or fly.

Scientists now think that some dinosaurs were endotherms (warm-blooded) due to the evidence that has been collected over the decades. There are still some scientists who do not agree, but the amount of evidence makes

FIGURE 4.17
The earliest known fossil of a flowering plant is this 125 million year old Cretaceous fossil.

it likely. Some dinosaurs lived in polar regions where animals that needed sunlight for warmth could not survive in winter. Dinosaurs bones had canals, similar to those of birds, indicating that they grew fast and were very active. Fast growth usually indicates an active metabolism typical of endotherms. Dinosaurs had erect posture and large brains, both correlated with endothermy.

Rise of the Mammals

Mammals appeared near the end of the Triassic, but the Mesozoic is known as the age of the reptiles. In a great advance over amphibians, which must live near water, reptiles developed adaptations for living away from water. Their thick skin keeps them from drying out, and the evolution of the amniote egg allowed them to lay their eggs on dry land. The **amniote egg** has a shell and contains all the nutrients and water required for the developing embryo (**Figure** 4.19).

Cretaceous Mass Extinction

Between the Mesozoic and the Cenozoic, 65 million years ago, about 50% of all animal species, including the dinosaurs, became extinct. Although there are other hypotheses, most scientists think that this mass extinction took place when a giant meteorite struck Earth with 2 million times the energy of the most powerful nuclear weapon (**Figure** 4.20).

The impact kicked up a massive dust cloud, and when the particles rained back onto the surface they heated the atmosphere until it became as hot as a kitchen oven. Animals roasted. Dust that remained in the atmosphere blocked sunlight for a year or more, causing a deep freeze and temporarily ending photosynthesis. Sulfur from the impact mixed with water in the atmosphere to form acid rain, which dissolved the shells of the tiny marine plankton that form the base of the food chain. With little food being produced by land plants and plankton, animals starved. Carbon dioxide was also released from the impact and eventually caused global warming. Life forms could not survive the dramatic temperature swings.

You may be surprised to know that dinosaurs in one form survived the mass extinctions and live all over the world today. Birds evolved from theropod dinosaurs, and these creatures not only survived the asteroid impact and its aftermath, but they have also diversified into some of the most fantastic creatures we know (**Figure** 4.21).

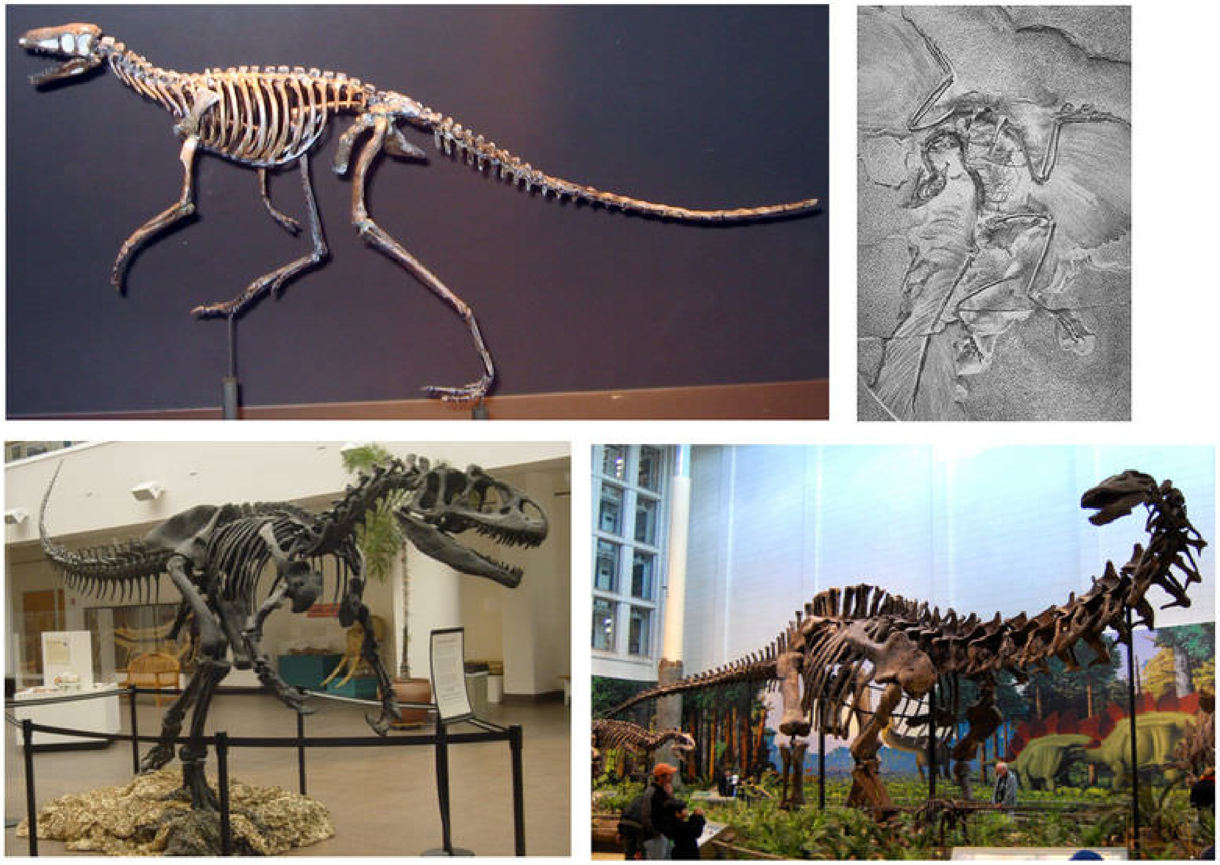


FIGURE 4.18
Some examples of Mesozoic dinosaurs include the Ornithopods. Pictured clockwise, starting from the upper left: Marasuchus, Archaeopteryx, Apatosaurus, and Allosaurus.

FIGURE 4.19
Amniotic eggs containing snake hatchlings.

FIGURE 4.20
An artist's painting of the impact that caused the Cretaceous extinctions.

FIGURE 4.21
Archeopteryx, the earliest known bird, lived during the late Jurassic.

Summary

- Phytoplankton evolved to become the base of the marine food web.
- In the Mesozoic dinosaurs filled the niches that mammals fill today.
- Life of the Mesozoic appears to have ended with a giant asteroid impact.

Review

1. How did life in the Mesozoic resemble life today? How did it differ from life today?

2. What was the importance of the amniotic egg for Mesozoic life?
3. Why do scientists say that dinosaurs didn't entirely go extinct? What is their evidence?

4.8 History of Cenozoic Life

Learning Objectives

- Describe the diversification of life during the Cenozoic and its relationship to modern biodiversity.

Why are Pleistocene animals so large?

A smaller surface area-to-volume ratio is better for keeping warm, so many ice age mammals were huge. Although the dominant animals were mammals, you might not recognize the Pleistocene Earth any more than the Mesozoic Earth.

Cenozoic Life

The extinction of so many species at the end of the Mesozoic again left many niches available to be filled. Although we call the Cenozoic the age of mammals, birds are more common and more diverse. Early in the era, terrestrial crocodiles lumbered around along with large, primitive mammals and prehistoric birds.

Diversification of the Mammals

Their adaptations have allowed mammals to spread to even more environments than reptiles. The success of mammals is due to several of their unique traits. Mammals are endothermic and have fur, hair, or blubber for warmth. Mammals can swim, fly, and live in nearly all terrestrial environments. Mammals initially filled the forests that covered many early Cenozoic lands. Over time, the forests gave way to grasslands, which created more niches for mammals to fill.

Pleistocene Megafauna

As climate cooled during the ice ages, large mammals were able to stand the cold weather, so many interesting megafauna developed. These included giant sloths, saber-toothed cats, wooly mammoths, giant condors, and many other animals that are now extinct (**Figure** 4.22).

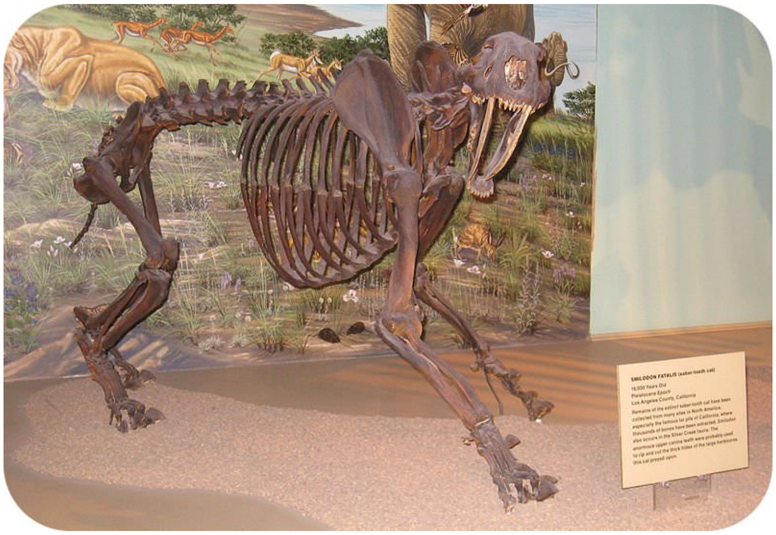


FIGURE 4.22
The saber-toothed cat lived during the Pleistocene.

Many of the organisms that made up the Pleistocene megafauna went extinct as conditions warmed. Some may have been driven to extinction by human activities.

Imagine a vast grassy plain covered with herds of elephants, bison and camels stretching as far as the eye can see. Lions, tigers, wolves and later, humans, hunt the herds on their summer migration. This was the San Francisco Bay Area at the close of the last Ice Age.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/524

Summary

- With the extinction of the dinosaurs, mammals diversified and took over the available niches.
- Many of the organisms of the Pleistocene were enormous, probably in have a low surface area to body ratio.
- Many of the Pleistocene megafauna have gone extinct but some remain.

Review

1. What are the Pleistocene megafauna and why were they so large?

2. What characteristics do mammals have that allow them to fill so many niches?
3. How does climate affect evolution? How about climate change?

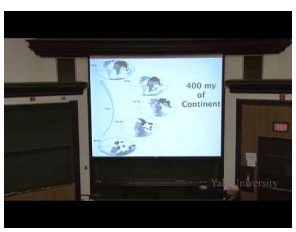
Explore More

Use this resource to answer the questions that follow.

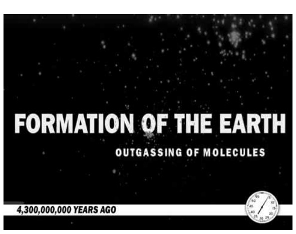
MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178274

1. What are the characteristics of the Clovis spear points?
2. What does Paul Martin suggest caused the extinction of the Pleistocene megafauna? What else could have been the cause?
3. What happened to the environment at the end of the Pleistocene?
4. Why do we still have megafauna in Africa, but the megafauna in North America is largely extinct?
5. What happened in Australia?
6. What is the evidence that the extinctions in North America were caused by a combination of humans and climate change?

Resources



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178270



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178272

4.9 Cnidarians

Learning Objectives

- Give examples of cnidarians.
- Outline characteristics of cnidarians.
- Describe a nematocyst.
- Compare a polyp to a medusa.
- Outline a general cnidarian life cycle.

The sea anemone. Plant or animal?

It may look like a plant, but it's not. Sea anemones are a group of water-dwelling, predatory animals in the phylum Cnidaria. A sea anemone is a polyp attached at the bottom to the surface beneath it. They can have anywhere from a few tens of tentacles to a few hundred tentacles. And they eat small fish and shrimp.

Cnidarians

Cnidarians are invertebrates such as jellyfish and corals. They belong to the phylum Cnidaria. All cnidarians are aquatic. Most of them live in the ocean. Cnidarians are a little more complex than sponges. They have radial symmetry and tissues. There are more than 10,000 cnidarian species. They are very diverse, as shown in **Figure** 4.23.

Structure and Function of Cnidarians

All cnidarians have something in common. It's a nematocyst, like the one shown in **Figure** 4.24. A **nematocyst** is a long, thin, coiled stinger. It has a barb that may inject poison. These tiny poison "darts" are propelled out of special cells. They are used to attack prey or defend against predators.

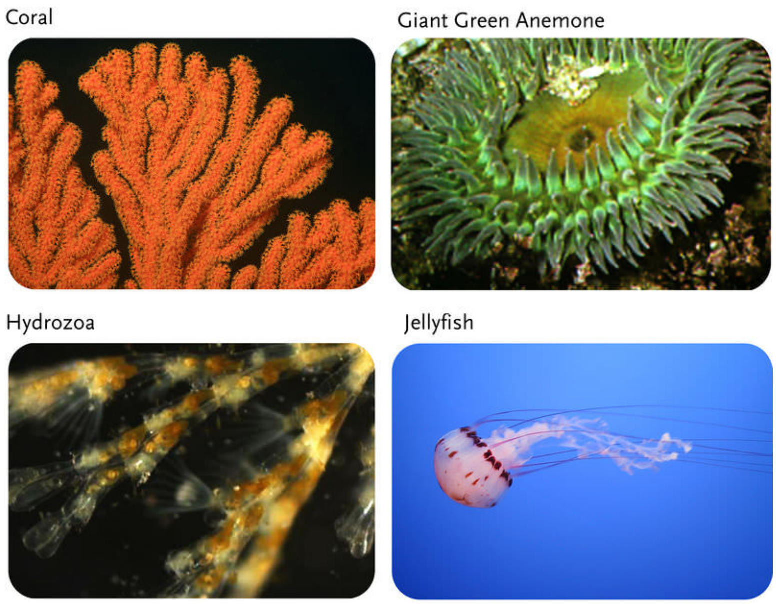


FIGURE 4.23
Cnidarian Diversity. Cnidarians show a lot of variability.

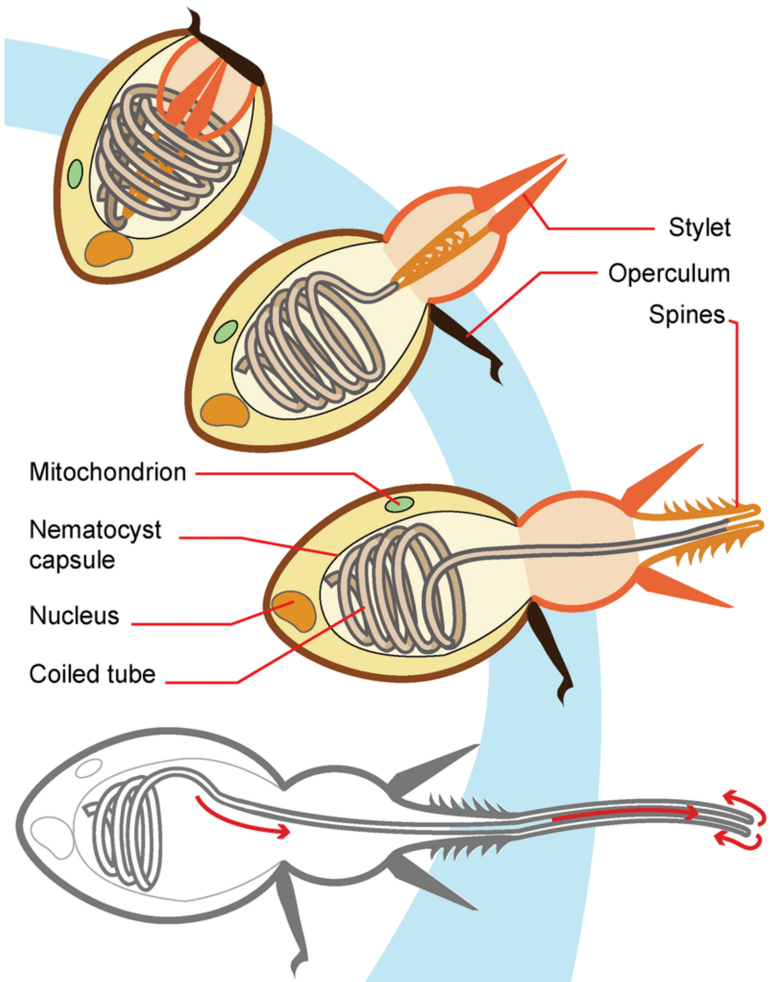


FIGURE 4.24
Cnidarian Nematocyst. A cnidarian nematocyst is like a poison dart. It is ejected from a specialized cell.

There are two basic body plans in cnidarians. They are called the polyp and medusa. Both are shown in **Figure** 4.25. The **polyp** has a tubular body and is usually sessile. The **medusa** (plural, **medusae**) has a bell-shaped body and is typically motile. Some cnidarian species alternate between polyp and medusa forms. Other species exist in just one form or the other.

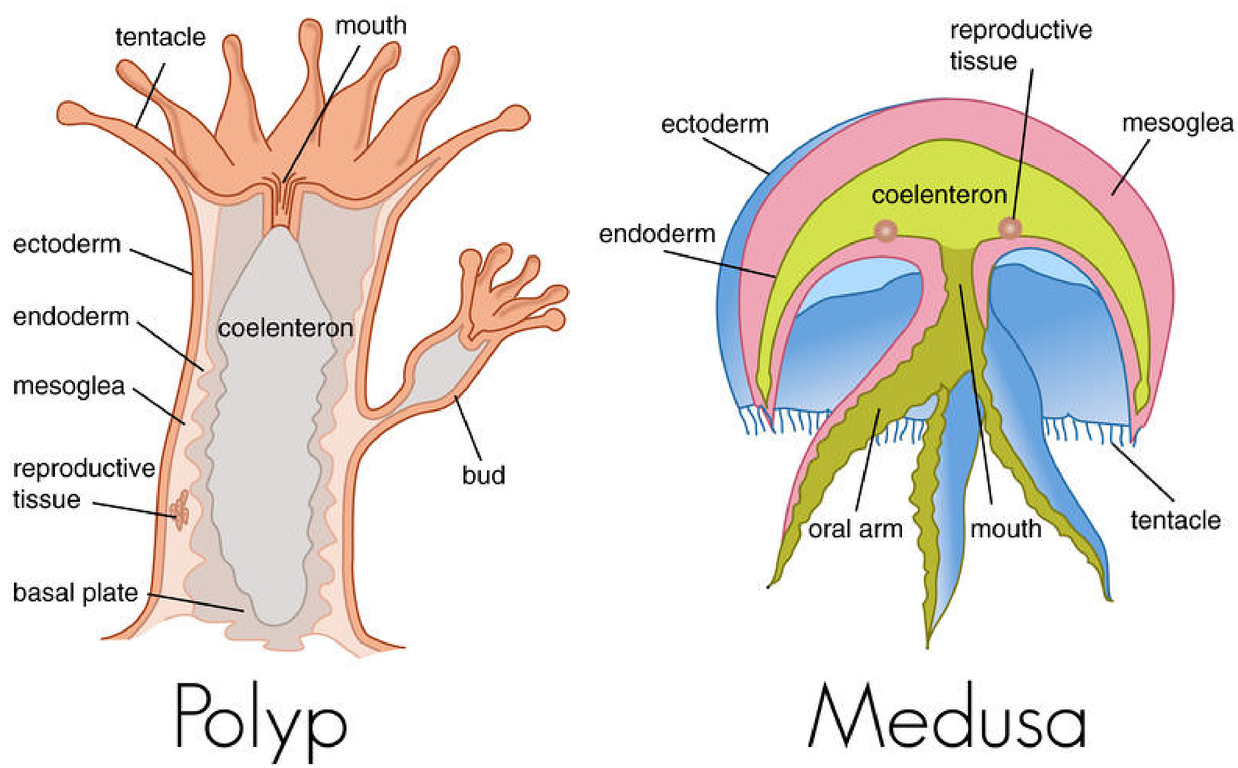


FIGURE 4.25

Cnidarian Body Plans. Cnidarians may exist in the polyp (left) or medusa (right) form.

The body of a cnidarian consists of two cell layers, ectoderm and endoderm. The cells surround a digestive cavity called the **coelenteron** (see **Figure** 4.26). Cnidarians have a simple digestive system. The single opening is surrounded by tentacles, which are used to capture prey. The tentacles are covered with nematocyst cells. Digestion takes place in the coelenteron. Nutrients are absorbed and gases exchanged through the cells lining this cavity. Fluid in the coelenteron creates a hydrostatic skeleton.

Cnidarians have a simple nervous system consisting of a **nerve net** that can detect touch. They may also have other sensory structures. For example, jellyfish have light-sensing structures and gravity-sensing structures. These senses give them a sense of up versus down. It also helps them balance.

Cnidarian Reproduction

Figure 4.26 shows a general cnidarian life cycle. Polyps usually reproduce asexually. One type of asexual reproduction in polyps leads to the formation of new medusae. Medusae usually reproduce sexually. Sexual reproduction forms a zygote. The zygote develops into a larva called a **planula**. The planula, in turn, develops into a polyp. There are many variations on the general life cycle. Obviously, species that exist only as polyps or medusae have a life cycle without the other form.

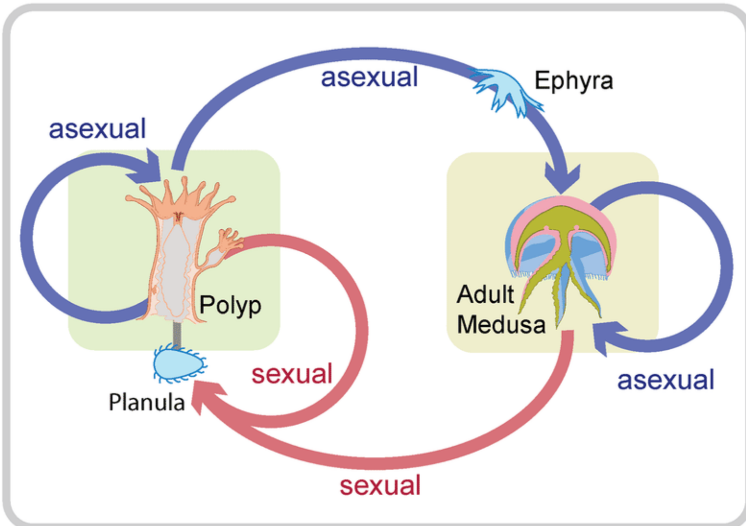


FIGURE 4.26
General Cnidarian Life Cycle. Cnidarians may reproduce both asexually and sexually.

Ecology of Cnidarians

Cnidarians can be found in almost all ocean habitats. They may live in water that is shallow or deep, warm or cold. A few species live in freshwater. Some cnidarians live alone, while others live in colonies.

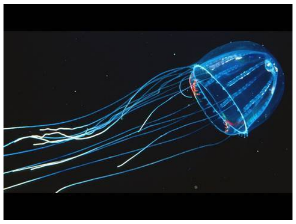
Corals form large colonies in shallow tropical water. They are confined to shallow water because they have a mutualistic relationship with algae that live inside them. The algae need sunlight for photosynthesis, so they must be relatively close to the surface of the water. Corals exist only as polyps. They catch plankton with their tentacles. Many secrete a calcium carbonate exoskeleton. Over time, this builds up to become a coral reef (see **Figure** 4.27). Coral reefs provide food and shelter to many ocean organisms. They also help protect shorelines from erosion by absorbing some of the energy of waves. Coral reefs are at risk of destruction today.

FIGURE 4.27
Great Barrier Reef. The Great Barrier Reef is a coral reef off the coast of Australia.

Unlike corals, jellyfish spend most of their lives as medusae. They live virtually everywhere in the ocean. They are typically carnivores. They prey on zooplankton, other invertebrates, and the eggs and larvae of fish.

KQED: Amazing Jellies

Jellyfish. They are otherworldly creatures that glow in the dark, without brains or bones, some more than 100 feet long. And there are many different types. Jellyfish are free-swimming members of the phylum Cnidaria. Jellyfish are found in every ocean, from the surface to the deep sea.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/456

Summary

- Cnidarians include jellyfish and corals.
- Cnidarians are aquatic invertebrates. They have tissues and radial symmetry. They also have tentacles with stingers.
- There are two cnidarian body plans: the polyp and the medusa. They differ in several ways.
- Many corals secrete an exoskeleton that builds up to become a coral reef.

Review

1. What is a nematocyst? What is its function?
2. How do coral reefs form?
3. Compare and contrast cnidarian polyps and medusae.

4.10 References

1. Courtesy of NASA Ames Research Center/K. Jobse, P. Jenniskens. The gases that create a comet's tail can become part of the atmosphere of a planet . Public Domain
2. Graeme Churchard. A banded iron formation, showing the appearance of oxygen . CC BY 2.0
3. Zachary Wilson. Hypothetical first cell on Earth . CC BY-NC 3.0
4. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. History of Earth compressed into oneday . CC BY-NC 3.0
5. User:Karora/Wikimedia Commons. Fossil of an extinct lion . Public Domain
6. Frog in resin: Image copyright Galyna Andrushko, 2014; Footprint: Edmondo Gnerre. A frog trapped in amber, and the fossil footprints of a dinosaur . Frog in resin: Used under license from Shutterstock.com; Footprint: CC BY 2.0
7. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Relative dating using rock layers . CC BY-NC 3.0
8. Hana Zavadska. The geologic time scale . CC BY-NC 3.0
9. Kevin Walsh. Fossils of trilobites, which lived in the lower Paleozoic . CC BY 2.0
10. Image copyright Nicola Gavin, 2014. Picture of a modern rainforest, similar to those during the Carboniferou s . Used under license from Shutterstock.com
11. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. The period of the Paleozoic Era . CC BY-NC 3.0
12. Left: Stanton F. Fink; Right: User:TheoricienQuantique/Wikimedia Commons. Illustration of reef-building sponges, and a fossil of a trilobite . Left: CC BY 2.5; Right: Public Domain
13. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. And early vascular plant, Cooksonia . CC BY-NC 3.0
14. Eduard Riou. Paleozoic era Devonian period forest, with club mosses, horsetails, and ferns . Public Domain
15. Laura Guerin. The supercontinent Pangaea . CC BY-NC 3.0
16. Neethis. Snowball Earth during the early Precambrian . The copyright holder of this work allows anyone to use it for any purpose including unrestricted redistribution, commercial use, and modification
17. James St. John. Fossilized flowering plant from the Cretaceous . CC BY 2.0
18. Marasuchus: User:Mitternacht90/Wikipedia; Archaeopteryx: Richard Owen; Apatosaurus: User:FunkMonk/Wikimedia Commons; Allosaurus: User:Sheep81/Wikimedia Commons. Fossils of dinosaurs . Marasuchus, Archaeopteryx, Allosaurus: Public Domain; Apatosaurus: CC BY 2.0
19. Erik Paterson. Amniotic eggs containing snake hatchlings . CC BY 2.0
20. User:Fredrik/Wikipedia. Drawing of the asteroid impact that caused the Cretaceous extinctions . Public Domain
21. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons). Fossil of Archeopteryx, the earliest known bird . Public Domain
22. User:Daderot/Wikimedia Commons. Skeleton of a saber-toothed cat . Public Domain
23. Coral: Laszlo Ilyes; Anemone: Courtesy of National Oceanic and Atmospheric Administration; Hydrozoa: User:Tims/Wikipedia; Jellyfish: NBPhotostream. Cnidarian diversity: coral, anemone, hydrozoa . Coral: CC BY 2.0; Anemone: Public Domain; Hydrozoa: Public Domain; Jellyfish: CC BY 2.0
24. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Cnidarian nematocyst development . CC BY-NC 3.0
25. CK-12 Foundation. Cnidarian body plans . CC BY-NC 3.0
26. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. General cnidarian life cycle . CC BY-NC 3.0
27. Kyle Taylor. Great barrier reef . CC BY 2.0

Chapter 5 ESS3-1

Chapter Outline

5.1 Biogeography

Learning Objectives

- Define biogeography.
- Describe how biogeography relates to evolutionary change.
- Discuss the work of Peter and Rosemary Grant.

Why would geography have anything to do with evolution?

Similar to "how did the chicken cross the road?" but on a much grander scale. How did the animal cross Europe and into Asia? Or Asia into America? How did anything get into Australia?

Evidence from Biogeography

Biogeography is the study of how and why plants and animals live where they do. It provides more evidence for evolution. Let's consider the camel family as an example.

Biogeography of Camels: An Example

Today, the camel family includes different types of camels. They are shown in **Figure** 5.1. All of today's camels are descended from the same camel ancestors. These ancestors lived in North America about a million years ago.

Early North American camels migrated to other places. Some went to East Asia. They crossed a land bridge during the last ice age. A few of them made it all the way to Africa. Others went to South America. They crossed the Isthmus of Panama. Once camels reached these different places, they evolved independently. They evolved adaptations that suited them for the particular environment where they lived. Through natural selection, descendants of the original camel ancestors evolved the diversity they have today.

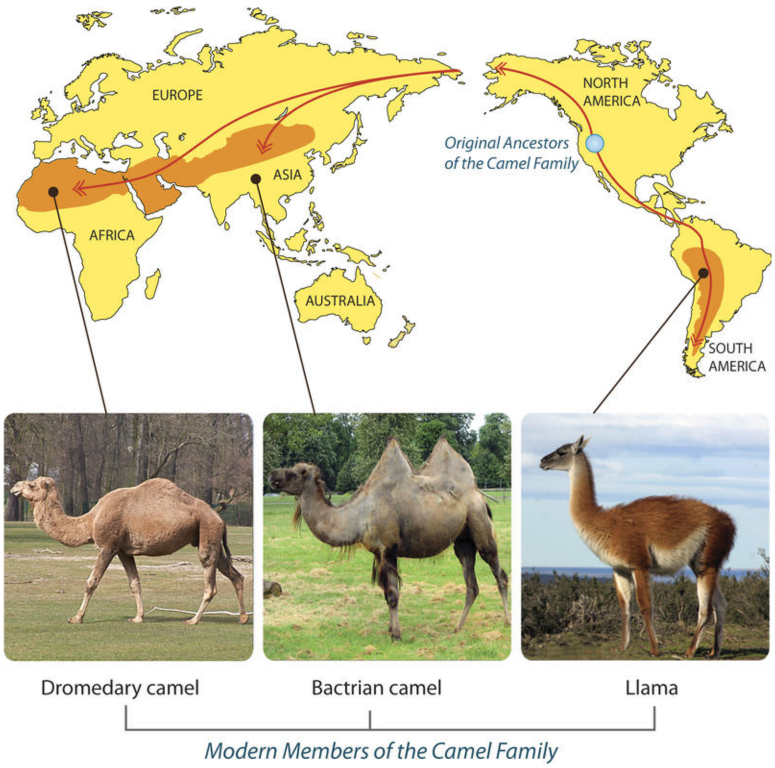


FIGURE 5.1

Camel Migrations and Present-Day Variation. Members of the camel family now live in different parts of the world. They differ from one another in a number of traits. However, they share basic similarities. This is because they all evolved from a common ancestor. What differences and similarities do you see?

Island Biogeography

The biogeography of islands yields some of the best evidence for evolution. Consider the birds called finches that Darwin studied on the Galápagos Islands (see **Figure** 5.2). All of the finches probably descended from one bird that arrived on the islands from South America. Until the first bird arrived, there had never been birds on the islands. The first bird was a seed eater. It evolved into many finch species. Each species was adapted for a different type of food. This is an example of **adaptive radiation**. This is the process by which a single species evolves into many new species to fill available niches.

Eyewitness to Evolution

In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands. They wanted to re-study Darwin's finches. They spent more than 30 years on the project. Their efforts paid off. They were able to observe evolution by natural selection actually taking place.

While the Grants were on the Galápagos, a drought occurred. As a result, fewer seeds were available for finches to eat. Birds with smaller beaks could crack open and eat only the smaller seeds. Birds with bigger beaks could crack and eat seeds of all sizes. As a result, many of the small-beaked birds died in the drought. Birds with bigger beaks survived and reproduced (see **Figure** 5.3). Within 2 years, the average beak size in the finch population increased. Evolution by natural selection had occurred.

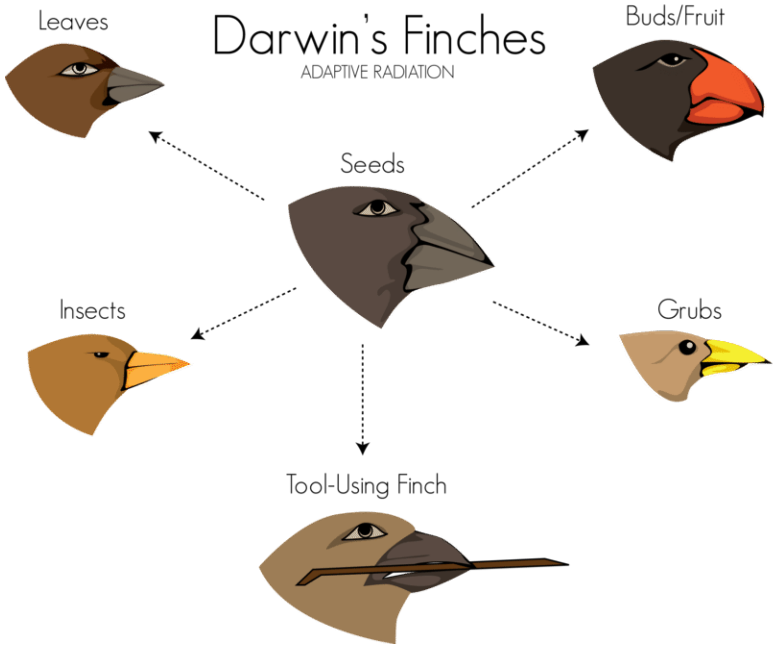


FIGURE 5.2
Galápagos finches differ in beak size and shape, depending on the type of food they eat.

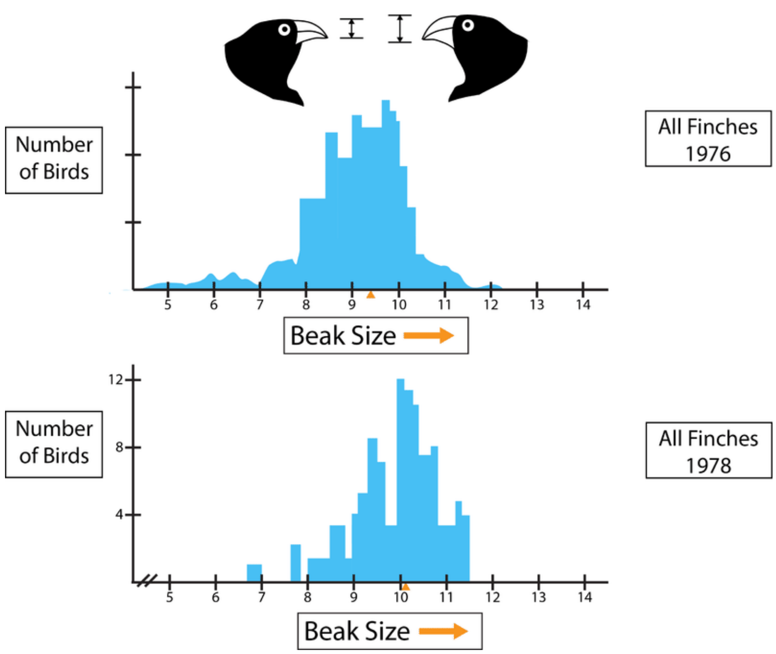


FIGURE 5.3
Evolution of Beak Size in Galápagos Finches. The top graph shows the beak sizes of the entire finch population studied by the Grants in 1976. The bottom graph shows the beak sizes of the survivors in 1978. In just 2 years, beak size increased.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185016

Summary

- Biogeography is the study of how and why plants and animals live where they do. It also provides evidence for evolution.
- On island chains, such as the Galápagos, one species may evolve into many new species to fill available niches. This is called adaptive radiation.

Review

1. Define biogeography.
2. Describe an example of island biogeography that provides evidence of evolution.
3. Describe the effects of the drought on the Galápagos Islands observed by the Grants.

5.2 Agriculture and Human Population Growth

Learning Objectives

- 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** 7.6). 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.

FIGURE 5.4
In a hunter-gatherer society, people relied on the resources they could find where they lived.

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?

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** 7.7). 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.

When advanced farming practices allowed farmers to grow more food than they needed for their families (**Figure** 7.8), some people were then able to do other types of work, such as crafts or shop keeping.

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** 7.9). This major historical event marks when products were first mass-produced and when fossil fuels were first widely used for power.

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.

FIGURE 5.5
More advanced farming practices allowed a single farmer to grow food for many more people.

FIGURE 5.6
Farming has increasingly depended on machines. Such advanced farming practices allow one farmer to feed many more people than in the past.

- 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** 7.10).
- 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.

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.

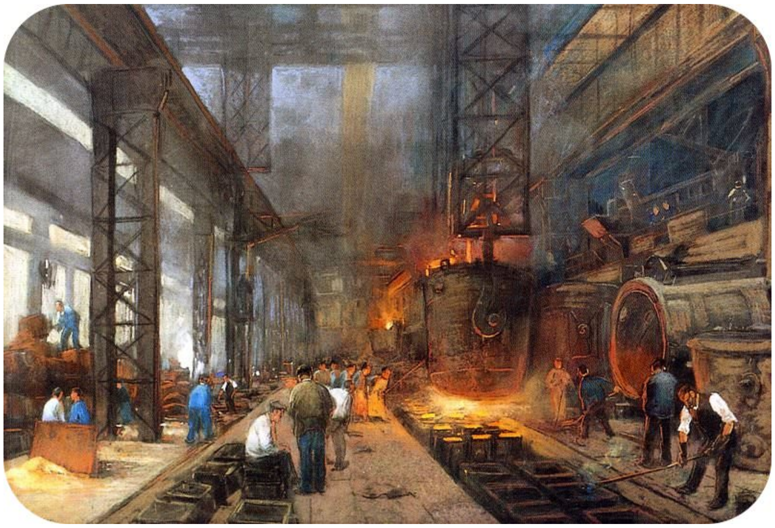


FIGURE 5.7

Early in the Industrial Revolution, large numbers of people who had been freed from food production were available to work in factories.

FIGURE 5.8

Rows of a single crop and heavy machinery are normal sights for modern day farms.

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** 7.11)? 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?

FIGURE 5.9
Manhattan is one of the most heavily populated regions in the world.

Summary

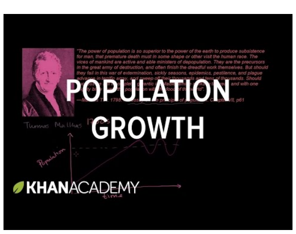
- Hunters and gatherers lived off the land, with no agriculture, and reached a total population of no more than around 10 million.
- Farming allowed people to settle down and allowed populations to grow.
- The Green Revolution and the Industrial Revolution are heavily dependent on fossil fuels.

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?

Explore More

Use this resource to answer the questions that follow.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/1554

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?

5.3 Soil and Water Resources

Learning Objectives

- Describe the components of soil.
- Summarize the importance of soil.
- Describe threats to soil and water resources.
- Discuss consequences of excess runoff.

Could this land be used for agriculture?

Probably not. The quality of soil is very important in determining what can grow in a particular area. Good soil is not so easy to come by. Soil should be considered another resource that we, as a population, must strive to protect.

Soil and Water Resources

Theoretically, soil and water are renewable resources. However, they may be ruined by careless human actions.

Soil

Soil is a mixture of eroded rock, minerals, partly decomposed organic matter, and other materials. It is essential for plant growth, so it is the foundation of terrestrial ecosystems. Soil is important for other reasons as well. For example, it removes toxins from water and breaks down wastes.

Although renewable, soil takes a very long time to form—up to hundreds of millions of years. So, for human purposes, soil is a nonrenewable resource. It is also constantly depleted of nutrients through careless use, and eroded by wind and water. For example, misuse of soil caused a huge amount of it to simply blow away in the 1930s during the Dust Bowl (see **Figure** 5.10). Soil must be used wisely to preserve it for the future. Conservation practices include contour plowing and terracing. Both reduce soil erosion. Soil also must be protected from toxic wastes.

FIGURE 5.10

The Dust Bowl occurred between 1933 and 1939 in Oklahoma and other southwestern U.S. states. Plowing had exposed prairie soil. Drought turned the soil to dust. Intense dust storms blew away vast quantities of the soil. Much of the soil blew all the way to the Atlantic Ocean.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/187151

Water

Water is essential for all life on Earth. For human use, water must be fresh. Of all the water on Earth, only 1 percent is fresh, liquid water. Most of the rest is either salt water in the ocean or ice in glaciers and ice caps.

Although water is constantly recycled through the **water cycle**, it is in danger. Over-use and pollution of freshwater threaten the limited supply that people depend on. Already, more than 1 billion people worldwide do not have adequate freshwater. With the rapidly growing human population, the water shortage is likely to get worse.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/187153

Too Much of a Good Thing

Water pollution comes from many sources. One of the biggest sources is runoff. **Runoff** picks up chemicals such as fertilizer from agricultural fields, lawns, and golf courses. It carries the chemicals to bodies of water. The added nutrients from fertilizer often cause excessive growth of algae, creating **algal blooms** (see **Figure** 5.11). The algae use up oxygen in the water so that other aquatic organisms cannot survive. This has occurred over large areas of the ocean, creating **dead zones**, where low oxygen levels have killed all ocean life. A very large dead zone exists in the Gulf of Mexico. Measures that can help prevent these problems include cutting down on fertilizer use. Preserving wetlands also helps because wetlands filter runoff water.

FIGURE 5.11

Algal Bloom. Nutrients from fertilizer in runoff caused this algal bloom.

Summary

- Soil and water are renewable resources but may be ruined by careless human actions. Soil can be depleted of nutrients. It can also be eroded by wind or water.
- Over-use and pollution of freshwater threaten the limited supply that people depend on.

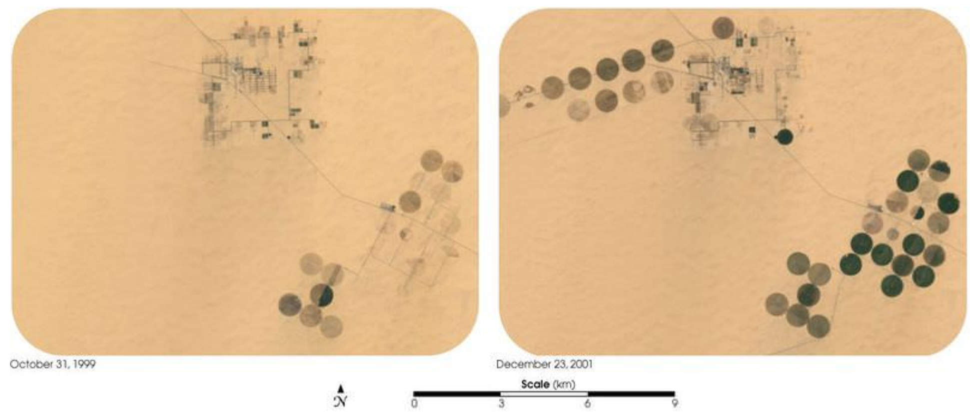
Review

1. What is soil?
2. Why is soil considered a nonrenewable resource?
3. How much water is drinkable?
4. Why would you expect a dead zone to start near the mouth of a river, where the river flows into a body of water?

5.4 Groundwater Depletion

Learning Objectives

- 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** 5.13). 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** 5.14).

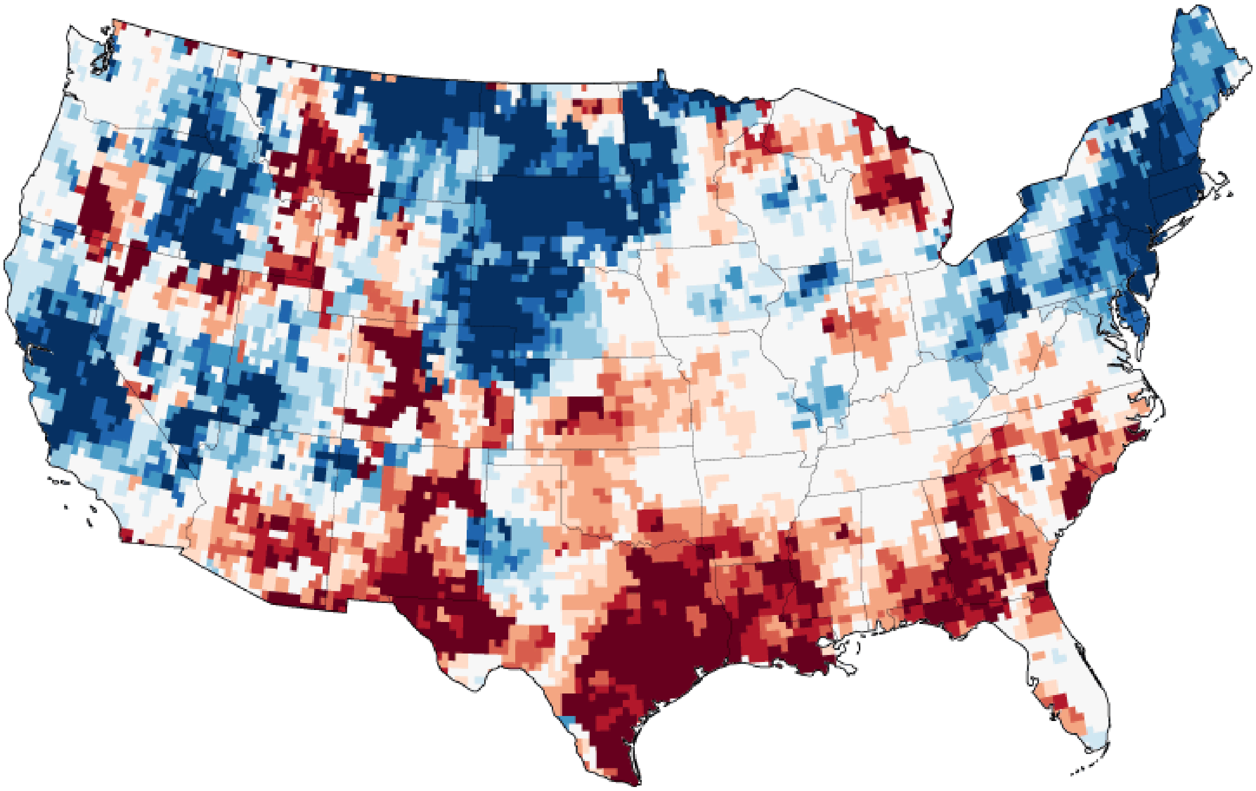


FIGURE 5.12
Intense drought has reduced groundwater levels in the southern U.S., particularly in Texas and New Mexico.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186880

Subsidence

Lowering the water table may cause the ground surface to sink. **Subsidence** may occur beneath houses and other structures (**Figure** 5.15).

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.

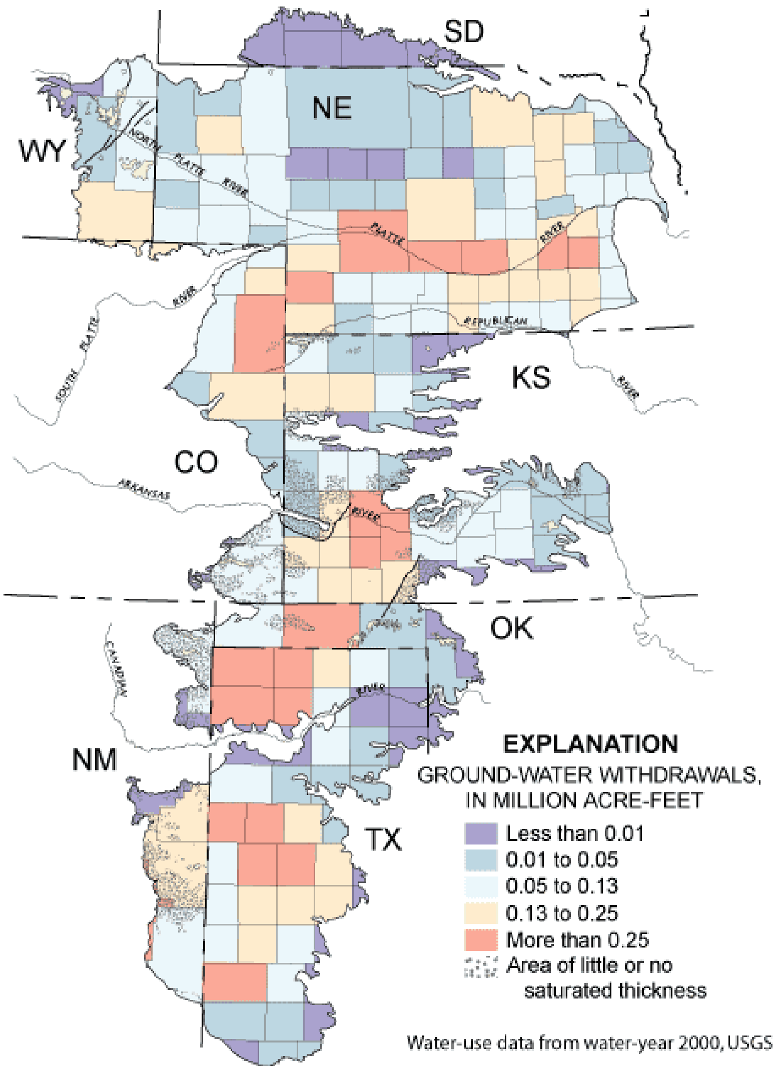


FIGURE 5.13

The Ogallala Aquifer is found beneath eight states and is heavily used.

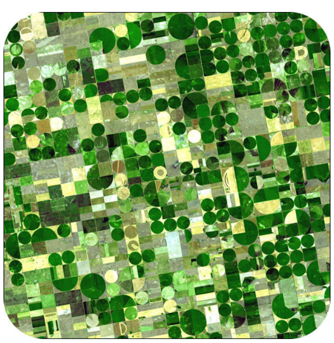


FIGURE 5.14

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.

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.

FIGURE 5.15
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.

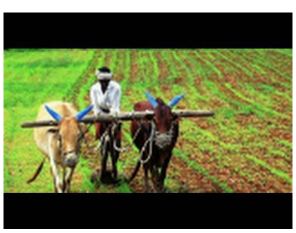
- Ground subsidence and saltwater intrusion are two possible consequences of groundwater overuse.

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?

Explore More

Use this resource to answer the questions that follow.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/1549

1. How has irrigation changed farming?
2. What is leading to people's demands for additional water?
3. What do scientists need to see to better plan for future water use?
4. What is the GRACE satellite doing?
5. How does GRACE find groundwater aquifers?
6. How people know the aquifers are being depleted?
7. What is happening in India? what will happen if the water continues to decline?
8. What is the future of water?

5.5 Flooding

Learning Objectives

- 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).

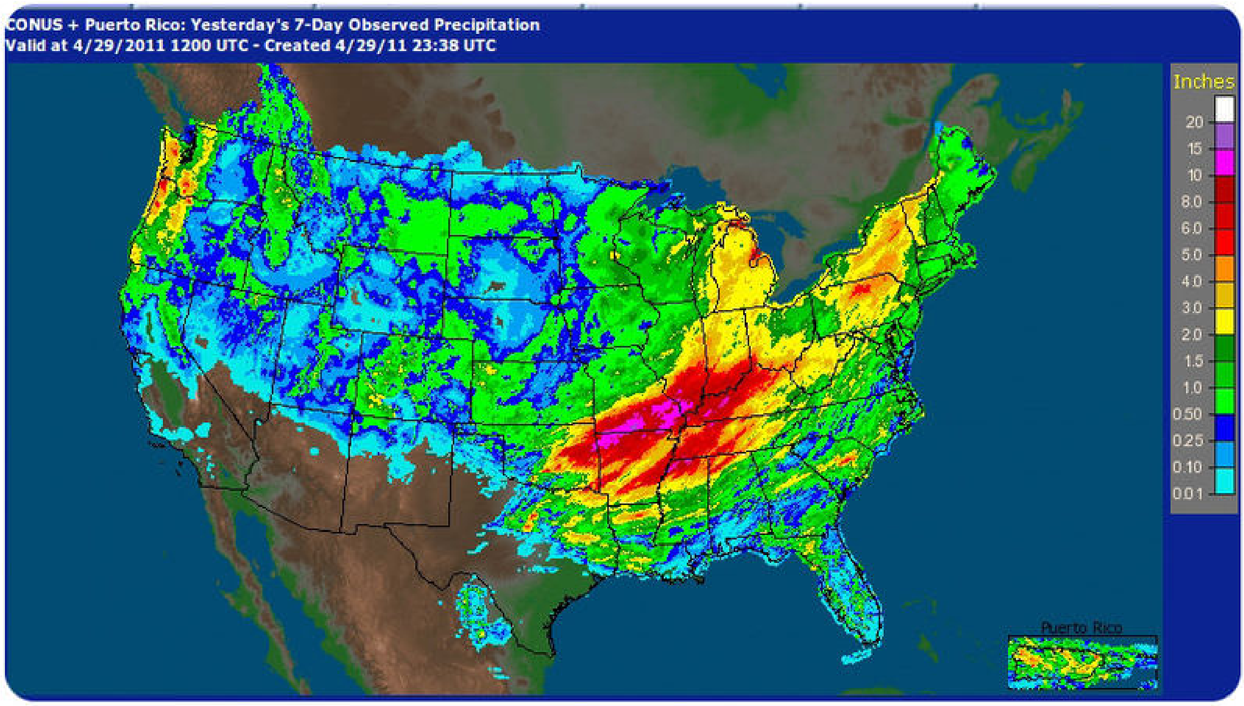
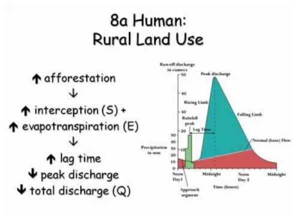


FIGURE 5.16

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.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186395

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 5.18

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.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186397

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

FIGURE 5.19
Within the floodplain of the Nile, soils are fertile enough for productive agriculture. Beyond this, infertile desert soils prevent viable farming.

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.

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

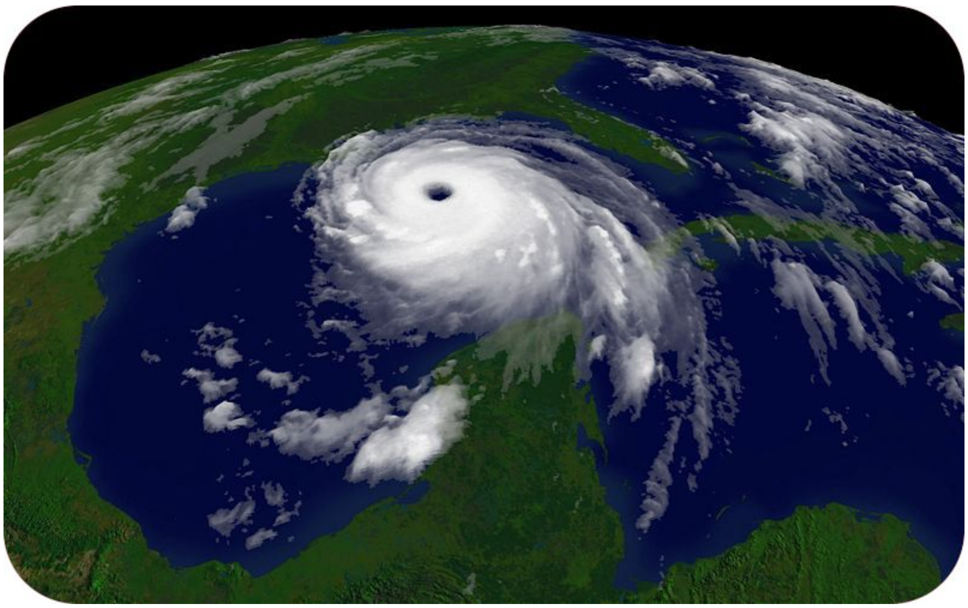
URL: http://www.ck12.org/flx/render/embeddedobject/178094

1. What is a flash flood?
2. What don't thunderstorms cause flash floods?
3. How might a mountainous region experience flash floods?
4. Where do flash floods occur?
5. Why might a flash flood occur not where the rain falls?
6. Why are urban areas prone to flash floods?
7. What is the difference between a flash flood and a flood?
8. If you are in a mountainous area and a flash flood is predicted what should you not do?
9. What are the safety tips for floods?

5.6 Hurricanes

Learning Objectives

- 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

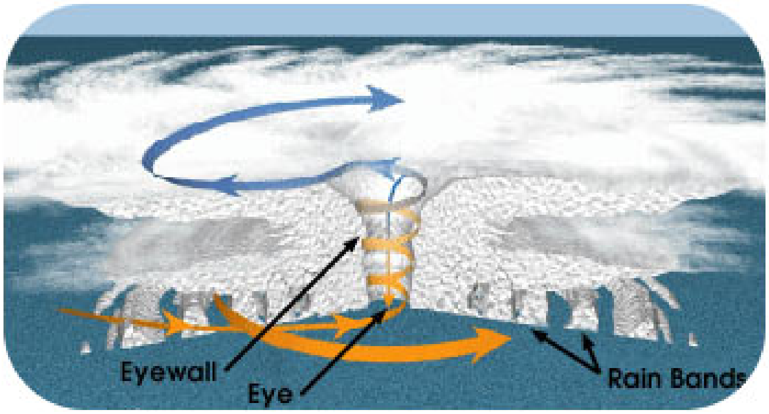


FIGURE 5.20
A cross-sectional view of a hurricane.

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.

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.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186517

Saffir-Simpson Scale

Hurricanes are assigned to categories based on their wind speed. The categories are listed on the Saffir-Simpson hurricane scale (**Table** 5.1).

TABLE 5.1: 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

TABLE 5.1: (continued)

Category	Kph	Mph	Estimated Damage
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 (24 foot) storm surge that traveled 125 miles (200 km) inland.

The End

Hurricanes typically last for 5 to 10 days. The winds push them to the northwest and then to the northeast. Eventually a hurricane will end up over cooler water or land. At that time the hurricane's latent heat source shut downs and the storm weakens. When a hurricane disintegrates, it is replaced with intense rains and tornadoes.

There are about 100 hurricanes around the world each year, plus many smaller tropical storms and tropical depressions. As people develop coastal regions, property damage from storms continues to rise. However, scientists are becoming better at predicting the paths of these storms and fatalities are decreasing. There is, however, one major exception to the previous statement: Hurricane Katrina.

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** 5.21).

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.

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?

FIGURE 5.21
Flooding in New Orleans after Hurricane Katrina caused the levees to break and water to pour through the city.

3. Under what circumstances does a hurricane die?

Resources

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178141

5.7 21st Century Tsunami

Learning Objectives

- Describe the consequences of major 21st-century tsunami.

Why should you pay attention in school?

Tilly Smith, an 11-year old English schoolgirl, was vacationing with her family in Phuket, Thailand on December 26, 2004. Walking along the beach Tilly noticed that the bubbling sea in Phuket resembled a video taken just before a tsunami in Hawaii in 1946. She'd seen the video in geography class two weeks earlier and insisted to her parents that a tsunami was coming. Her warning saved the approximately 100 tourists and others who were on that beach.

Boxing Day Tsunami 2004

Not everyone had the same warning the people on Tilly's beach had. The Boxing Day Tsunami of December 26, 2004 was by far the deadliest of all time (**Figure** 5.22). The tsunami was caused by the 2004 Indian Ocean Earthquake. With a magnitude of 9.2, it was the second largest earthquake ever recorded.

The extreme movement of the crust displaced trillions of tons of water along the entire length of the rupture. Several tsunami waves were created with about 30 minutes between the peaks of each one. The waves that struck nearby Sumatra 15 minutes after the quake reached more than 10 meters (33 feet) in height. The size of the waves decreased with distance from the earthquake and were about 4 meters (13 feet) high in Somalia.

The tsunami did so much damage because it traveled throughout the Indian Ocean. About 230,000 people died in eight countries. There were fatalities even as far away as South Africa, nearly 8,000 kilometers (5,000 miles) from

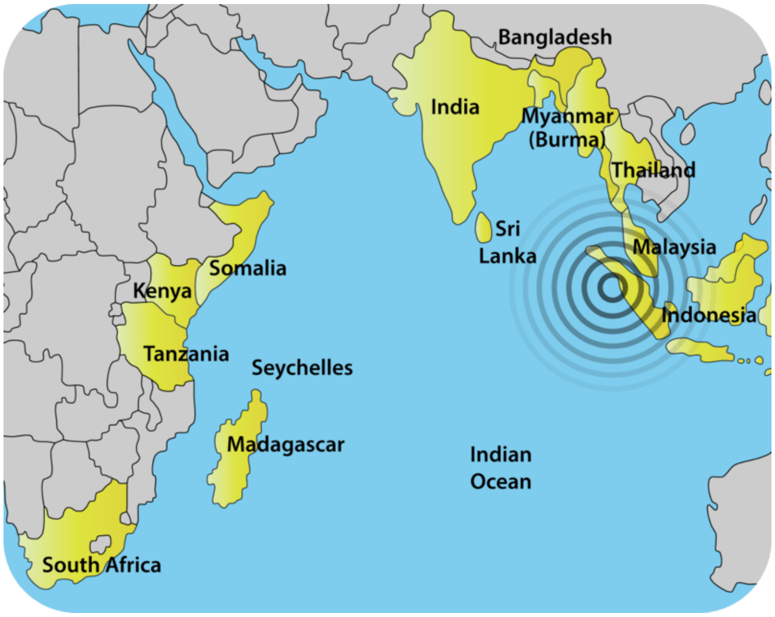


FIGURE 5.22
The countries that were most affected by the 2004 Boxing Day tsunami.

the earthquake epicenter. More than 1.2 million people lost their homes and many more lost their ways of making a living.

Japan Tsunami 2011

The Japanese received a one-two punch in March 2011. The 2011 Tōhoku earthquake offshore was a magnitude 9.0 and damage from the quake was extensive. People didn't have time to recover before massive tsunami waves hit the island nation. As seen in **Figure** 5.23, waves in some regions topped 9 meters (27 feet).

The tsunami did much more damage than the massive earthquake (**Figure** 5.24).

Worst was the damage done to nuclear power plants along the northeastern coast. Eleven reactors were automatically shut down. Power and backup power were lost at the Fukushima plant, leading to equipment failures, meltdowns, and the release of radioactive materials. Control and cleanup of the disabled plants will go on for many years.

Tsunami Warning Systems

As a result of the 2004 tsunami, an Indian Ocean warning system was put into operation in June 2006. Prior to 2004, no one had thought a large tsunami was possible in the Indian Ocean.

In comparison, a warning system has been in effect around the Pacific Ocean for more than 50 years. The system was used to warn of possible tsunami waves after the Tōhoku earthquake, but most were too close to the quake to get to high ground in time. Further away, people were evacuated along many Pacific coastlines, but the waves were not that large.

Summary

- The Boxing Day Tsunami of 2004 came from a massive earthquake and traveled across the Indian Ocean, causing death and destruction in 12 nations.
- In Japan, the tsunami struck very quickly after the 9.0 earthquake in the subduction zone offshore. Many more people died from the tsunami than the quake.

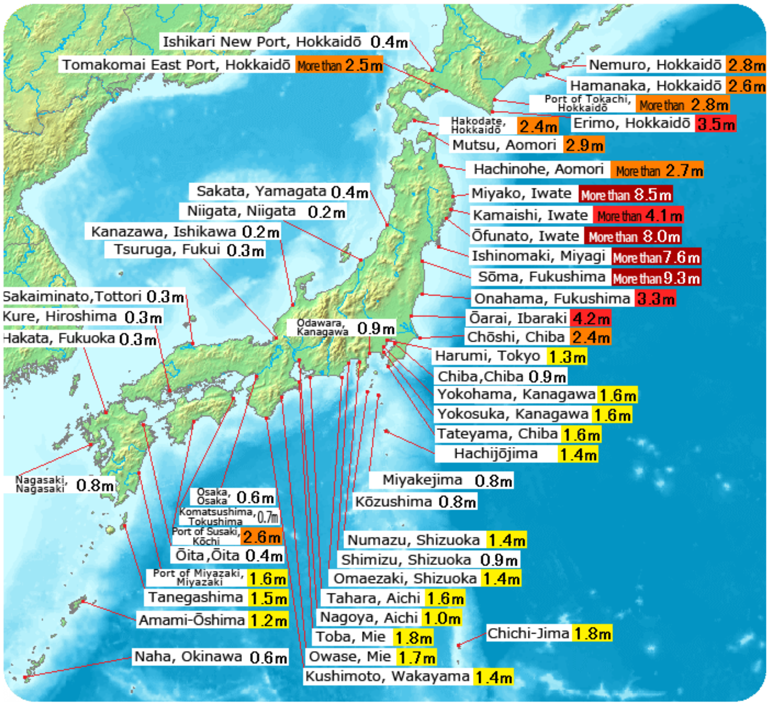


FIGURE 5.23
This map shows the peak tsunami wave heights.

FIGURE 5.24
An aerial view shows the damage to Sendai, Japan caused by the earthquake and tsunami. The black smoke is coming from an oil refinery, which was set on fire by the earthquake. The tsunami prevented efforts to extinguish the fire until several days after the earthquake.

- Tsunami warning systems are important but are not useful in locations that are very close to the earthquake that generated them.

Review

1. How does an earthquake generate a tsunami?
2. Why did so many people die in the Indian Ocean tsunami?
3. Why do you think there was more damage from the tsunami in Japan than from the earthquake that caused it?

FIGURE 5.25
A sign in Thailand shows an evacuation route.

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/116523

1. What was the magnitude of the Japan Tsunami?
2. How tall was the world's deepest and largest sea wall?
3. How many people died or were missing?
4. How does a tsunami move in deep water?
5. How far inland did some waves reach?
6. How fast were the waves moving on land?

5.8 Earthquake Damage

Learning Objectives

- Identify factors that make an earthquake damaging and deadly.

Is magnitude all that matters for determining earthquake damage?

The type and quality of construction has a tremendous effect on what happens during an earthquake. Damage and fatalities are directly affected by the construction in an earthquake. For example, many more people died in the 1988 Armenia earthquake, where people live in mud houses, than in the 1989 earthquake in Loma Prieta. Most buildings in California's earthquake country are designed to be earthquake-safe.

Damage from Earthquakes

We know that earthquakes kill lots of people. However, the ground shaking almost never kills people, and the ground does not swallow someone up. Fatalities depend somewhat on an earthquake's size and the type of ground people inhabit. But much of what determines the number of fatalities depends on the quality of structures. People are killed when structures fall on them. More damage is done and more people are killed by the fires that follow an earthquake than the earthquake itself.

What Makes an Earthquake Deadly?

- Population density. The magnitude 9.2 Great Alaska Earthquake, near Anchorage, of 1964 resulted in only 131 deaths. At the time few people lived in the area (**Figure** 5.26).

FIGURE 5.26
A landslide in a neighborhood in Anchorage, Alaska, after the 1964 Great Alaska earthquake.

- Not size. Only about 2,000 people died in the 1960 Great Chilean earthquake, the largest earthquake ever recorded. The Indian Ocean earthquake of 2004 was one of the largest ever, but most of the 230,000 fatalities were caused by the tsunami, not the earthquake itself.
- Ground type. Solid bedrock vibrates less than soft sediments, so there is less damage on bedrock. Sediments that are saturated with water undergo **liquefaction** and become like quicksand (**Figure** 5.27). Soil on a hillside may become a landslide.

FIGURE 5.27
Liquefaction of sediments in Mexico City caused the collapse of many buildings in the 1985 earthquake.

City Planning

In earthquake-prone areas, city planners try to reduce hazards. For example, in the San Francisco Bay Area, maps show how much shaking is expected for different ground types (**Figure** 5.28). This allows planners to locate new hospitals and schools more safely.

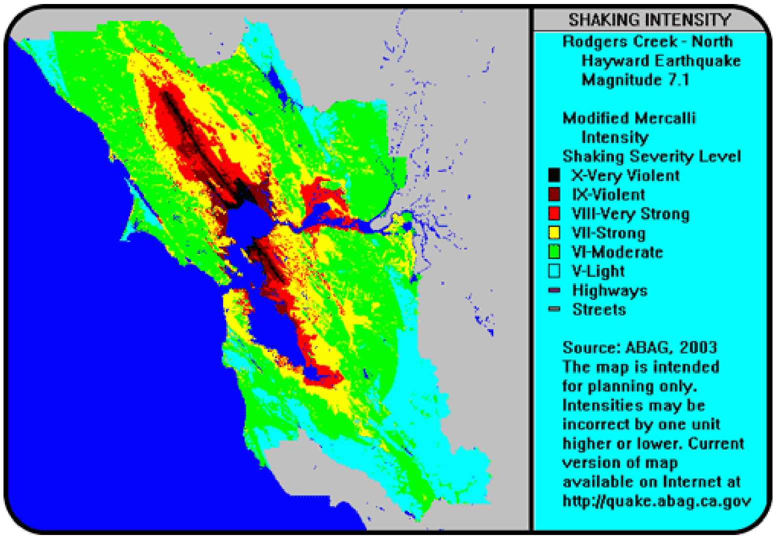


FIGURE 5.28
The expected Modified Mercalli Intensity Scale for an earthquake of magnitude 7.1 on the northern portion of the Hayward Fault.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186220

Summary

- Seismic waves rarely kill anyone. Structures falling on people and fires or tsunamis after the earthquake cause many more fatalities.
- City planning can lessen the damage done by earthquakes.
- Population density and ground type affect the number of fatalities.

Review

1. In the map of expected Modified Mercalli Intensity for the Bay Area of a hypothetical earthquake on the Hayward Fault, why do you think there is red and black north of the bay and up the Sacramento River? Why do you think there are much safer areas in rings around the bay?
2. What causes liquefaction and why is it damaging?
3. If a 9.2 earthquake struck near Anchorage, Alaska today, what do you think the fatalities would be compared with the quake in 1964?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178026

1. What is one reason that earthquakes are so scary?
2. On an average day, how many earthquakes take place around the world? How many large earthquakes take place?
3. What causes earthquakes?
4. What happens when plates can't move for long periods of time?
5. What would happen if Earth didn't have internal heat?

5.9 Materials Humans Use

Learning Objectives

- Identify resources commonly consumed by human uses.

What resources are in those electronics?

Everyone may realize that we use resources like trees, copper, water, and gemstones, but how many of us realize the tremendous variety of elements we need to make a single electronic device? A tablet computer with a touch screen contains many common chemical elements and a variety of rare earth elements.

Common Materials We Use From The Earth

People depend on natural resources for just about everything that keeps us fed and sheltered, as well as for the things that keep us entertained. Every person in the United States uses about 20,000 kilograms (40,000 pounds) of minerals every year for a wide range of products, such as cell phones, TVs, jewelry, and cars. **Table** 5.2 shows some common objects, the materials they are made from, and whether they are renewable or non-renewable.

TABLE 5.2: Common Objects We Use From the Earth

Common Object	Natural Resources Used	Are These Resources Renewable or Non-Renewable?
Cars	15 different metals, such as iron, lead, and chromium to make the body.	Non-renewable

TABLE 5.2: (continued)

Common Object	Natural Resources Used	Are These Resources Renewable or Non-Renewable?
Jewelry	Precious metals like gold, silver, and platinum. Gems like diamonds, rubies, emeralds, turquoise.	Non-renewable
Electronic Appliances (TV's, computers, DVD players, cell phones, etc.)	Many different metals, like copper, mercury, gold.	Non-renewable
Clothing	Soil to grow fibers such as cotton. Sunlight for the plants to grow. Animals for fur and leather.	Renewable
Food	Soil to grow plants. Wildlife and agricultural animals.	Renewable
Bottled Water	Water from streams or springs. Petroleum products to make plastic bottles.	Non-renewable and Renewable
Gasoline	Petroleum drilled from wells.	Non-renewable
Household Electricity	Coal, natural gas, solar power, wind power, hydroelectric power.	Non-renewable and Renewable
Paper	Trees; Sunlight Soil.	Renewable
Houses	Trees for timber. Rocks and minerals for construction materials, for example, granite, gravel, sand.	Non-renewable and Renewable

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186827

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186829

Summary

- Many objects, such as a car, contain many types of resources.
- Resources may be renewable or non-renewable, and an object may contain some of each.
- Rare earth elements and other unusual materials are used in some electronic devices.

Review

1. What resources are important to you that are renewable? Non-renewable?
2. What resources do you use that you could use less or not use at all?
3. How might one of these resources go from being renewable to non-renewable?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/171334

1. What do we use neodymium for?
2. What are rare earth elements used for in general?
3. Where do we get our REEs? Why are there signs that this can't continue?
4. Can we develop alternatives?
5. What is the problem with the deposit of REEs that is offshore of Japan?
6. What is the danger for the future?

Vocabulary

5.10 Global Warming

Learning Objectives

- 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**.

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 10 warmest years in the 134-year record have all occurred in the 21st century. The warmest year on record was 2016, with 2015 and 2014 being the second and third warmest (through 2016) (**Figure** below). People who are younger than 30, have never experienced a month in which Earth's average surface temperature was below average for that month during the 20^{th} century. The last time global temperatures were below that average was in February 1985. (**Figure** below).

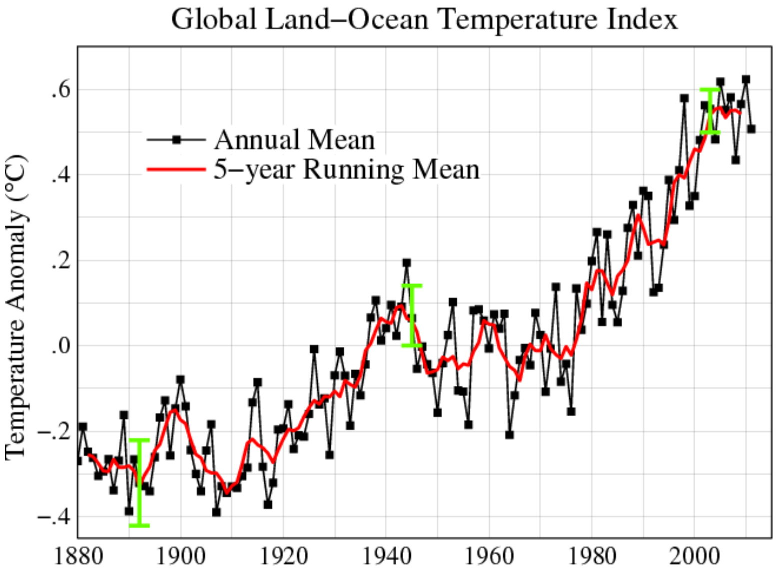


FIGURE 5.29
Recent temperature increases show how much temperature has risen since the Industrial Revolution began.

Annual variations aside, the average global temperature increased about 01.0°C (1.8°F) between 1880 and 2015, according to the Goddard Institute for Space Studies, NASA. This number doesn't seem very large. Why is it important?

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.

Changes Due to Warming Temperatures

The following images show changes in the Earth and organisms as a result of global warming: **Figure** 5.30, **Figure** 5.31, **Figure** 5.32.

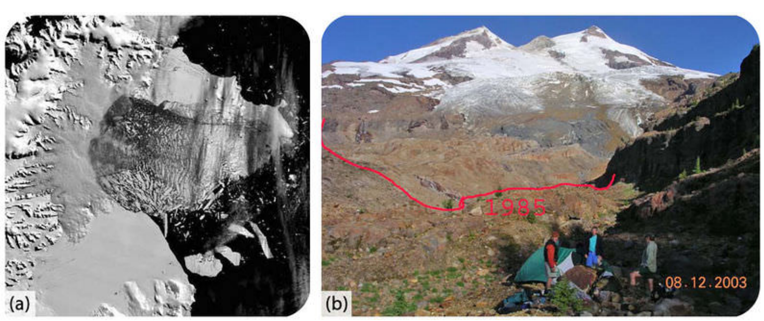


FIGURE 5.30
(a) Breakup of the Larsen Ice Shelf in Antarctica in 2002 was related to climate warming in the region. (b) The Boulder Glacier has melted back tremendously since 1985. Other mountain glaciers around the world are also melting.

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

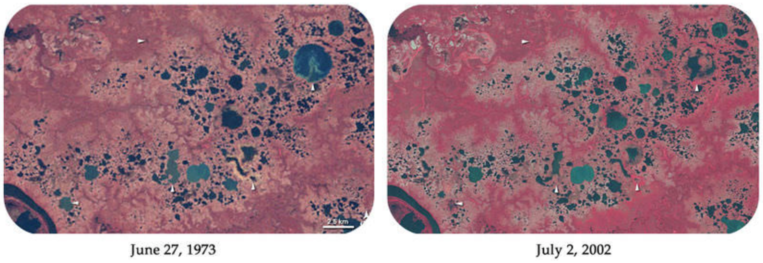


FIGURE 5.31
Permafrost is melting and its extent decreasing. There are now fewer summer lakes in Siberia.

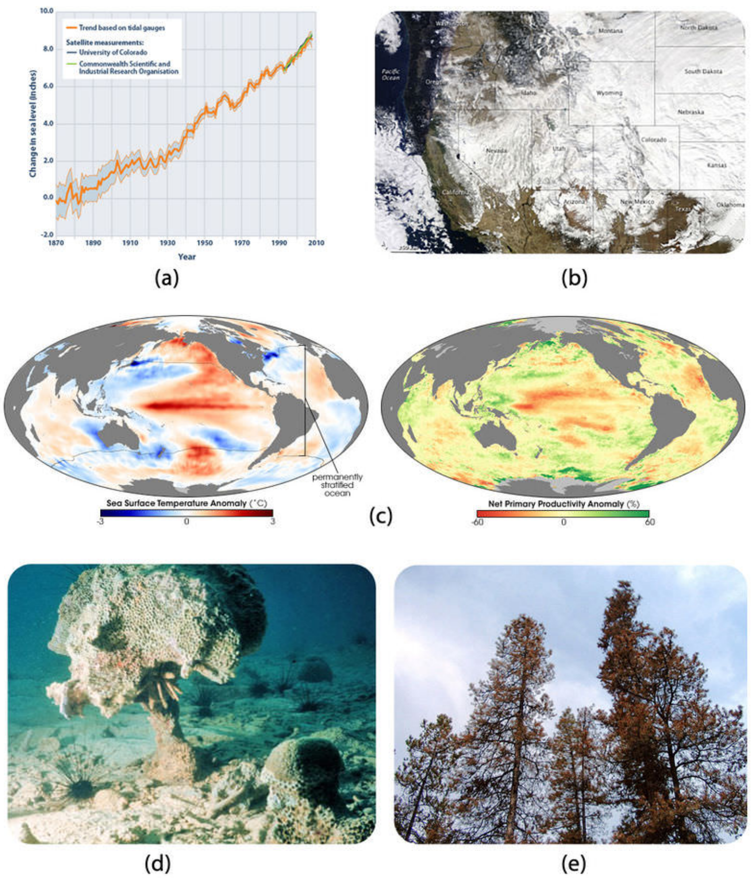


FIGURE 5.32
(a) Melting ice caps add water to the oceans, so sea level is rising. Remember that water slightly expands as it warms — this expansion is also causing sea level to rise. (b) Weather is becoming more variable with more severe storms and droughts. Snow blanketed the western United States in 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.

because they have become too warm or dry.

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?

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.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/414

Summary

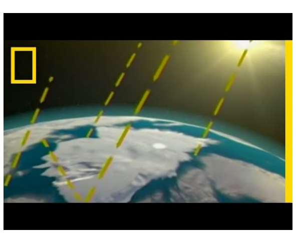
- Greenhouse gases trap heat in the atmosphere; burning fossil fuels and other human activities release greenhouse gases into the atmosphere; greenhouse gas levels in the atmosphere are increasing; and global temperatures are increasing.
- Average global temperature has been rising since the end of the 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.

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?

Explore More

Use the resource below to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/1542

1. How much has the global temperature risen in the last century?
2. What is the major human activity that contributes to global warming and why?
3. What is the greenhouse effect?
4. Is average global temperature rising? What is your evidence?
5. Which greenhouse gases are at their highest levels in history? When was the last time they were as high?
6. What do researchers predict will happen?
7. What can we do now to slow the rise in temperatures?

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/169911

5.11 Impact of Continued Global Warming

Learning Objectives

- 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

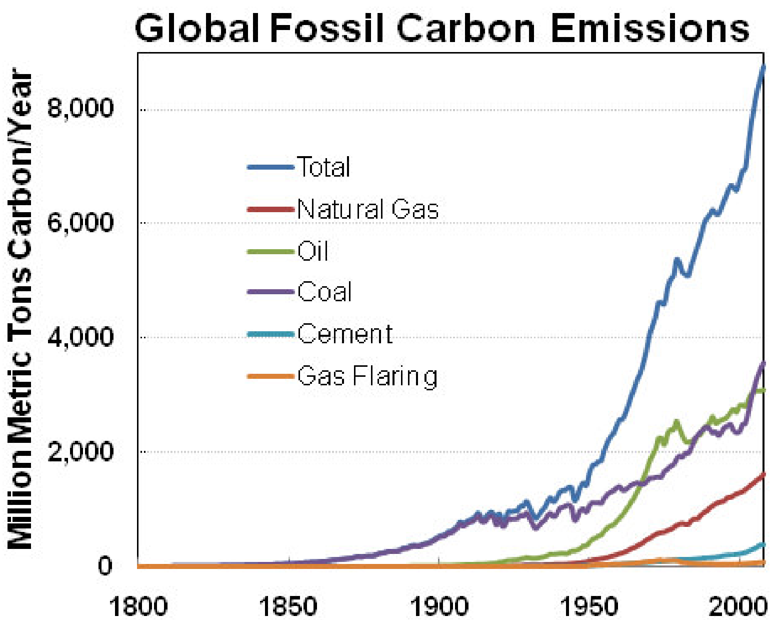
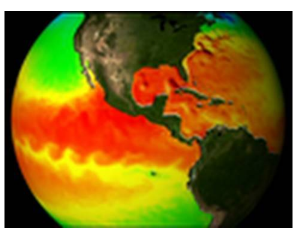


FIGURE 5.33

Global CO_2 emissions are rising rapidly. The industrial revolution began about 1850 and industrialization has been accelerating.

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.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/1436

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** 5.34).

Global Changes

As greenhouse gases increase, changes will be more extreme. Oceans will become 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.

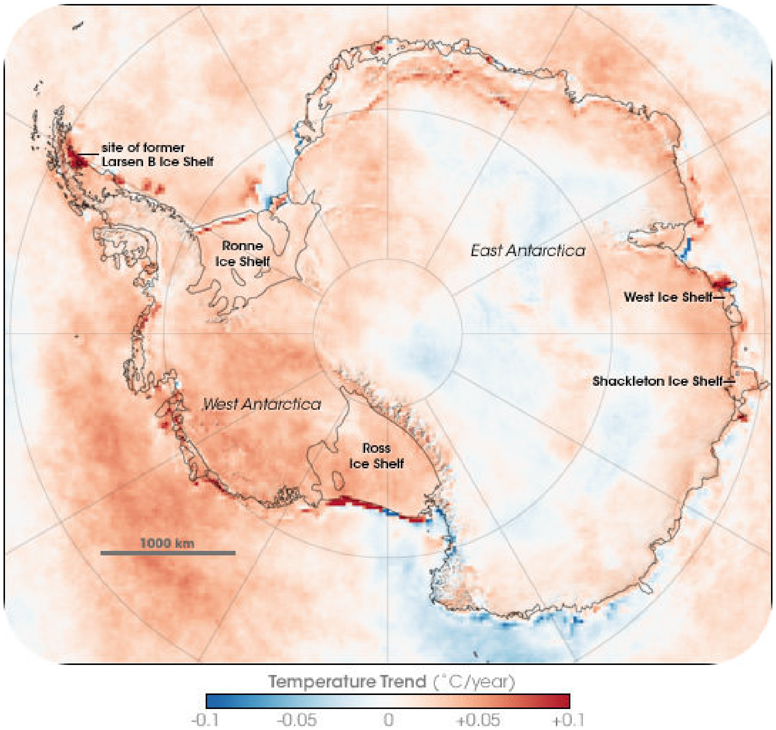


FIGURE 5.34
Temperature changes over Antarctica.

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 to melt and sea level is predicted to rise 18 to 97 cm (7 to 38 inches) by 2100 (**Figure** 5.35). 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.

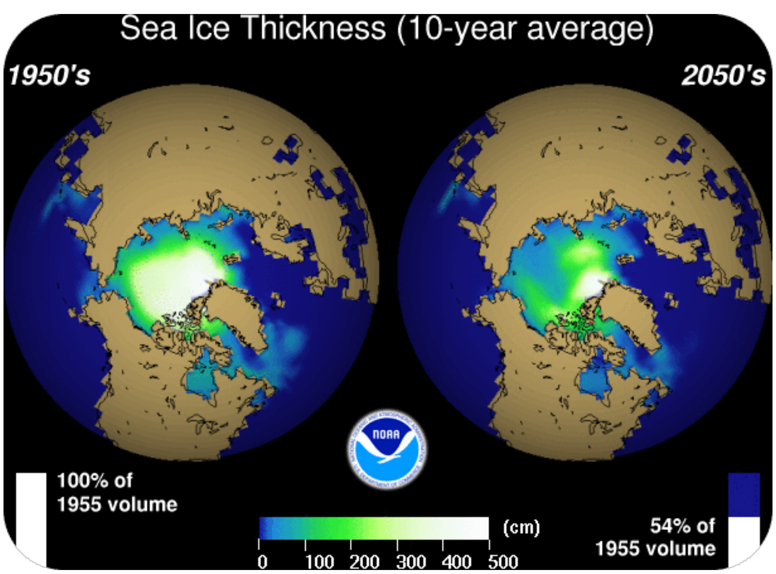


FIGURE 5.35
Sea ice thickness around the North Pole has been decreasing in recent decades and will continue to decrease in the coming decades.

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.

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.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/116515

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.

Review

1. What factors 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?

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/169946

1. What have the world's top scientists concluded? What are the main causes?
2. What has happened over the past 250 years and why?
3. What changes are happening to the atmosphere?
4. What is causing sea level to rise? What will happen to small island nations?
5. What happens to biodiversity?
6. What could happen to food supplies?
7. Who is the most vulnerable to climate changes?
8. What will happen to coastal areas?
9. What must we do to change this future?
10. What must each of us do? Governments?
11. What should be reflected in the costs of fossil fuels?

Resources

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/169922

5.12 Global Climate Change

Learning Objectives

- Explain the greenhouse effect.
- Define global warming.
- Explain the effects of global climate change.

Is the Earth really fragile?

Maybe not the planet, but how about the ecosystems? It may soon be hard to argue that global climate change does not exist. Climate change can definitely be seen in numerous ecosystems. So what will we do about it?

Global Climate Change

Another major problem caused by air pollution is global climate change. Gases such as carbon dioxide from the burning of fossil fuels increase the natural greenhouse effect. This raises the temperature of Earth's surface.

What Is The Greenhouse Effect?

The **greenhouse effect** is a natural feature of Earth's atmosphere. It occurs when gases in the atmosphere radiate the sun's heat back down to Earth's surface (see **Figure** 10.4). Otherwise, the heat would escape into space. Without the greenhouse effect, Earth's surface temperature would be far cooler than it is. In fact, it would be too cold to support life as we know it.

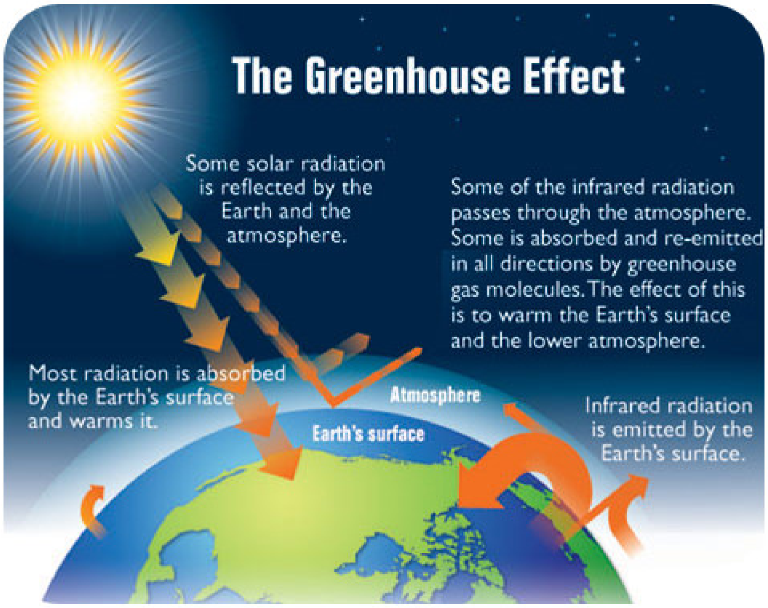


FIGURE 5.36
The Greenhouse Effect. Without greenhouse gases, most of the sun's energy would be radiated from Earth's surface back out to space.

Global Warming

Global warming refers to a recent increase in Earth's average surface temperature (see **Figure** 10.5). During the past century, the temperature has risen by almost 1°C (about 1.3°F). That may not seem like much. But consider that just 10°C is the difference between an ice-free and an ice-covered Earth.

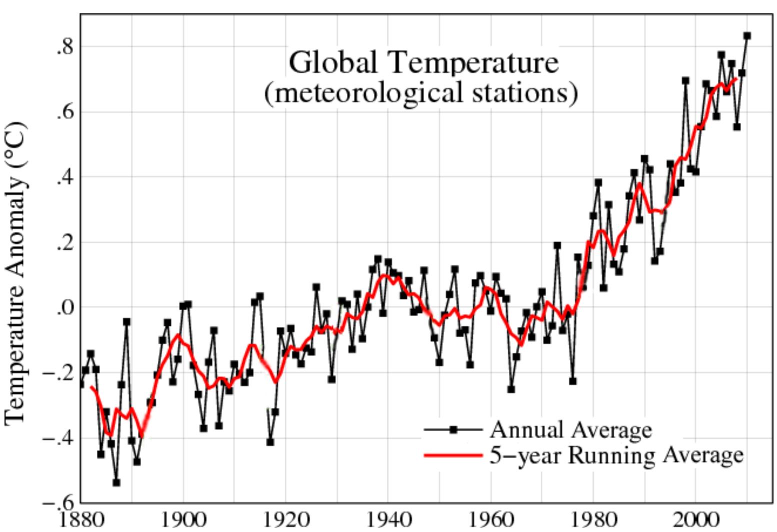


FIGURE 5.37
The average annual temperature on Earth has been rising for the past 100 years.

Most scientists agree that global warming is caused by more carbon dioxide in the atmosphere (see **Figure** 10.6). This increases the greenhouse effect. There is more carbon dioxide mainly because of the burning of fossil fuels. Destroying forests is another cause. With fewer forests, less carbon dioxide is removed from the atmosphere by photosynthesis.

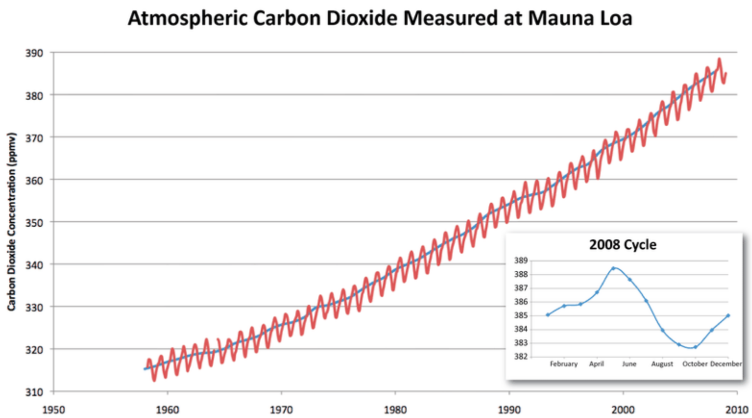


FIGURE 5.38
This graph shows the recent trend in carbon dioxide in the atmosphere.

Effects of Climate Change

How has global warming affected Earth and its life? Some of its effects include:

- Decline in cold-adapted species such as polar bears.
- Melting of glaciers and rising sea levels.
- Coastal flooding and shoreline erosion.
- Heat-related human health problems.
- More droughts and water shortages.
- Changing patterns of precipitation.
- Increasing severity of storms.
- Major crop losses.

KQED: Climate Watch: California at the Tipping Point

The world's climate is changing and California is now being affected in both dramatic and subtle ways. In 2008, scientists determined that California's temperatures increased by more than 2.1°F during the last century. What's more, the data showed that human activity has played a significant role in that climate change. "What's just 2 degrees?" you may wonder. But, as the science shows, just 2 degrees is extremely significant.

What does all this temperature change mean? For starters, declining mountain snowpack and prolonged drought conditions could pose a threat to limited water supplies. Heat waves are projected to be longer, bringing increased danger from wildfires and heat-related deaths. Rising sea levels due to temperature shifts jeopardize life in coastal areas, both for human communities and the plants and animals that rely on intertidal and rich wetland ecosystems. Also, more precipitation is expected to fall as rain rather than snow, thereby increasing the risk of floods. And, as heat increases the formation of smog, poor air quality could get even worse.

Climate change may also profoundly affect the economy in California and elsewhere. Shorter ski seasons and damage to the marine ecosystem mean a reduction in tourism. Water shortages mean issues with the commercial and recreational fishing industry, and higher temperatures will affect crop growth and quality, weakening the agricultural industry, to name just a few of the economic issues associated with climate change.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/414

Melting glaciers, rising temperatures and droughts are all impacts of global warming. But how does global warming actually affect the oceans? The sea, it turns out, absorbs carbon dioxide emissions. The ocean acts like a giant sponge, absorbing carbon dioxide emissions from the air. And as we add more and more carbon dioxide to air by burning fossil fuels, the ocean is absorbing it. On one level, it's done us a big favor. Scientists say that we would be experiencing much more extreme climate change were it not for the ocean's ability to remove the heat-trapping gas. However, these emissions are causing the oceans to become more acidic. Changing pH levels threaten entire marine food webs, from coral reefs to salmon.

As carbon dioxide levels increase in the atmosphere, the levels also increase in the oceans. What effects does this have? Can ocean acidification make it difficult for sea life to produce their hard exoskeletons?

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/108467

Efforts to reduce future global warming mainly involve energy use. We need to use less energy, for example, by driving more fuel-efficient cars. We also need to switch to energy sources that produce less carbon dioxide, such as solar and wind energy. At the same time, we can increase the amount of carbon dioxide that is removed from air. We can stop destroying forests and plant new ones.

Summary

- Gases such as carbon dioxide from the burning of fossil fuels increase the natural greenhouse effect. This is raising the temperature of Earth's surface, and is called global warming.

Review

1. How does air pollution contribute to global warming?
2. What is the greenhouse effect?
3. What are three effects of global warming?

5.13 References

1. Map by CK-12 Foundation; Camels (left to right): User:Agadez/Wikimedia Commons; Adrian Pingstone (User:Arpingstone/Wikimedia Commons); User:PowersPhotos/Wikipedia; Composite created by CK-12 Foundation. Camel migration patterns, and comparisons of camels and llamas . Map: CC BY-NC 3.0; Camels (left to right): CC BY 2.5; Public Domain; Public Domain
2. Christopher Auyeung. Galapagos finches' beak size and shape . CC BY-NC 3.0
3. Jodi So. Evolution of beak size in Galapagos finches . CC BY-NC 3.0
4. Image copyright Pichugin Dmitry, 2014. Picture of a hunter-gatherer society . Used under license from Shutterstock.com
5. Flickr:AnanthBS. Farming using mules and a plow . CC BY 2.0
6. Courtesy of the US Department of Agriculture. Farming using machines . Public Domain
7. Herman Heyenbrock. Picture of a iron factory during the Industrial Revolution . Public Domain
8. User:NightThree/Wikipedia. Tractors farming a single crop . CC BY 2.0
9. User:(WT-shared) Rangliker/Wts.Wikivoyage. Manhattan, New York is one of the most heavily populated regions in the world . Public Domain
10. Left: National Oceanic and Atmospheric Administration; Right: U.S. Department of Agriculture. Images of the Dust Bowl . Public Domain
11. Dr. Jennifer L. Graham/U.S. Geological Survey. Nutrients in fertilizer cause an algal bloom . Public Domain
12. Courtesy of Chris Poulsen, National Drought Mitigation Center at the University of Nebraska-Lincoln, NASA Goddard Space Flight Center, and the GRACE science team. Map of groundwater levels in the United States . Public Domain
13. Courtesy of the US Geological Survey. Map of the Ogallala Aquifer . Public Domain
14. Courtesy of NASA/GSFC/METI/ERSDAC/JAROS and US/Japan ASTER Science Team. Satellite image of f arms using central pivot irrigation . Public Domain
15. Courtesy of the US Geological Survey. The ground has subsided tens of feet in the San Joaquin Valley in Ca lifornia due to groundwater used for agriculture . Public Domain
16. Courtesy of Advanced Hydrologic Prediction Service/National Oceanic and Atmospheric Administration. Heavy rainfall in 2011 lead to the Mississippi River floods . Public Domain
17. Courtesy of Jesse Allen and Robert Simmon/NASA's Earth Observatory. Flooding in 2011 of the Mississippi River, and the opening of the New Madrid Floodway . Public Domain
18. Benjamin Evans. Results of a flash flood in England . The copyright holder of this work allows anyone to use it for any purpose including unrestricted redistribution, commercial use, and modification
19. Andrew Griffith. Image of the fertile Nile floodplain . CC BY 2.0
20. Courtesy of US National Oceanic and Atmospheric Administration. A cross-sectional view of a hurricane . Public Domain
21. Courtesy of Petty Officer 2nd Class Kyle Niemi, US Coast Guard. Flooding in New Orleans after Hurricane Katrina hit . Public Domain
22. Zachary Wilson. Map of the area hit by the Boxing Day Tsunami . CC BY-NC 3.0
23. User:Pekachu/Wikimedia Commons and User:Eastwind41/Wikimedia Commons. Peak tsunami heights from the 2011 tsunami . Public Domain
24. Courtesy of the US Navy. Damage caused by the 2011 earthquake and tsunami . Public Domain
25. Esme Vos. Picture of a tsunami warning sign . CC BY 2.0
26. Courtesy of US Geological Survey. A landslide in a neighborhood in Anchorage, Alaska, after the 1964 Great Alaska earthquake . Public Domain
27. Courtesy of I.D. Celebi, US Geological Survey. Liquefaction of sediments in Mexico City caused the collapse of many buildings in the 1985 earthquake . Public Domain

28. Courtesy of Association of Bay Area Governments. The expected Modified Mercalli Intensity Scale for an ea rthquake of magnitude 7.1 on the northern portion of the Hayward Fault . Public Domain
29. Courtesy of NASA. Graph of temperature increases on Earth . Public Domain
30. (a) Courtesy of Ted Scambos, National Snow and Ice Data Center, NASA's Earth Observatory; (b) User:Peltoms/Wikipedia. Breakup of the Larsen Ice Shelf, and retreat of the Boulder Glacier . (a) Public Domain; (b) The copyright holder of this work allows anyone to use it for any purpose including unrestricted redistribution, commercial use, and modification
31. Courtesy of Jesse Allen, NASA's Earth Observatory. Satellite image of permafrost melting in Siberia . Public Domain
32. (a) Courtesy of US EPA; (b) Courtesy of Jesse Allen/MODIS Rapid Response Team and NASA's Earth Observatory; (c) Courtesy of Jesse Allen and NASA's Earth Observatory; (d) Courtesy of the US National Oceanic and Atmospheric Administration; (e) User:RadRafe/Wikimedia Commons. Graphs and pictures of t he effects of rising temperature . Public Domain
33. Courtesy of the National Energy Technology Laboratory/DOE, using data from CDIAC. Graph of rising carb on dioxide emissions . Public Domain
34. Courtesy of Robert Simmon, NASA. Temperature changes over Antarctica . Public Domain
35. Courtesy of the National Oceanic and Atmospheric Administration. Map of decreasing sea ice thickness arou nd the North Pole . Public Domain
36. U.S. Environmental Protection Agency. Diagram of the greenhouse effect . Public Domain
37. NASA, modified by Zachary Wilson/CK-12 Foundation. Annual temperature over the last 100 years . Public Domain
38. Steven Lai and Zachary Wilson, based on data from the Carbon Dioxide Information Analysis Center (http://cdiac.ornl.gov/ Carbon dioxide concentration in the atmosphere over time . CC BY-NC 3.0

CHAPTER 6 ESS3-2

Chapter Outline

6.1 Availability of Natural Resources

Learning Objectives

- 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** 6.1). As the cost of desalination plants comes down, more will likely be built.

FIGURE 6.1
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** 6.2). 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** 6.3).

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.

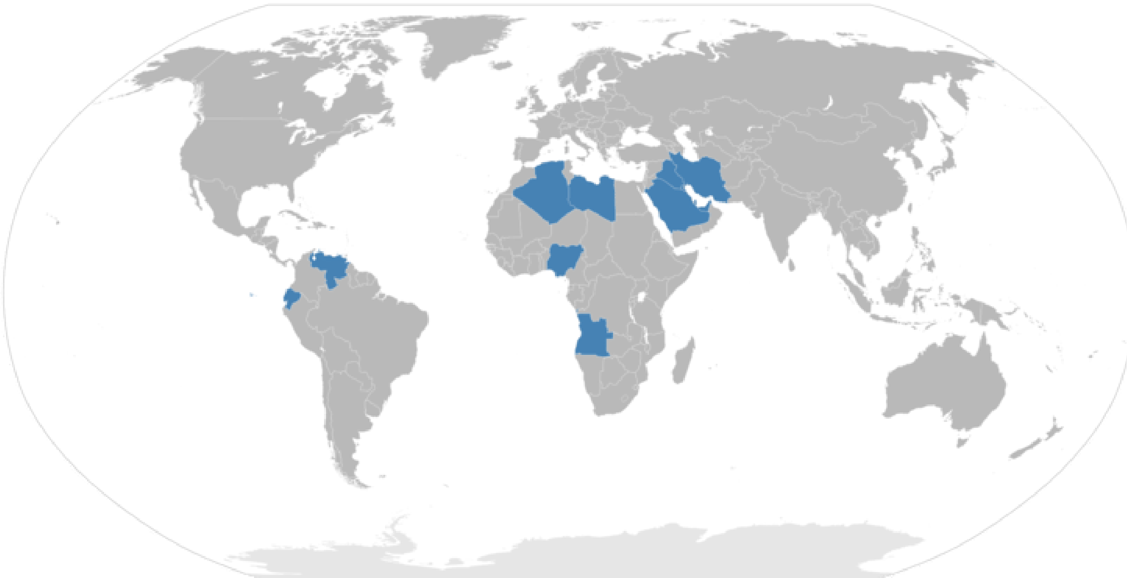
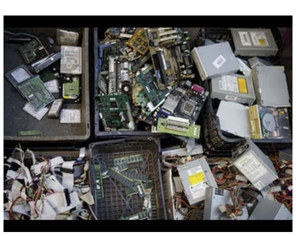


FIGURE 6.2
The nations in blue are the 12 biggest producers of oil; they are Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.

FIGURE 6.3
Pollution from discarded materials degrades the environment and reduces the availability of natural resources.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/180339

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.

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?

Explore More

Use the resource below to answer the questions that follow.

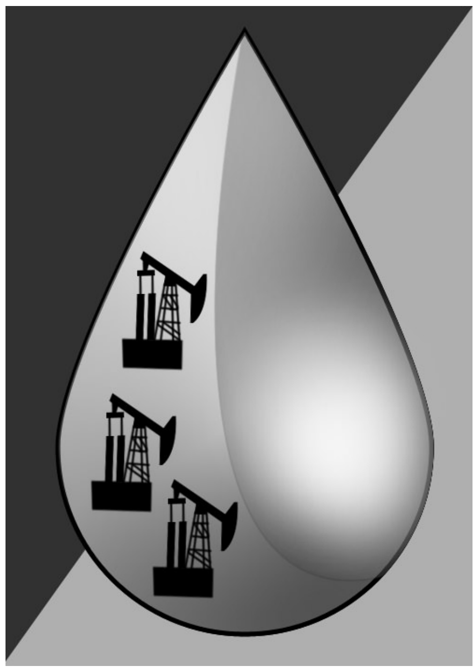
MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/1564

1. What is **e-waste**?
2. Why are they melting computer circuit boards?
3. Why are the workers doing this work?
4. What metals are they extracting from these computers?
5. What do CRTs contain?
6. What do computer batteries contain?
7. How can these chemicals harm people? Which people are most at risk and why?
8. Why do computers from North America and Europe end up in India for recycling? #Which factors go into this difference in costs?
9. How often do you replace you computer or cell phone?

6.2 Renewable and Nonrenewable Resources

Learning Objectives

- Define natural resource.
- Give examples of natural resources.
- Distinguish between renewable and nonrenewable resources.



Renewable or nonrenewable, what's the difference?

That's like asking the difference between having an endless supply and having a limited supply. Will this planet eventually run out of oil? Probably. So oil is a nonrenewable resource.

Renewable and Nonrenewable Resources

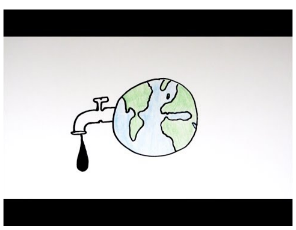
A **natural resource** is something supplied by nature that helps support life. When you think of natural resources, you may think of minerals and fossil fuels. However, ecosystems and the services they provide are also natural resources. **Biodiversity** is a natural resource as well.

Renewable Resources

Renewable resources can be replenished by natural processes as quickly as humans use them. Examples include sunlight and wind. They are in no danger of being used up (see **Figure** 6.4). Metals and other minerals are renewable too. They are not destroyed when they are used and can be recycled.

FIGURE 6.4
Wind is a renewable resource. Wind turbines like this one harness just a tiny fraction of wind energy.

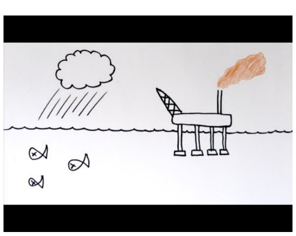
Living things are considered to be renewable. This is because they can reproduce to replace themselves. However, they can be over-used or misused to the point of extinction. To be truly renewable, they must be used sustainably. **Sustainable use** is the use of resources in a way that meets the needs of the present and also preserves the resources for future generations.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/177625

Nonrenewable Resources

Nonrenewable resources are natural resources that exist in fixed amounts and can be used up. Examples include fossil fuels such as petroleum, coal, and natural gas. These fuels formed from the remains of plants over hundreds of millions of years. We are using them up far faster than they could ever be replaced. At current rates of use, petroleum will be used up in just a few decades and coal in less than 300 years. Nuclear power is also considered to be a nonrenewable resource because it uses up uranium, which will sooner or later run out. It also produces harmful wastes that are difficult to dispose of safely.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/187150

FIGURE 6.5
Gasoline is made from crude oil. The crude oil pumped out of the ground is a black liquid called petroleum, which is a nonrenewable resource.

FIGURE 6.6
Coal is another nonrenewable resource.

Turning Trash Into Treasure

Scientists at the Massachusetts of Technology are turning trash into coal, which can readily be used to heat homes and cook food in developing countries. This coal burns cleaner than that from fossil fuels. It also save a tremendous amount of energy.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/176739

Summary

- Renewable resources can be replaced by natural processes as quickly as humans use them. Examples include sunlight and wind.
- Nonrenewable resources exist in fixed amounts. They can be used up. Examples include fossil fuels such as coal.

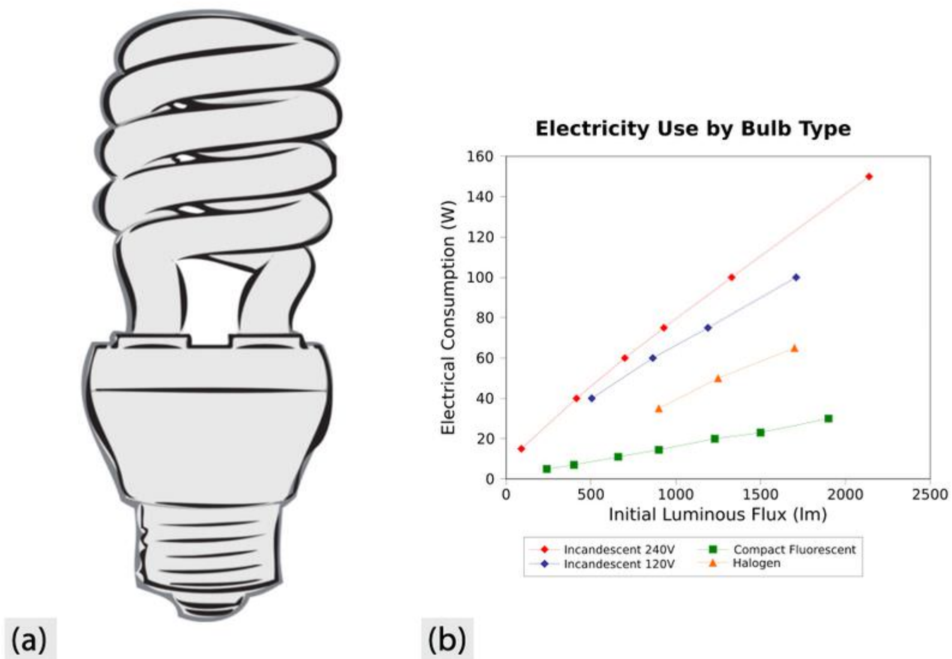
Review

1. Define natural resource. Give an example.
2. Distinguish between renewable and nonrenewable resources and give examples.
3. Infer factors that determine whether a natural resource is renewable or nonrenewable.

6.3 Obtaining Energy Resources

Learning Objectives

- 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** 6.7). If the energy cost of obtaining energy increases, the resource will be used even faster.

FIGURE 6.7
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.

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 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 6.1 shows the net-energy ratios for some common energy sources.

TABLE 6.1: 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** 6.8).

FIGURE 6.8
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

- Less energy is being wasted.
- Non-renewable resources will last longer.
- 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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/114939

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)?

6.4 Finding and Mining Ores

Learning Objectives

- 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** 6.9) 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.

FIGURE 6.9
Aluminum is made from the aluminum-bearing minerals in bauxite.

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.

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** 6.10, 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.

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.

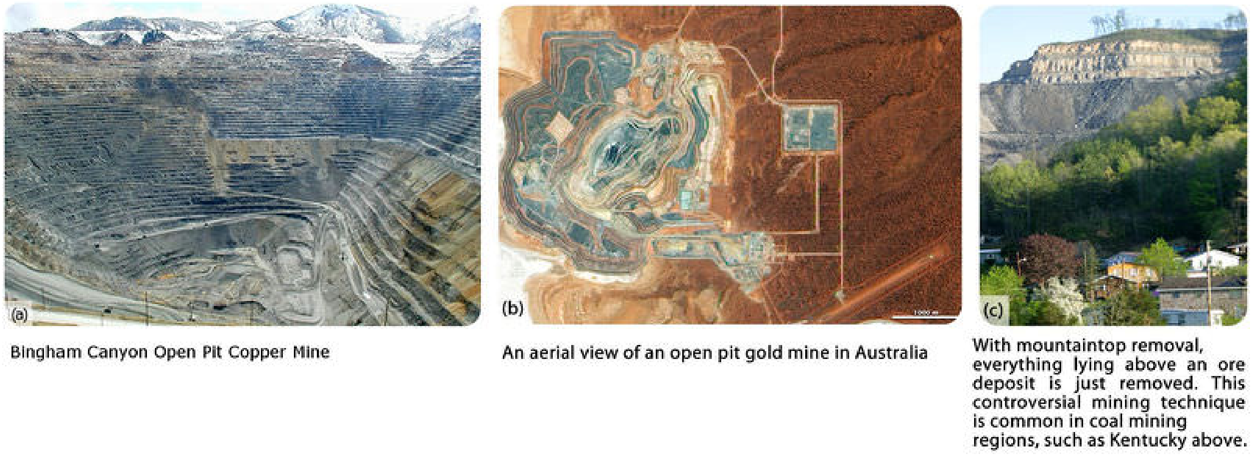


FIGURE 6.10
These different forms of surface mining are methods of extracting ores close to Earth's surface.

FIGURE 6.11
Underground mine.

Ore Extraction

The ore's journey to becoming a useable material is only just beginning when the ore leaves the mine (**Figure** 6.12). 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.

FIGURE 6.12
Enormous trucks haul rock containing ore from a mine site to where the rock is processed.

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 6.13
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.

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?
4. Why should you recycle your aluminum cans?

6.5 Energy Conservation

Learning Objectives

- 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** 6.14) shows how energy is used in the United States.

Table 6.2 shows some ways that people can decrease energy use and use energy more efficiently in transportation, residences, industries, and office settings.

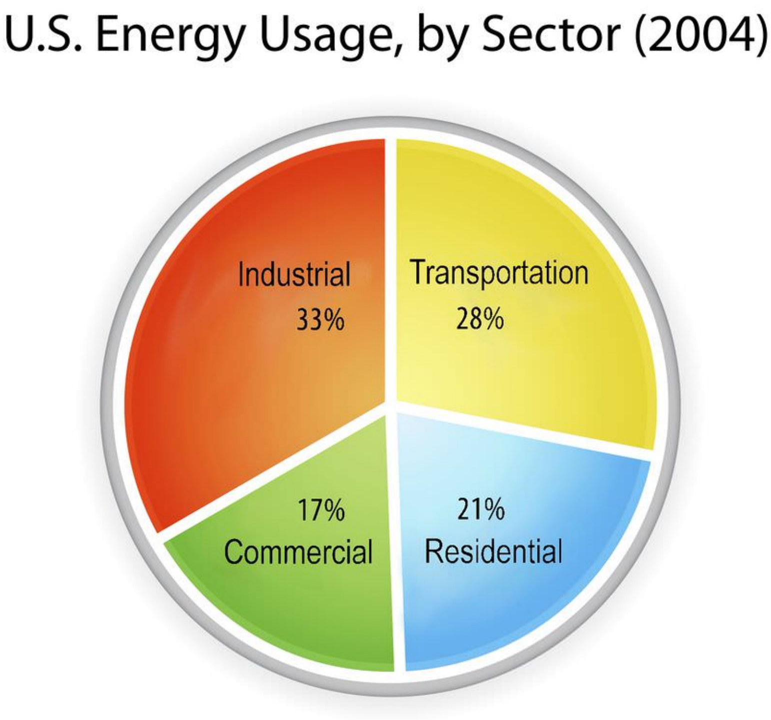


FIGURE 6.14
Almost one-half of the energy used in the United States is for transportation and home use. This means individual choices can make a big impact on energy conservation.

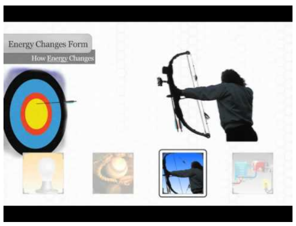
TABLE 6.2: Ways to Use Energy More Efficiently

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.

TABLE 6.2: (continued)

Where Energy is Used	How We Can Use Less Energy	How We Can Use Energy More Efficiently
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.

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.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186730

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.

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.

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/1556

1. What will the population be in 2030?
2. How much will our energy demands increase by 2030? How much will that elevate global carbon dioxide emissions if this demand is met by fossil fuels?
3. What is the single most important source of future energy?
4. What is energy efficiency?
5. How can industries optimize their energy efficiency?
6. What can be done to make vehicles more efficient?
7. How can we make our homes more energy efficient?
8. How effective can using energy efficiently be?

6.6 Uses of Water

Learning Objectives

- 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** 6.15). 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?

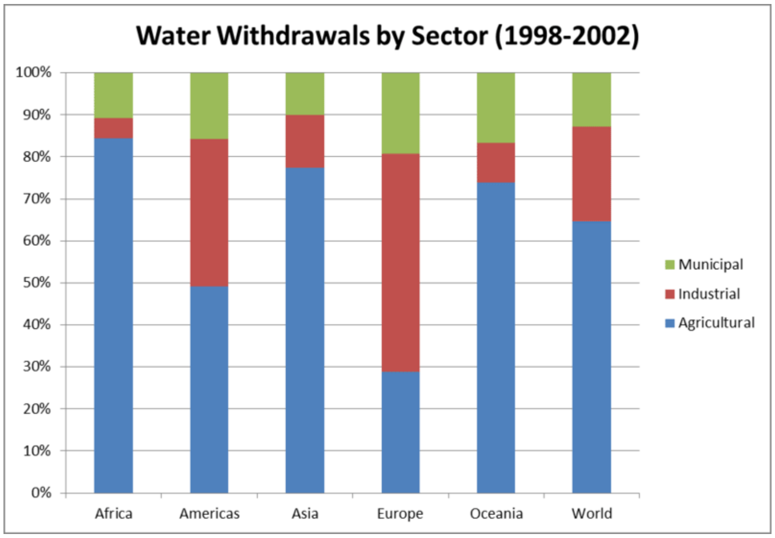


FIGURE 6.15
Water used for home, industrial, and agricultural purposes in different regions. Globally more than two-thirds of water is for agriculture.

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 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** 6.16). 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.

FIGURE 6.16
Drip irrigation delivers water to the base of each plant so little is lost to evaporation and runoff.

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?

Aquaculture

Aquaculture is a different type of agriculture. Aquaculture is farming to raise fish, shellfish, algae, or aquatic plants (**Figure** 6.17). 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.

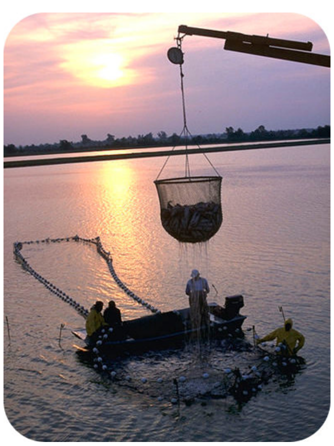


FIGURE 6.17
Workers at a fish farm harvest fish they will sell to stores.

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** 6.18). 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 6.18
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

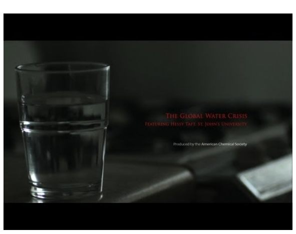
People love water for swimming, fishing, boating, river rafting, and other activates. Even activities such as golf, where there may not be any standing water, require plenty of water to make the grass on the course green. Despite its value, the amount of water that most recreational activities use is 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.

Environmental Use

Environmental use of water includes creating wildlife habitat. Lakes are built to create places for fish and water birds (**Figure** 6.19). 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 6.19
Wetlands and other environments depend on clean water to survive.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186869

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.

Review

1. Why do people in developed countries 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?

Explore More

Use these resources to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178380

1. Since so little water is drinkable, what could be done to make undrinkable water drinkable?
2. How much of the world's population doesn't have safe water?
3. Do people around the world die from water-related diseases?
4. How much water does the average person in North America use per day?
5. How much water does the average person in Europe use per day? What percentage of North America's use is that roughly?
6. How much water does the average person in Mozambique and other developing countries use per day? About what percentage of North America's water use is that roughly?
7. What happens to water availability as population grows?

6.7 Avoiding Soil Loss

Learning Objectives

- 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.

FIGURE 6.20
A farmer and his sons walk through a dust storm in Cimarron County, Oklahoma in 1936.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186856

Soil Conservation

Soil is only a renewable resource if it is carefully managed. There are many practices that can protect and preserve soil resources.

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** 6.21). 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.

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.

FIGURE 6.21
Organic material can be added to soil to help increase its fertility.

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** 6.22). No-till or low-tillage farming helps to keep soil in place by disturbing the ground as little as possible when planting.

FIGURE 6.22
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 6.3 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 6.3: Erosion

Source of Erosion	Strategies for Prevention

TABLE 6.3: (continued)

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.
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.

TABLE 6.3: (continued)

Source of Erosion	Strategies for Prevention
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.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186858

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.

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?

Explore More

Use this resource (watch up to 7:25) to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178374

1. What is soil erosion?
2. What increases soil erosion?
3. What are the negative effects of soil erosion?
4. What caused the Dust Bowl?
5. Is soil a renewable or nonrenewable resource on US cropland? Is that changing?
6. What did the 1985 Food Security Act do to protect sol?
7. What is conservation tillage?
8. What can be done on steep slopes to reduce erosion and why?
9. What is contour farming?
10. What is strip cropping?
11. What is alley-cropping or agroforestry?
12. How should water be added?
13. What is desertification?
14. How can desertification be slowed?

6.8 References

1. Image copyright Anthony Jay D. Villalon, 2014. Desalination plant in Tampa Bay, Florida . Used under license from Shutterstock.com
2. User:Bourgeois/Wikimedia Commons. Map of the 12 biggest producers of oil . Public Domain
3. Courtesy of the US Environmental Protection Agency. Garbage and trash alongside a road . Public Domain
4. Patrick Finnegan. Wind turbines use a renewable resource . CC BY 2.0
5. Flickr:Images_of_Money. Fueling a car using gas . CC BY 2.0
6. Richard Lewis. Lumps of coal . CC BY 2.0
7. Chad Teer. Picture of an offshore drilling oil platform . CC BY 2.0
8. Image copyright Brad Sauter, 2014. Picture of a train hauling coal . Used under license from Shutterstock.com
9. Courtesy of US Geological Survey/Mineral Information Institute. Aluminum is made from the aluminum-bearing minerals in bauxite . Public Domain
10. (a) Flickr:Loco Steve; (b) Courtesy of Jesse Allen/NASA's Earth Observatory; (c) Matt Wasson; Composite created by CK-12 Foundation. Open pit mines, and mountaintop removal . (a) CC BY 2.0; (b) Public Domain; (c) CC BY 2.0
11. Flickr:mjtmail (tiggy). An underground mine . CC BY 2.0
12. Peter Craven. Enormous trucks haul rock containing ore from a mine site to where the rock is processed . CC BY 2.0
13. Třinecké železárny. Picture of a steel mill . The copyright holder of this file allows anyone to use it for any purpose provided that the copyright holder is properly attributed
14. Hana Zavadska. Graph of energy use in the United States . CC BY-NC 3.0
15. Joy Sheng, based on data from the Food and Agriculture Organization of the United Nations, 2012. Water use in different regions of the world . CC BY-NC 3.0
16. Courtesy of the Agricultural Research Service/US Department of Agriculture. Picture of drip irrigation . Public Domain
17. Courtesy of Ken Hammond, US Department of Agriculture. Workers at a fish farm harvesting fish . Public Domain
18. Courtesy of Jesse Allen, NASA's Earth Observatory. Satellite image of shrimp farms, which have replaced mangrove forests, salt flats, and salt marshes . Public Domain
19. Courtesy of the US Army Corps of Engineers. Wetlands and other environments depend on clean water to survive . Public Domain
20. Courtesy of Arthur Rothstein/Farm Security Administration. A farmer in a dust storm during the Dust Bowl . Public Domain
21. Joi Ito. Organic material can be added to soil to help increase its fertility . CC BY 2.0
22. User:Bcasterline/Wikipedia. Steep slopes can be terraced to make level planting areas and decrease surface water runoff and erosion . Public Domain

CHAPTER 7 ESS3-3

Chapter Outline

7.1 Water Distribution

Learning Objectives

- Describe how water is distributed across the globe.
- Explain the causes and consequences of water scarcity.

Will water cause the next war?

Wars have been fought over oil, but many people predict that the next war will be fought over water. Certainly, water is becoming scarcer.

Water Distribution

Water is unevenly distributed around the world. Large portions of the world, such as much of northern Africa, receive very little water relative to their population (**Figure** 7.1). The map shows the number of months in which there is little rainfall in each region. In developed nations, water is stored, but in underdeveloped nations, water storage may be minimal.

Over time, as population grows, rainfall totals will change, resulting in less water per person in some regions. In 2025, many nations, even developed nations, are projected to have less water per person than now

Water Shortages

Water scarcity is a problem now and will become an even larger problem in the future as water sources are reduced or polluted and population grows. In 1995, about 40% of the world's population faced water scarcity. Scientists

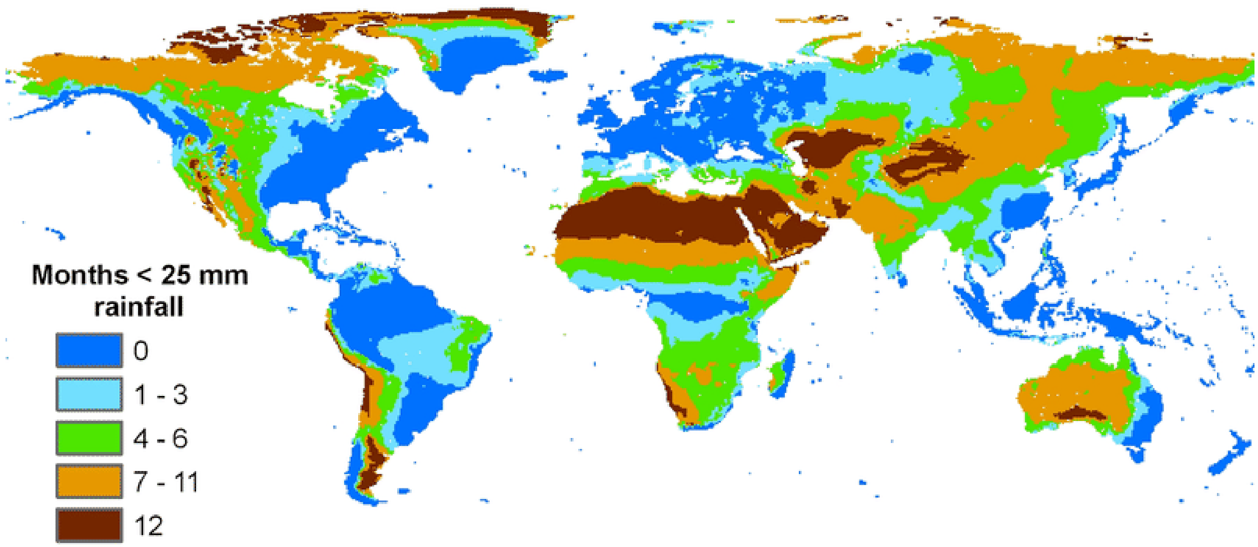


FIGURE 7.1
Some regions have very little rainfall per month.

estimate that by the year 2025, nearly half of the world's people won't have enough water to meet their daily needs. Nearly one-quarter of the world's people will have less than 500 m^3 of water to use in an entire year. That amount is less water in a year than some people in the United States use in one day.

Droughts

Droughts occur when a region experiences unusually low precipitation for months or years (**Figure** 7.2). Periods of drought may create or worsen water shortages.

Human activities can contribute to the frequency and duration of droughts. For example, deforestation keeps trees from returning water to the atmosphere by transpiration; part of the water cycle becomes broken. Because it is difficult to predict when droughts will happen, it is difficult for countries to predict how serious water shortages will be each year.

Effect of Changing Climate

Global warming will change patterns of rainfall and water distribution. As the Earth warms, regions that currently receive an adequate supply of rain may shift. Regions that rely on snowmelt may find that there is less snow and the melt comes earlier and faster in the spring, causing the water to run off and not be available through the dry summers. A change in temperature and precipitation would completely change the types of plants and animals that can live successfully in that region.

FIGURE 7.2
Extended periods with lower than normal rainfall cause droughts.

Water Scarcity

Water scarcity can have dire consequences for the people, the economy, and the environment. Without adequate water, crops and livestock dwindle and people go hungry. Industry, construction, and economic development is halted, causing a nation to sink further into poverty. The risk of regional conflicts over scarce water resources rises. People die from diseases, thirst, or even in war over scarce resources.

California's population is growing by hundreds of thousands of people a year, but much of the state receives as much annual rainfall as Morocco. With fish populations crashing, global warming, and the demands of the country's largest agricultural industry, the pressures on our water supply are increasing.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178381

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186871

Conflicts Over Water

As water supplies become scarce, conflicts will arise between the individuals or nations that have enough clean water and those that do not (**Figure** 7.3). Some of today's greatest tensions are happening in places where water is scarce.

Water disputes may add to tensions between countries where differing national interests and withdrawal rights have been in conflict. Just as with energy resources today, wars may erupt over water.

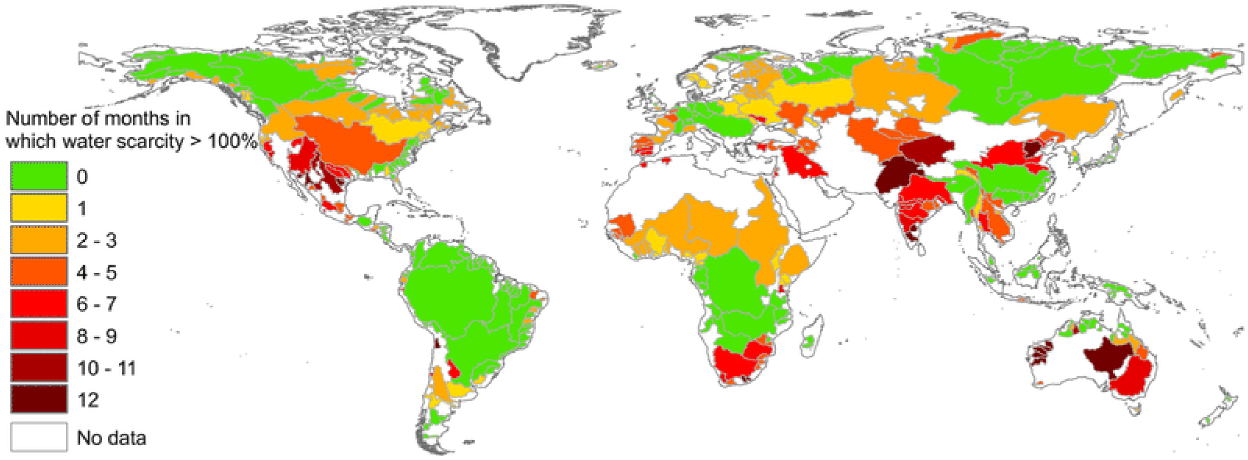


FIGURE 7.3
Many regions already experience water scarcity. This map shows the number of months in which the amount of water that is used exceeds the availability of water that can be used sustainably. This is projected to get worse as demand increases.

Water disputes are happening along 260 different river systems that cross national boundaries. Some of these disputes are potentially very serious. International water laws, such as the Helsinki Rules, help interpret water rights among countries.

Science Friday: Forecasting the Meltdown: The Aerial Snow Observatory

75% of Southern California's water supply comes from the snowpack in the Sierra Nevada Mountain Range. This video by Science Friday explains how NASA uses the Airborne Snow Observatory that uses specialized instrumentation to carefully measure the water content.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/194571

Summary

- A lot of the problem with water is that it is not evenly distributed across the planet.
- Many of the world's people live with water scarcity, and that percentage will increase as populations increase and climate changes.
- Some people predict that, just as wars are fought over energy now, future wars will be fought over water.

Review

1. How will changing climate affect the availability and distribution of water?
2. How do human activities affect the occurrence of droughts?
3. How do so many people live with so little water?

Explore More

Use these resources to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

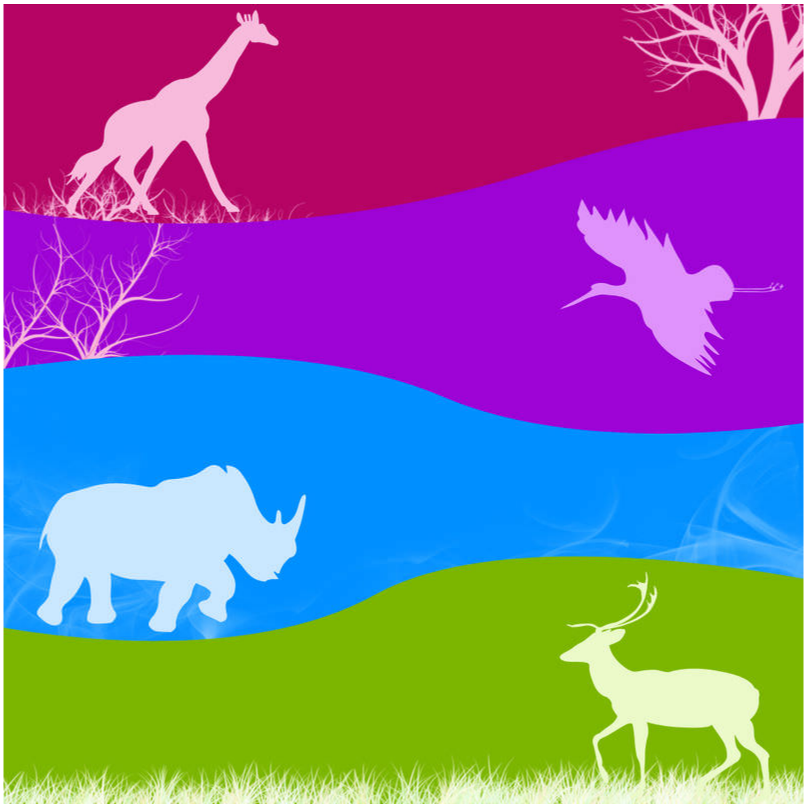
URL: http://www.ck12.org/flx/render/embeddedobject/178383

1. What does the water footprint of a product refer to?
2. What is the water footprint of developed nations, like the United States and southern Europe, per capita compared with developing nations? How about compared with the global average?
3. What is the water footprint of the United Kingdom and other northern European countries compared with the global average? How about with the developing nations?
4. What is used as the water footprint cap? Is that sustainable?
5. Besides living within the water footprint cap, what should governments do?
6. How can the issue of water equity be addressed?

7.2 Importance of Biodiversity

Learning Objectives

- Identify economic benefits of biodiversity.
- Discuss ecosystem services of biodiversity.



Why is biodiversity important?

Think about how many species exist. Most likely well over 5 million. Now think about how much information about those species we do not yet understand. We do not know what we can learn from them.

Why Is Biodiversity Important?

Human beings benefit in many ways from **biodiversity**. Biodiversity has direct economic benefits. It also provides services to entire ecosystems.

Economic Benefits of Biodiversity

The diversity of species provides humans with a wide range of economic benefits:

- Wild plants and animals maintain a valuable pool of **genetic variation**. This is important because domestic species are genetically uniform. This puts them at great risk of dying out due to disease.
- Other organisms provide humans with many different products. Timber, fibers, adhesives, dyes, and rubber are just a few.
- Certain species may warn us of toxins in the environment. When the peregrine falcon nearly went extinct, for example, it warned us of the dangers of DDT.
- More than half of the most important prescription drugs come from wild species. Only a fraction of species have yet been studied for their medical potential.
- Other living things provide inspiration for engineering and technology. For example, the car design in **Figure** 7.4 was based on a fish.

FIGURE 7.4

From flowers to fish, biodiversity benefits humans in many ways.

Ecosystem Services of Biodiversity

Biodiversity generally increases the productivity and stability of **ecosystems**. It helps ensure that at least some species will survive environmental change. It also provides many other ecosystem services. For example:

- Plants and algae maintain the atmosphere. During photosynthesis, they add oxygen and remove carbon dioxide.
- Plants help prevent soil erosion. They also improve soil quality when they decompose.
- Microorganisms purify water in rivers and lakes. They also return nutrients to the soil.
- Bacteria fix nitrogen and make it available to plants. Other bacteria recycle the nitrogen from organic wastes and remains of dead organisms.
- Insects and birds pollinate flowering plants, including crop plants.
- Natural predators control insect pests. They reduce the need for expensive pesticides, which may harm people and other living things.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/181092

Summary

- Biodiversity has direct economic benefits. It also provides services to entire ecosystems.

Review

1. List three economic benefits of biodiversity.
2. Identify three ecosystem services of biodiversity.
3. Predict what would happen to other organisms in an ecosystem in which all the decomposers went extinct?

7.3 Human Actions and the Sixth Mass Extinction

Learning Objectives

- Describe the sixth mass extinction.
- Relate human actions to the sixth mass extinction.
- Define habitat loss and exotic species.
- Give examples of the effects of extinction.
- Describe how biodiversity can be protected.

This is one of the most powerful birds in the world. Could it go extinct?

The Philippine Eagle, also known as the Monkey-eating Eagle, is among the rarest, largest, and most powerful birds in the world. It is critically endangered, mainly due to massive loss of habitat due to deforestation in most of its range. Killing a Philippine Eagle is punishable under Philippine law by twelve years in jail and heavy fines.

Human Actions and the Sixth Mass Extinction

Over 99 percent of all species that ever lived on Earth have gone extinct. Five mass extinctions are recorded in the fossil record. They were caused by major geologic and climatic events. Evidence shows that a **sixth mass extinction** is occurring now. Unlike previous mass extinctions, the sixth extinction is due to human actions.

Some scientists consider the sixth extinction to have begun with early hominids during the Pleistocene. They are blamed for over-killing big mammals such as mammoths. Since then, human actions have had an ever greater impact on other species. The present rate of extinction is between 100 and 100,000 species per year. In 100 years, we could lose more than half of Earth's remaining species.

Causes of Extinction

The single biggest cause of extinction today is **habitat loss**. Agriculture, forestry, mining, and urbanization have disturbed or destroyed more than half of Earth's land area. In the U.S., for example, more than 99 percent of tall-grass prairies have been lost. Other causes of extinction today include:

- **Exotic species** introduced by humans into new habitats. They may carry disease, prey on native species, and disrupt food webs. Often, they can out-compete native species because they lack local predators. An example is described in **Figure** 13.1.
- Over-harvesting of fish, trees, and other organisms. This threatens their survival and the survival of species that depend on them.
- Global climate change, largely due to the burning of fossil fuels. This is raising Earth's air and ocean temperatures. It is also raising sea levels. These changes threaten many species.
- Pollution, which adds chemicals, heat, and noise to the environment beyond its capacity to absorb them. This causes widespread harm to organisms.
- Human overpopulation, which is crowding out other species. It also makes all the other causes of extinction worse.

FIGURE 7.5
The brown tree snake is an exotic species that has caused many extinctions on Pacific islands such as Guam.

Effects of Extinction

The results of a study released in the summer of 2011 have shown that the decline in the numbers of large predators like sharks, lions and wolves is disrupting Earth's ecosystem in all kinds of unusual ways. The study, conducted by scientists from 22 different institutions in six countries, confirmed the sixth mass extinction. The study states that this mass extinction differs from previous ones because it is entirely driven by human activity through changes in land use, climate, pollution, hunting, fishing and poaching. The effects of the loss of these large predators can be seen in the oceans and on land.

- Fewer cougars in the western US state of Utah led to an explosion of the deer population. The deer ate more vegetation, which altered the path of local streams and lowered overall biodiversity.
- In Africa, where lions and leopards are being lost to poachers, there is a surge in the number of olive baboons, who are transferring intestinal parasites to humans living nearby.
- In the oceans, industrial whaling led a change in the diets of killer whales, who eat more sea lions, seals, and otters and have dramatically lowered the population counts of those species.

The study concludes that the loss of big predators has likely driven many of the pandemics, population collapses and ecosystem shifts the Earth has seen in recent centuries.

Disappearing Frogs

Around the world, frogs are declining at an alarming rate due to threats like pollution, disease, and climate change. Frogs bridge the gap between water and land habitats, making them the first indicators of ecosystem changes.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/443

Nonnative Species

Scoop a handful of critters out of the San Francisco Bay and you'll find many organisms from far away shores. Invasive kinds of mussels, fish, and more are choking out native species, challenging experts around the state to change the human behavior that brings them here.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/444

How You Can Help Protect Biodiversity

There are many steps you can take to help protect biodiversity. For example:

- Consume wisely. Reduce your consumption wherever possible. Re-use or recycle rather than throw out and buy new. When you do buy new, choose products that are energy efficient and durable.
- Avoid plastics. Plastics are made from petroleum and produce toxic waste.
- Go organic. Organically grown food is better for your health. It also protects the environment from pesticides and excessive nutrients in fertilizers.
- Save energy. Unplug electronic equipment and turn off lights when not in use. Take mass transit instead of driving.

Lost Salmon

Why is the salmon population of Northern California so important? Salmon do not only provide food for humans, but also supply necessary nutrients for their ecosystems. Because of a sharp decline in their numbers, in part due to human interference, the entire salmon fishing season off California and Oregon was canceled in both 2008 and 2009. The species in the most danger of extinction is the California coho salmon.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/445

Summary

- Evidence shows that a sixth mass extinction is occurring. The single biggest cause is habitat loss caused by human actions.
- There are many steps you can take to help protect biodiversity. For example, you can use less energy.

Review

1. How is human overpopulation related to the sixth mass extinction?
2. Why might the brown tree snake or the Philippine Eagle serve as "poster species" for causes of the sixth mass extinction?
3. Describe a hypothetical example showing how rising sea levels due to global warming might cause extinction.
4. Create a poster that conveys simple tips for protecting biodiversity.

Resources

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/164843

7.4 Agriculture and Human Population Growth

Learning Objectives

- 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** 7.6). 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.

FIGURE 7.6
In a hunter-gatherer society, people relied on the resources they could find where they lived.

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?

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** 7.7). 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.

When advanced farming practices allowed farmers to grow more food than they needed for their families (**Figure** 7.8), some people were then able to do other types of work, such as crafts or shop keeping.

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** 7.9). This major historical event marks when products were first mass-produced and when fossil fuels were first widely used for power.

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.

FIGURE 7.7
More advanced farming practices allowed a single farmer to grow food for many more people.

FIGURE 7.8
Farming has increasingly depended on machines. Such advanced farming practices allow one farmer to feed many more people than in the past.

- 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** 7.10).
- 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.

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.

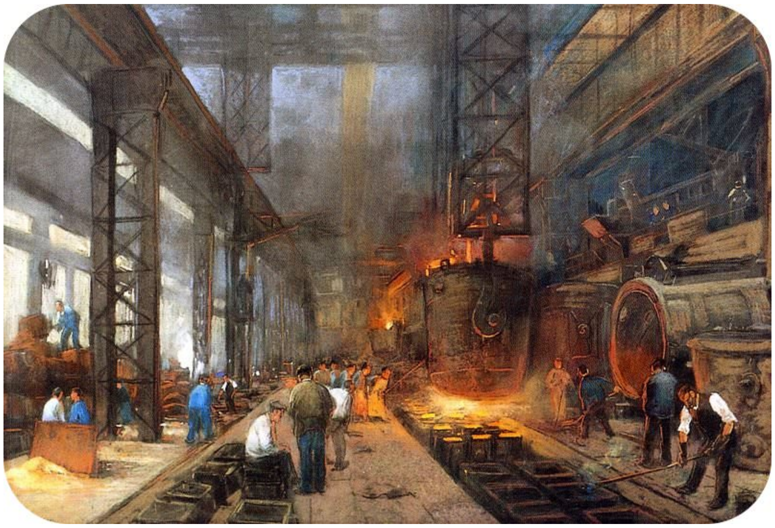


FIGURE 7.9
Early in the Industrial Revolution, large numbers of people who had been freed from food production were available to work in factories.

FIGURE 7.10
Rows of a single crop and heavy machinery are normal sights for modern day farms.

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** 7.11)? 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?

FIGURE 7.11
Manhattan is one of the most heavily populated regions in the world.

Summary

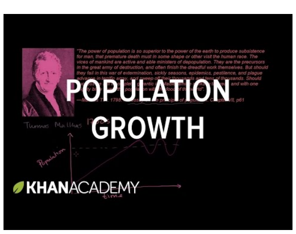
- Hunters and gatherers lived off the land, with no agriculture, and reached a total population of no more than around 10 million.
- Farming allowed people to settle down and allowed populations to grow.
- The Green Revolution and the Industrial Revolution are heavily dependent on fossil fuels.

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?

Explore More

Use this resource to answer the questions that follow.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/1554

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?

7.5 Recent and Future Population Growth

Learning Objectives

- Explain trends in recent human population growth.
- Summarize expectations of future human population growth.
- Discuss issues associated with a large human population.

Should the population of the planet by characterized by individual country, or as one general population?

How many people is too many? Is there a limit? Is there a carrying capacity for humans? These are important questions that do not have an easy answer. But as our population continues to grow, these questions and others should be discussed.

Recent Population Growth

At one time, scientists predicted that all human populations would pass through the same **demographic transition** as Europe and North America. Now, they are not so sure. Death rates have fallen throughout the world. No country today remains in Stage 1 of the transition. However, birth rates are still high in many poor countries. These populations seem to be stuck in Stage 2. An example is the African country of Angola. Its population pyramid for 2005 is shown in **Figure** 7.12. The wide base of the pyramid base reflects the high birth rate of this population.

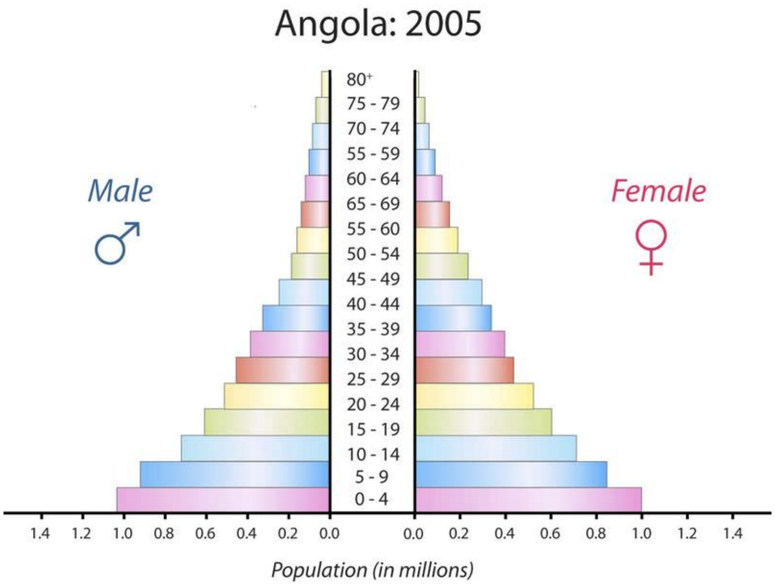


FIGURE 7.12
Angola's population pyramid is typical of Stage 2 of the demographic transition.

Many other countries have shifted to Stage 3 of the transition. Birth rates have started to fall. As a result, population growth is slowing. An example is Mexico. Its population pyramid for 1998 is shown in **Figure** 7.13. It reflects a recent fall in the birth rate.

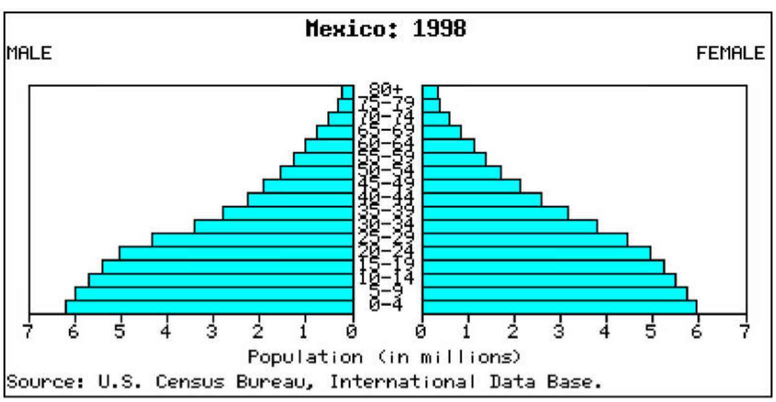


FIGURE 7.13
Mexico's 1998 population pyramid is typical of Stage 3 population. How can you tell that the birth rate has started to fall?

Most developed nations have entered Stage 4. Sweden is an example (see **Figure** 7.14). The birth rate has been low for many years in Sweden. Therefore, the rate of population growth is near zero.

In some countries, birth rates have fallen even lower than death rates. As result, their population growth rates are negative. In other words, the populations are shrinking in size. These populations have top-heavy population pyramids, like the one for Italy shown in **Figure** 7.15. This is a new stage of the demographic transition, referred to as Stage 5. You might think that a negative growth rate would be a good thing. In fact, it may cause problems. For example, growth-dependent industries decline. Supporting the large aging population is also a burden for the shrinking younger population of workers.

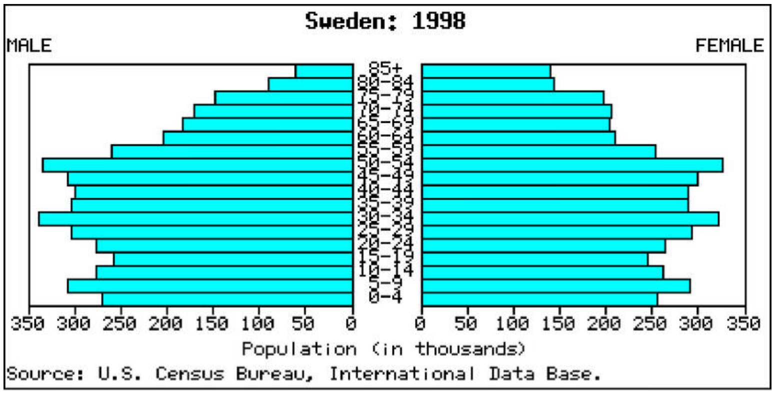


FIGURE 7.14
Sweden's 1998 population pyramid shows a population in Stage 4.

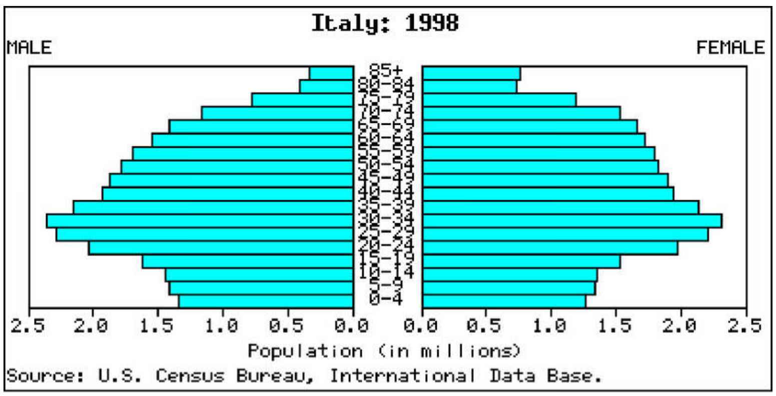


FIGURE 7.15
This 1998 population pyramid for Italy represents a Stage 5 population.

Future Population Growth

During the month of October 2011, the world's population surpassed 7 billion people. It took just 12 years for the population to increase by a billion people. At this rate, there may be well over 9 billion people by 2050, and easily 10 billion people by 2100. This raises many questions for both people and the planet.

The human population is now growing by more than 200,000 people a day. The human population may well be close to its carrying capacity. It has already harmed the environment. An even larger human population may cause severe environmental problems. This could lead to outbreaks of disease, starvation, and global conflict. There are three potential solutions:

1. Use technology to make better use of resources to support more people.
2. Change behaviors to reduce human numbers and how much humans consume.
3. Distribute resources more fairly among all the world's people.

Which solution would you choose?

"If growth continued at this rate...by 2600 we would all be standing literally shoulder to shoulder" - Steven Hawking

Census Update: What the World Will Look like in 2050

On June 30, 2011, Time.com published *Census Update: What the World Will Look Like in 2050* at http://www.time.com/time/nation/article/0,8599,2080404,00.html . According to the U.S. Census Bureau, in 2050, there will be 9.4

billion people:

- India will be the most populous nation, surpassing China sometime around 2025.
- The U.S. will remain the third most populous nation, with a population of 423 million (up from 308 million in 2010).
- Declining birth rates in Japan and Russia will cause them to fall from their current positions as the 9th and 10th most populous nations, respectively, to 16th and 17th.
- Nigeria will have a population of 402 million, up from 166 million people.
- Ethiopia's population will likely triple, from 91 million to 278 million, making the East African nation one of the top 10 most populous countries in the world.

So what does all this mean?

- The African continent is expected to experience significant population growth in the coming decades, which could compound existing food supply problems in some African nations.
- Immigration and differing birth rates among races will change the ethnic composition of the U.S.
- Population booms in Africa and India, the decline of Russia, and the expected plateau of China will all change the makeup of the estimated 9.4 billion people who will call Earth home in 2050.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/163097

Summary

- Other countries have completed similar demographic transitions. However, some countries seem stalled at early stages. They have high birth rates and rapidly growing populations.
- The total human population may have to stop growing eventually. Even if we reduce our use of resources and distribute them more fairly, at some point the carrying capacity will be reached.

Review

1. Why was a fifth stage added to the demographic transition model? Describe a population at this stage.
2. Which stage of the demographic transition is represented by the population pyramid in the **Figure** 7.16? Why?
3. Evaluate how well the original demographic transition model represents human populations today.
4. What is the human population problem? What are some potential solutions? Which solution do you think is best?

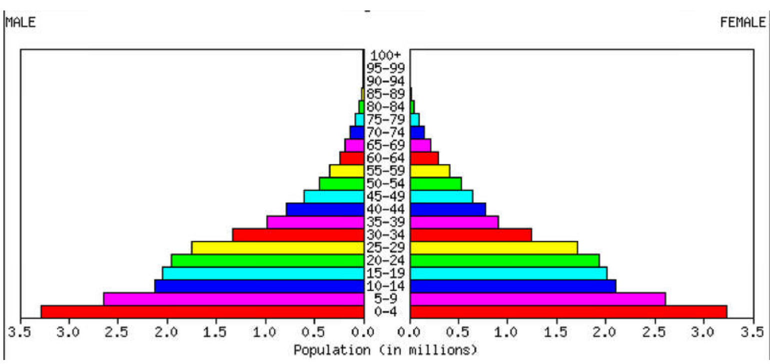

MALE
FEMALE
100+
95-99
90-94
85-89
80-84
75-79
70-74
65-69
60-64
55-59
50-54
45-49
40-44
35-39
30-34
25-29
20-24
15-19
10-14
5-9
0-4
3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Population (in millions)

FIGURE 7.16

7.6 Population Size

Learning Objectives

- 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** 7.17). The size of a population is tied to its limiting factor.

FIGURE 7.17
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** 7.18). 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.

FIGURE 7.18
A frog in frog spawn. An animal produces many more offspring than will survive.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/183969

Summary

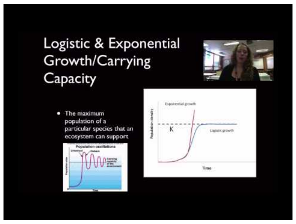
- Biotic factors that a population needs include food availability. Abiotic factors may include space, water, and climate.
- The carrying capacity of an environment is reached when the number of births equal the number of deaths.
- A limiting factor determines the carrying capacity for a species.

Review

1. Why don't populations continue to grow and grow?
2. What happens if a population exceeds its carrying capacity?
3. What happens if a factor that has limited a population's size becomes more available?

Explore More

Use this resource to answer the questions that follow. (Note: that when he says "people," he's really talking about any population of organisms.)



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178259

1. Under what circumstances can population growth be exponential?
2. What is carrying capacity?
3. What does reaching the carrying capacity do to population growth?
4. What does carrying capacity depend on?
5. What happens if a population exceeds its carrying capacity?
6. Is the carrying capacity constant? What changes it?
7. What are the two ways to eliminate a pest from your home?
8. Give the definition of density dependent factors that are limiting to population growth.
9. Give four examples and explain them for density dependent factors.
10. How do natural disasters affect the population size in a region?

7.7 References

1. PR Hunter, AM MacDonald, RC Carter. Map of the world showing average rainfall . CC BY 2.5
2. Tomas Castelazo. Picture of drought cracked land . CC BY 3.0
3. AY Hoekstra, MM Mekonnen, et al.. Map of the world showing areas of water scarcity . CC BY 2.5
4. Flower: User:Ulhaspa/Wikimedia Commons; Fish: J. Petersen; Car: CK-12 Foundation. How biodiversity benefits humans . Flower: CC BY 3.0; Fish: CC BY 2.5; Car: CC BY-NC 3.0
5. National Park Service. A brown tree snake . Public Domain
6. Image copyright Pichugin Dmitry, 2014. Picture of a hunter-gatherer society . Used under license from Shutterstock.com
7. Flickr:AnanthBS. Farming using mules and a plow . CC BY 2.0
8. Courtesy of the US Department of Agriculture. Farming using machines . Public Domain
9. Herman Heyenbrock. Picture of a iron factory during the Industrial Revolution . Public Domain
10. User:NightThree/Wikipedia. Tractors farming a single crop . CC BY 2.0
11. User:(WT-shared) Rangliker/Wts.Wikivoyage. Manhattan, New York is one of the most heavily populated regions in the world . Public Domain
12. Hana Zavadska, based on data from the U.S. Census Bureau. Angola's population pyramid is typical of Stage 2 demographic transition . CC BY-NC 3.0
13. U.S. Census Bureau. Mexico's population pyramid is typical of Stage 3 population . Public Domain
14. U.S. Census Bureau. Sweden's population pyramid is typical of Stage 4 population . Public Domain
15. U.S. Census Bureau. Italy's population pyramid is typical of Stage 5 population . Public Domain
16. U.S. Census Bureau. A population pyramid . Public Domain
17. Miles Orchinik. Water is the limiting factor on plant population in the desert . CC BY-NC 3.0
18. Image copyright Birute Vijeikiene, 2014. A frog in frog spawn . Used under license from Shutterstock.com

CHAPTER 8 LS2-1

Chapter Outline

8.1 Ecosystems

Learning Objectives

- Define ecology and ecosystem.
- Distinguish between abiotic and biotic factors.
- Describe a niche and habitat.
- Explain the competitive exclusion principle.

What lives in the forest?

Take a close look at this ecosystem. Obviously there are deer and many types of plants. But there are organisms that live there that cannot be seen in the picture. Many other animals, such as rabbits, mice, and countless insects. There are also bacteria and fungi. Add in the nonliving aspects of the area, such as the water, and you have an ecosystem.

The Ecosystem

Ecology is the study of how living things interact with each other and with their environment. It is a major branch of biology, but has areas of overlap with geography, geology, climatology, and other sciences. The study of ecology begins with two fundamental concepts in ecology: the ecosystem and their organisms.

Organisms are individual living things. Despite their tremendous diversity, all organisms have the same basic needs: energy and matter. These must be obtained from the environment. Therefore, organisms are not closed systems. They depend on and are influenced by their environment. The environment includes two types of factors: abiotic and biotic.

1. **Abiotic factors** are the nonliving aspects of the environment. They include factors such as sunlight, soil, temperature, and water.

2. **Biotic factors** are the living aspects of the environment. They consist of other organisms, including members of the same and different species.

An **ecosystem** is a unit of nature and the focus of study in ecology. It consists of all the biotic and abiotic factors in an area and their interactions. Ecosystems can vary in size. A lake could be considered an ecosystem. So could a dead log on a forest floor. Both the lake and log contain a variety of species that interact with each other and with abiotic factors. Another example of an ecosystem is pictured in **Figure** 8.1.

FIGURE 8.1
A desert ecosystem. What are some of the biotic and abiotic factors in this desert ecosystem?

When it comes to energy, ecosystems are not closed. They need constant inputs of energy. Most ecosystems get energy from sunlight. A small minority get energy from chemical compounds. Unlike energy, matter is not constantly added to ecosystems. Instead, it is recycled. Water and elements such as carbon and nitrogen are used over and over again.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/94023

Niche

One of the most important concepts associated with the ecosystem is the niche. A **niche** refers to the role of a species in its ecosystem. It includes all the ways that the species interacts with the biotic and abiotic factors of the environment. Two important aspects of a species' niche are the food it eats and how the food is obtained. Look at **Figure** 8.2. It shows pictures of birds that occupy different niches. Each species eats a different type of food and obtains the food in a different way.

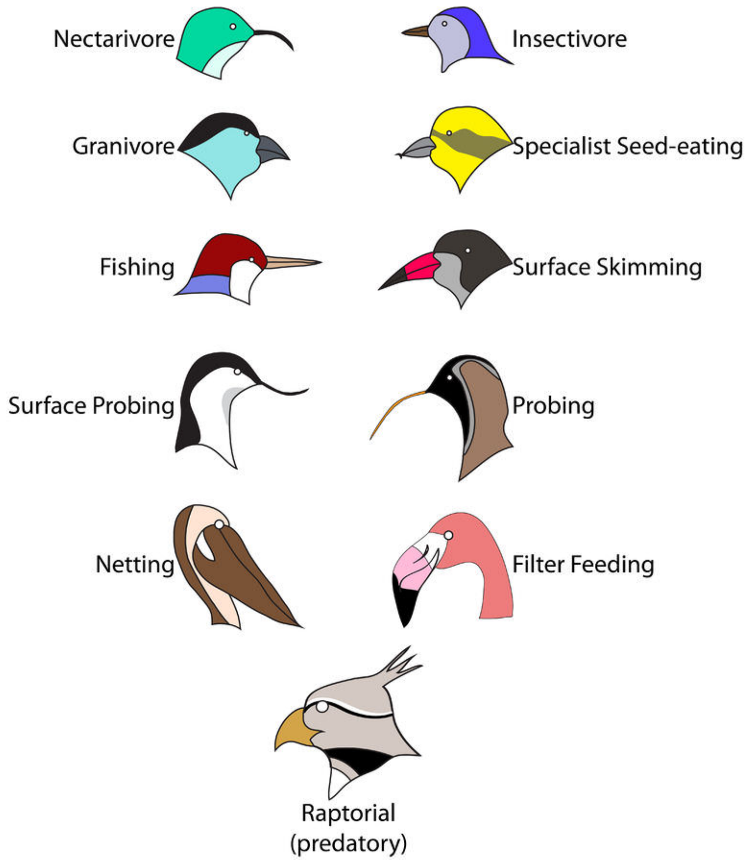


FIGURE 8.2

Bird Niches. Each of these species of birds has a beak that suits it for its niche. For example, the long slender beak of the nectarivore allows it to sip liquid nectar from flowers. The short sturdy beak of the granivore allows it to crush hard, tough grains.

Habitat

Another aspect of a species' niche is its habitat. The **habitat** is the physical environment in which a species lives and to which it is adapted. A habitat's features are determined mainly by abiotic factors such as temperature and rainfall. These factors also influence the traits of the organisms that live there.

Competitive Exclusion Principle

A given habitat may contain many different species, but each species must have a different niche. Two different species cannot occupy the same niche in the same place for very long. This is known as the **competitive exclusion principle**. If two species were to occupy the same niche, what do you think would happen? They would compete with one another for the same food and other resources in the environment. Eventually, one species would be likely to outcompete and replace the other.

Summary

- Ecology is the study of how living things interact with each other and with their environment.
- The environment includes abiotic (nonliving) and biotic (living) factors.
- An ecosystem consists of all the biotic and abiotic factors in an area and their interactions.
- A niche refers to the role of a species in its ecosystem.
- A habitat is the physical environment in which a species lives and to which it is adapted.
- Two different species cannot occupy the same niche in the same place for very long.

Review

1. Define ecology.
2. Define biotic and abiotic factors of the environment. Give an example of each.
3. How do ecologists define the term *ecosystem*? What makes up an ecosystem?
4. State the competitive exclusion principle.
5. Compare and contrast the ecosystem concepts of *niche* and *habitat*.

8.2 Biological Communities

Learning Objectives

- 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** 8.3). Living things include bacteria, algae, fungi, plants, and animals, including invertebrates, animals without backbones, and vertebrates, animals with backbones.

FIGURE 8.3

(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.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186539

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** 8.4). Every species fills a niche, and niches are almost always filled in an ecosystem.

FIGURE 8.4
The top carnivore niche is filled by lions on the savanna.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186541

Habitat

An organism's **habitat** is where it lives (**Figure** 8.5). 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.

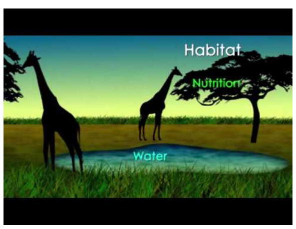
Review

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.

FIGURE 8.5
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.

Explore More

Use this resource to answer the questions that follow.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178244

1. What are the two primary parts of an ecosystem?
2. What are the biotic parts?
3. What are the abiotic parts?
4. How big is an ecosystem?
5. Where does the energy to run an ecosystem come from?
6. How does that energy move through an ecosystem?
7. What is a habitat? What is included in it?
8. What is a niche? What is included in it?

8.3 Biodiversity

Learning Objectives

- Define biodiversity.
- Distinguish between species diversity, genetic diversity, and ecosystem diversity.

What is biodiversity?

How many species exist? We don't really know for sure. But all those species together, from the smallest bacteria, the deadliest protist, the most bizarre fungi, the prettiest plant, and the biggest mammal, compile the diversity of life, or biodiversity.

What Is Biodiversity?

Biodiversity refers to the variety of life and its processes, including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur. Scientists have identified about 1.9 million species alive today. They are divided into the six kingdoms of life shown in **Figure** 8.6. Scientists are still discovering new species. Thus, they do not know for sure how many species really exist today. Most estimates range from 5 to 30 million species.

Cogs and Wheels

"The first rule of intelligent tinkering is to save all the pieces." –attributed to Aldo Leopold, but probably a shortened version of: ***"To save every cog and wheel is the first precaution of intelligent tinkering."*** **- Aldo Leopold,** ***Round River: from the Journals of Aldo Leopold*****, 1953**

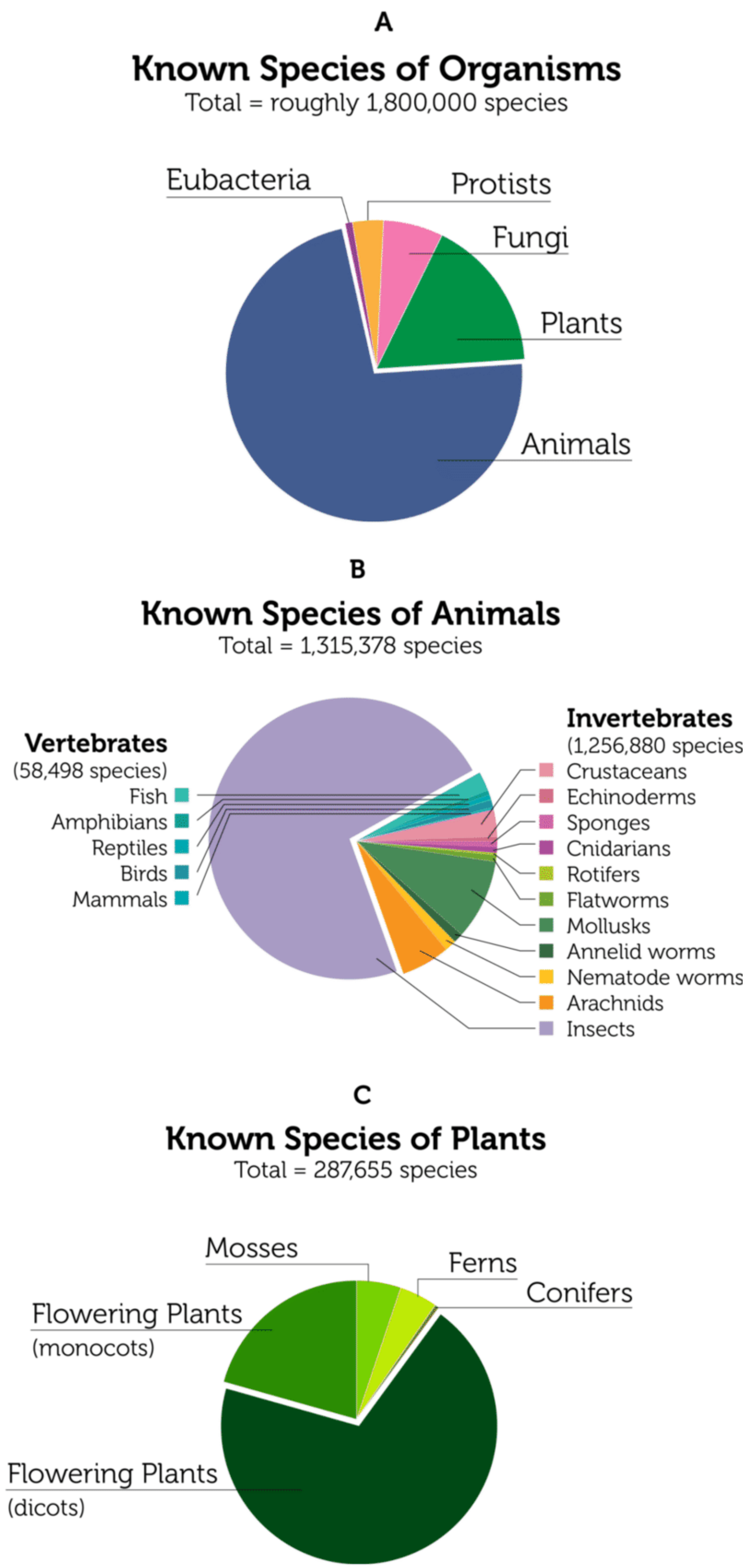


FIGURE 8.6

Known species represent only a fraction of all species that exist on Earth.

What are the "cogs" and "wheels" of life?

Although the concept of biodiversity did not become a vital component of biology and political science until nearly 40 years after Aldo Leopold's death in 1948, Leopold - often considered the father of modern ecology - would have likely found the term an appropriate description of his "cogs and wheels." Literally, biodiversity is the many different kinds (*diversity*) of life (*bio-*). Biologists, however, always alert to levels of organization, have identified three measures of life's variation. **Species diversity** best fits the literal translation: the number of different species in a particular ecosystem or on Earth. A second measure recognizes variation within a species: differences among individuals or populations make up **genetic diversity**. Finally, as Leopold clearly understood, the "cogs and wheels" include not only life but also the land, sea, and air that support life. **Ecosystem diversity** describes the many types of functional units formed by living communities interacting with their environments. Although all three levels of diversity are important, the term biodiversity usually refers to species diversity.

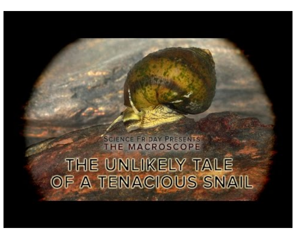
MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/164672

Science Friday: The Unlikely Tale of a Tenacious Snail

For over 70 years, no one had seen the oblong rocksnail. Declared extinct in 2000, the species was considered to be another native Alabaman mollusk gone and forgotten. But one day in the spring of 2011, biology grad student Nathan Whelan picked up a tiny rock and got a big surprise.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/193677

Summary

- Biodiversity refers to the number of species in an ecosystem or the biosphere as a whole.

Review

1. What is biodiversity?
2. What are the three measures of life's variations?
3. What is meant by ecosystem diversity?

8.4 Interdependence of Living Things

Learning Objectives

- Explain the meaning of interdependence.
- Describe how living organisms interact.

What other species do you need to survive?

Species cannot live alone. All life needs other life to survive. Here surgeon fish are feeding on the algae growth on this turtle shell, a classic example of two species needing each other. This is an example of a symbiotic relationship.

Interdependence of Living Things

All living things depend on their environment to supply them with what they need, including food, water, and shelter. Their environment consists of physical factors—such as soil, air, and temperature—and also of other organisms. An **organism** is an individual living thing. Many living things interact with other organisms in their environment. In fact, they may need other organisms in order to survive. This is known as **interdependence**. For example, living things that cannot make their own food must eat other organisms for food. Other interactions between living things include symbiotic relationships and competition for resources.

Symbiosis

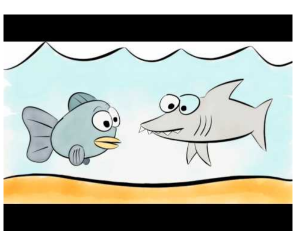
Symbiosis is a close relationship between organisms of different species in which at least one of the organisms benefits. The other organism may also benefit, it may be unaffected by the relationship, or it may be harmed by the relationship. **Figure** 8.7 shows an example of symbiosis. The birds in the picture are able to pick out food from the fur of the deer. The deer won't eat the birds. In fact, the deer knowingly lets the birds rest on it. What, if anything, do you think the deer gets out of the relationship?

FIGURE 8.7
A flock of starlings looks out, before searching for parasites on a red deer stag.

Competition

Competition is a relationship between living things that depend on the same resources. The resources may be food, water, or anything else they both need. Competition occurs whenever the two species try to get the same resources in the same place and at the same time. The two organisms are likely to come into conflict, and the organism better able to obtain that resource will "win" out over the other organism. What makes an organism better able to obtain a resource? They may be any of countless reasons, but each is considered an adaptation that makes an organism more fit to live in their environment.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/183279



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/183280

Summary

- All living things depend on their environment to supply them with what they need, including food, water, and shelter.
- Symbiosis is a close relationship between organisms of different species in which at least one of the organisms benefits.
- Competition is a relationship between living things that depend on the same resources.

Review

1. What is meant by interdependence?
2. Describe an example of a way that you depend on other living things.
3. Compare and contrast symbiosis and competition.
4. Give three examples of resources organisms may compete for.

8.5 Competition

Learning Objectives

- Distinguish between intraspecific and interspecific competition.
- Explain why interspecific competition leads to extinction or greater specialization.

Does there have to be a winner?

When animals compete? Yes. Animals, or other organisms, will compete when both want the same thing. One must "lose" so the winner can have the resource. But competition doesn't necessarily involve physical altercations.

Competition

Competition is a relationship between organisms that strive for the same resources in the same place. The resources might be food, water, or space. There are two different types of competition:

1. **Intraspecific competition** occurs between members of the same species. For example, two male birds of the same species might compete for mates in the same area. This type of competition is a basic factor in natural selection. It leads to the evolution of better adaptations within a species.
2. **Interspecific competition** occurs between members of different species. For example, predators of different species might compete for the same prey.

Interspecific Competition and Extinction

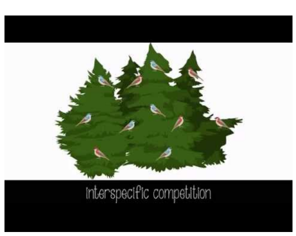
Interspecific competition often leads to **extinction**. The species that is less well adapted may get fewer of the resources that both species need. As a result, members of that species are less likely to survive, and the species may go extinct.

Interspecific Competition and Specialization

Instead of extinction, interspecific competition may lead to greater specialization. **Specialization** occurs when competing species evolve different adaptations. For example, they may evolve adaptations that allow them to use different food sources. **Figure** 8.8 describes an example.

FIGURE 8.8
Specialization lets different species of anole lizards live in the same area without competing.

Watch the beginning of the following video to learn more about competition.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/187108

Summary

- Competition is a relationship between organisms that strive for the same resources in the same place.
- Intraspecific competition occurs between members of the same species. It improves the species' adaptations.
- Interspecific competition occurs between members of different species. It may lead to one species going extinct or both becoming more specialized.

Review

1. What is competition?
2. Describe the evolutionary effects of intraspecific and interspecific competition.

8.6 Predation

Learning Objectives

- Describe predation and its effects on population size and evolution.
- Define a keystone species.
- Describe the use of camouflage as an adaptation.

What may be the most common way different species interact?

Biomes as different as deserts and wetlands share something very important. All biomes have populations of interacting species. Species interact in the same basic ways in all biomes. For example, all biomes have some species that prey on others for food.

Predation

Predation is a relationship in which members of one species (the **predator**) consume members of another species (the **prey**). The lionesses and zebra in **Figure** 8.9 are classic examples of predators and prey. In addition to the lionesses, there is another predator in this figure. Can you spot it? The other predator is the zebra. Like the lionesses, it consumes prey species, in this case species of grass. However, unlike the lionesses, the zebra does not kill its prey. Predator-prey relationships such as these account for most energy transfers in food chains and food webs.

FIGURE 8.9
Predators and Their Prey. These lionesses feed on the carcass of a zebra.

Predation and Population

A predator-prey relationship tends to keep the populations of both species in balance. This is shown by the graph in **Figure** 8.10. As the prey population increases, there is more food for predators. So, after a slight lag, the predator population increases as well. As the number of predators increases, more prey are captured. As a result, the prey population starts to decrease. What happens to the predator population then?

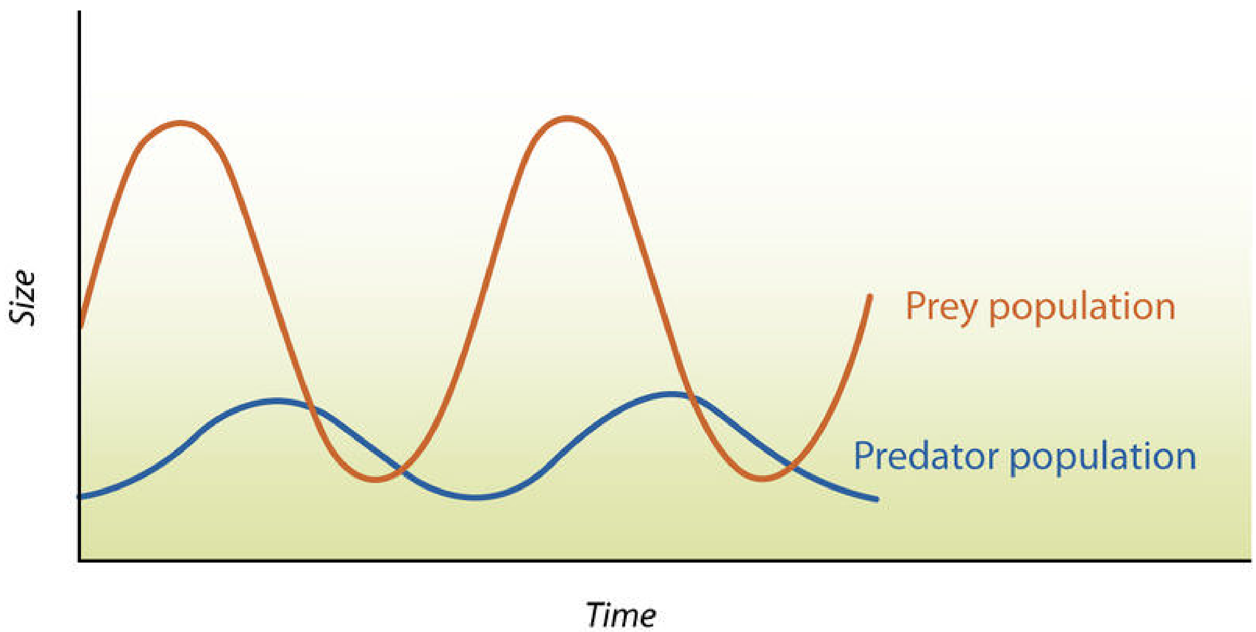


FIGURE 8.10
Predator-Prey Population Dynamics. As the prey population increases, why does the predator population also increase?

In the predator-prey example, one factor limits the growth of the other factor. As the prey population deceases, the predator population is begins to decrease as well. The prey population is a limiting factor. A **limiting factor** limits the growth or development of an organism, population, or process.

Keystone Species

Some predator species are known as keystone species. A **keystone species** is one that plays an especially important role in its community. Major changes in the numbers of a keystone species affect the populations of many other species in the community. For example, some sea star species are keystone species in coral reef communities. The sea stars prey on mussels and sea urchins, which have no other natural predators. If sea stars were removed from a coral reef community, mussel and sea urchin populations would have explosive growth. This, in turn, would drive out most other species. In the end, the coral reef community would be destroyed.

Adaptations to Predation

Both predators and prey have adaptations to predation that evolve through natural selection. Predator adaptations help them capture prey. Prey adaptations help them avoid predators. A common adaptation in both predator and prey is **camouflage**. Several examples are shown in **Figure** 8.11. Camouflage in prey helps them hide from predators. Camouflage in predators helps them sneak up on prey.

FIGURE 8.11

Camouflage in Predator and Prey Species. Can you see the crab in the photo on the left? It is camouflaged with the sand. The preying mantis in the middle photo looks just like the dead leaves in the background. Can you tell where one zebra ends and another one begins? This may confuse a predator and give the zebras a chance to run away.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/190196

Science Friday: Can Underwater Parks Protect Coral?

Coral communities are incredibly important for marine life. In this video by Science Friday, Marine scientists John Bruno and Elizabeth Selig describe the effects of local Marine Protection Areas on preserving coral.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/194517

Summary

- Predation is a relationship in which members of one species (the predator) consume members of another species (the prey).
- A predator-prey relationship keeps the populations of both species in balance.

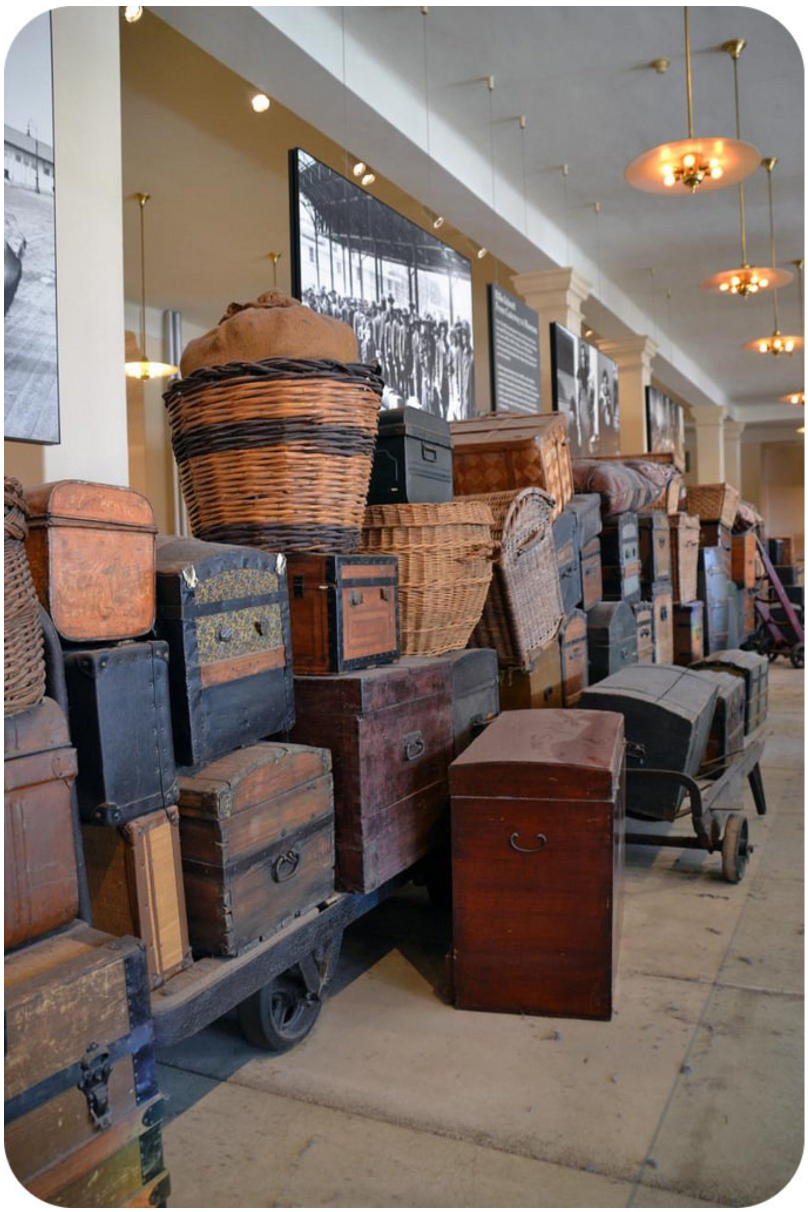
Review

1. Describe the relationship between a predator population and the population of its prey.
2. What is a keystone species? Give an example.
3. What is a limiting factor?
4. What is the role of camouflage in prey and predator?

8.7 Population Growth

Learning Objectives

- Identify factors that determine population growth rate.
- Give the formula for the population growth rate.
- Distinguish between dispersal and migration.



What would old luggage have to do with population growth?

Moving into an area, or immigration, is a key factor in the growth of populations. Shown above is actual vintage luggage left by some of the millions of immigrants who came through Ellis Island and into the United States.

Population Growth

Populations gain individuals through births and immigration. They lose individuals through deaths and emigration. These factors together determine how fast a population grows.

Population Growth Rate

Population growth rate (r) is how fast a population changes in size over time. A positive growth rate means a population is increasing. A negative growth rate means it is decreasing. The two main factors affecting population growth are the birth rate (b) and death rate (d). Population growth may also be affected by people coming into the population from somewhere else (**immigration**, i) or leaving the population for another area (**emigration**, e). The formula for population growth takes all these factors into account.

$r = (b + i) - (d + e)$

- r = population growth rate
- b = birth rate
- i = immigration rate
- d = death rate
- e = emigration rate

Dispersal

Other types of movements may also affect population size and growth. For example, many species have some means of **dispersal**. This refers to offspring moving away from their parents. This prevents the offspring from competing with the parents for resources such as light or water. For example, dandelion seeds have "parachutes." They allow the wind to carry the seeds far from the parents (see **Figure** 8.12).

FIGURE 8.12
Dandelion Seeds. These dandelion seeds may disperse far from the parent plant. Why might this be beneficial to both parents and offspring?

Migration

Migration is another type of movement that changes population size. **Migration** is the regular movement of individuals or populations each year during certain seasons. The purpose of migration usually is to find food, mates, or other resources. For example, many northern hemisphere birds migrate thousands of miles south each fall. They go to areas where the weather is warmer and more resources are available (see **Figure** 8.13). Then they return north in the spring to nest. Some animals, such as elk, migrate vertically. They go up the sides of mountains in spring as snow melts. They go back down the mountain sides in fall as snow returns.

FIGURE 8.13
Swainson's hawks migrate from North to South America and back again each year. This map shows where individual hawks have been identified during their migration.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/91491

Summary

- Population growth rate is how fast a population changes in size over time.
- Population growth is determined by rates of birth, death, immigration, and emigration.

Review

1. Define immigration and emigration.
2. What is migration? Give an example.
3. Write the formula for the population growth rate. Identify all the variables.
4. What is dispersal? State why dispersal of offspring away from their parents might be beneficial

8.8 Growth of Populations - Advanced

Learning Objectives

- Explain the structure and meaning of a generalized survivorship curve.
- Compare and contrast the three basic types of survivorship curves.
- Define population dynamics.
- Describe exponential (J-curve) growth, and explain the conditions under which it occurs.
- Explain Malthus' ideas about human population growth and their significance to evolutionary theory.

What starts out very small and has the potential to grow considerably larger?

Trees, of course. But also populations. Give a population everything it needs to survive, and the growth of that population will be tremendous.

How Do Populations Grow Under Ideal Conditions?

Imagine a huge bowl of your favorite potato salad, ready for a picnic on a beautiful, hot, midsummer day. The cook was careful to prepare it under strictly sanitary conditions, using fresh eggs, clean organic vegetables, and new jars of mayonnaise and mustard. Familiar with food poisoning warnings, the cook was so thorough that only a single bacterium made it into that vast amount of food. While such a scenario is highly unrealistic without authentic canning, it will serve as an example as we begin our investigation of how populations change, or **population dynamics**. Because potato salad provides an ideal environment for bacterial growth, just as your mother may have warned, we can use this single bacterial cell in the potato salad to ask:

Given food, warm temperatures, moisture, and oxygen, a single aerobic bacterial cell can grow and divide by binary fission to become two cells in about 20 minutes. The two new cells, still under those ideal conditions, can each repeat this performance, so that after 20 more minutes, four cells constitute the population. Given this modest doubling, how many bacteria do you predict will be happily feeding on potato salad after five hours at the picnic? After you've thought about this, compare your prediction with the "data" in **Table** 8.1.

Table 8.1: Like many populations under ideal conditions, bacteria show exponential or geometric growth. Each bacterium can undergo binary fission every 20 minutes. After 5 hours, a single bacterium can produce a population of 32,768 descendants.

Population Growth of Bacteria

Calculated for Ideal Conditions

TABLE 8.1:

Time (Hours and Minutes)	**Population Size** (Number of Bacteria)
0	1
20 minutes	2
40 minutes	4
1 hour	8
1 hour 20 minutes	16
1 hour 40 minutes	32
2 hours	64
2 hours 20 minutes	128
2 hours 40 minutes	256
3 hours	512
3 hours 20 minutes	1,024
3 hours 40 minutes	2,048
4 hours	4,096
4 hours 20 minutes	8,192
4 hours 40 minutes	16,384
5 hours	**32,768**

Are you surprised? This phenomenal capacity for growth of living populations was first described by Thomas Robert Malthus in his 1798 *Essay on the Principle of Population.* Although Malthus focused on human populations, biologists have found that many populations are capable of this explosive reproduction, if provided with ideal conditions. This pattern of growth is exponential (**exponential growth**), or **geometric growth**: as the population grows larger, the rate of growth increases. If you have worked compound interest problems in math or played with numbers for estimating the interest in your savings account, you can compare the growth of a population under ideal conditions to the growth of a savings account under a constant rate of compound interest. The graph in **Figure** 8.14, using potato salad bacterial "data," shows the pattern of exponential growth: the population grows very slowly at first, but more and more rapidly as time passes.

Of course, if bacterial populations always grew exponentially, they would long ago have covered the Earth many times over. While Thomas Malthus emphasized the importance of exponential growth on population, he also stated that ideal conditions do not often exist in nature. A basic limit for all life is energy. Growth, survival, and reproduction require energy. Because energy supplies are limited, organisms must "spend" them wisely. We will end this lesson with a much more realistic model of population growth and the implications of its limits, but first, let's look more carefully at the characteristics of populations which allow them to grow.

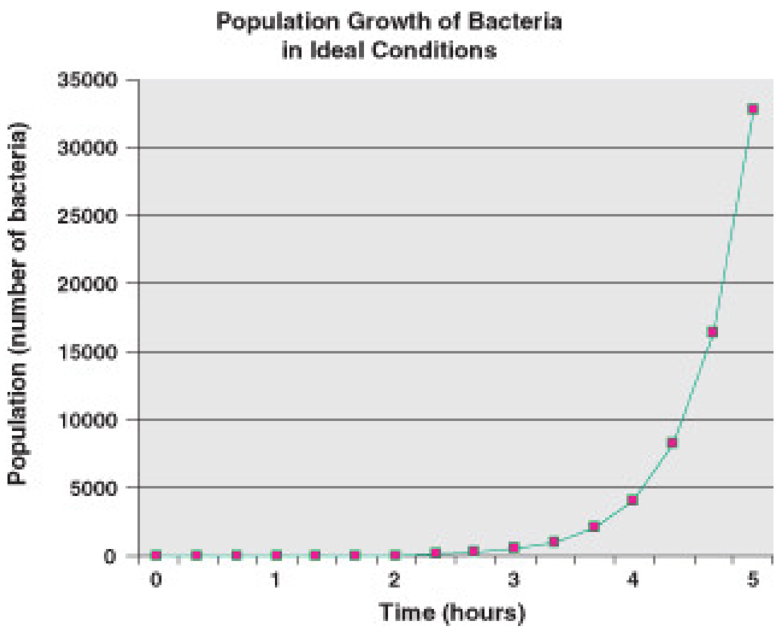
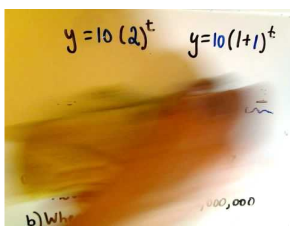


FIGURE 8.14
Exponential or geometric growth is very slow at first, but accelerates as the population grows. Because rate of growth depends on population size, growth rate increases as population increases. Most populations have the ability to grow exponentially, but such growth usually occurs only under ideal conditions that are not found in nature. Note the "J" shape of the curve. Recall that Malthus stated that the human population, under ideal conditions, can grow exponentially, and that this growth can continue until overpopulation causes resources, such as food, to become limited. What would happen to the curve when resources become limited?



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/190

Summary

- The ways in which populations change are called population dynamics.
- Populations have the potential to grow exponentially, at least under ideal conditions.
- Exponential growth begins with slow growth, but as population increases, growth rate increases.
- J-curves depict the pattern of exponential population growth.
- Malthus first described exponential growth for the human population and predicted that humans would outgrow their food resources, leading to widespread famine or war.

Review

1. Define exponential growth. When does this growth occur?
2. Explain Malthus' ideas about population growth and their significance to evolutionary theory.

8.9 References

1. Jon DeJong. An example of a desert ecosystem . CC BY 2.0
2. Jodi So. An illustration of different bird beak types adapted for its niche . CC BY-NC 3.0
3. (a) Martin Kozák; (b) Michael Apel; (c) Mark Jordahl. A plant, invertebrate, and vertebrates are all part of an ecosystem . (a) Public Domain; (b) CC BY 2.5; (c) CC BY 2.0
4. Tobias Brixen. The top carnivore niche is filled by lions on the savanna, wolves in the tundra, and tuna in the oceans . CC BY 2.0
5. Image copyright Terry Reimink, 2014. Birds living in a saguaro cactus . Used under license from Shutterstock.com
6. Barbara Akre and Jin Yu, based on data from http://cnx.org/content/m12174/latest/ and http://en.wikipedia.org/wiki/Biodive Graphs of known species of organisms, animals, and plants . CC BY-NC 3.0
7. Image copyright Godrick, 2014. Starlings and a stag in symbiosis . Used under license from Shutterstock.com
8. Ground Anole: Flickr:pondhawk; Tree Anole: Jordan Walmsley. Specialization lets ground anoles and tree a noles live together without competing . CC BY 2.0
9. Patti Sandoval. Lions feeding on the carcass of a zebra . CC BY 2.0
10. Hana Zavadska. Predator-Prey Population Dynamics . CC BY-NC 3.0
11. Crab: Thomas Hubauer; Mantis: Adrian Pingstone; Zebra: Paul Maritz, edited by User:Pharaoh Hound/Wikimedia Commons and User:Fir0002/Wikimedia Commons. Camouflage in crabs and preying mantis . Crab: CC BY 2.0; Mantis: Public Domain; Zebra: CC BY 2.5
12. John Liu. Dandelion seeds disperse far from the parent plant . CC BY 2.0
13. U.S. Geological Survey. Swainson's hawks migration pattern . Public Domain
14. CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0

CHAPTER 9 LS2-4

Chapter Outline

9.1 Flow of Matter in Ecosystems

Learning Objectives

- 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** 9.1).

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. Decaying leaves may be transported out of an ecosystem by a stream. Wind or water carries nutrients out of an ecosystem.

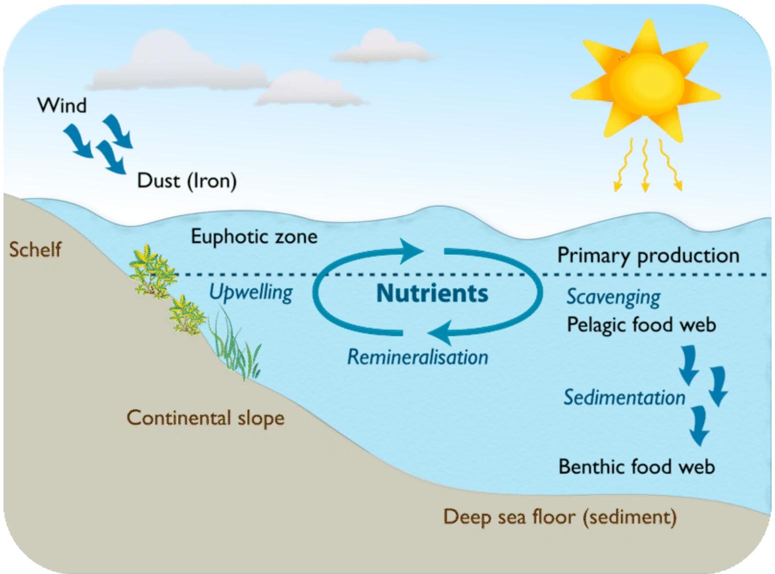


FIGURE 9.1
Nutrients cycle through ocean food webs.

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.

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?

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186556

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186558

9.2 Carbon Cycle

Learning Objectives

- Give an overview of the carbon cycle.
- Discuss the roles of photosynthesis and cellular respiration in the carbon cycle.
- Describe processes that have led to increased atmospheric carbon dioxide levels.

How could releasing this much pollution into the atmosphere not be a poor idea?

Burning of fossil fuels, such as oil, releases carbon into the atmosphere. This carbon must be cycled - removed from the atmosphere - back into living organisms, or it stays in the atmosphere. Increased carbon in the atmosphere contributes to the greenhouse effect on Earth.

The Carbon Cycle

Flowing water can slowly dissolve carbon in sedimentary rock. Most of this carbon ends up in the ocean. The deep ocean can store carbon for thousands of years or more. Sedimentary rock and the ocean are major reservoirs of stored carbon. Carbon is also stored for varying lengths of time in the atmosphere, in living organisms, and as fossil fuel deposits. These are all parts of the **carbon cycle**, which is shown in **Figure** 9.2.

Why is recycling carbon important? Recall that carbon is the cornerstone of organic compounds, the compounds necessary for life. But do organisms make their own carbon? Do they have the genes that encode proteins necessary to make carbon? No. In fact, there are no such genes. Carbon must be recycled from other living organisms, from carbon in the atmosphere, and from carbon in other parts of the biosphere.

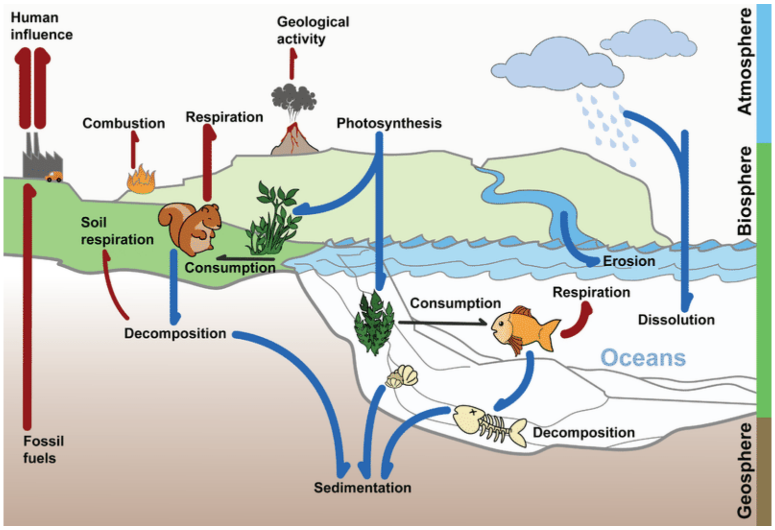


FIGURE 9.2
The Carbon Cycle. Carbon moves from one reservoir to another in the carbon cycle. What role do organisms play in this cycle?

Carbon in the Atmosphere

Though carbon can be found in ocean water, rocks and sediment and other parts of the biosphere, the atmosphere may be the most recognizable reservoir of carbon. Carbon occurs in various forms in different parts of the carbon cycle. Some of the different forms in which carbon appears are described in **Table** 9.1. KEY: C = Carbon, O = Oxygen, H = Hydrogen

TABLE 9.1: Forms of Carbon in the Carbon Cycle

Form of Carbon	Chemical Formula	State	Main Reservoir
Carbon Dioxide	CO_2	Gas	Atmosphere
Carbonic Acid	H_2CO_3	Liquid	Ocean
Bicarbonate Ion	HCO_3^-	Liquid(dissolved ion)	Ocean
Organic Compounds	*Examples:* $C_6H_{12}O_6$ (Glucose), CH_4 (Methane)	Solid Gas	Biosphere Organic Sediments (Fossil Fuels)
Other Carbon Compounds	*Examples:* $CaCO_3$ (Calcium Carbonate), $CaMg(CO_3)_2$ (Calcium Magnesium Carbonate)	Solid Solid	Sedimentary Rock, Shells, Sedimentary Rock

Carbon in Carbon Dioxide

Carbon cycles quickly between organisms and the atmosphere. In the atmosphere, carbon exists primarily as carbon dioxide (CO_2). Carbon dioxide cycles through the atmosphere by several different processes, including those listed below.

- Living organisms release carbon dioxide as a byproduct of **cellular respiration**.
- **Photosynthesis** removes carbon dioxide from the atmosphere and uses it to make organic compounds.
- Carbon dioxide is given off when dead organisms and other organic materials decompose.
- Burning organic material, such as fossil fuels, releases carbon dioxide.
- Carbon cycles far more slowly through geological processes such as **sedimentation**. Carbon may be stored in sedimentary rock for millions of years.
- When volcanoes erupt, they give off carbon dioxide that is stored in the mantle.
- Carbon dioxide is released when limestone is heated during the production of cement.
- Ocean water releases dissolved carbon dioxide into the atmosphere when water temperature rises.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/161121

Summary

- Carbon must be recycled through living organisms or it stays in the atmosphere.
- Carbon cycles quickly between organisms and the atmosphere.
- Due to human activities, there is more carbon dioxide in the atmosphere today than in the past hundreds of thousands of years.

Review

1. What is the role of the carbon cycle?
2. Why is cycling carbon important?
3. Describe a major method that carbon is cycled.
4. How have human activities increased atmospheric carbon dioxide levels?

9.3 Nitrogen Cycle

Learning Objectives

- Outline the steps of the nitrogen cycle.
- Explain nitrogen fixation.
- Discuss the roles of ammonification, nitrification and denitrification in the nitrogen cycle.

Alfalfa, clover, peas, beans, lentils, lupins, mesquite, carob, soy, and peanuts. What are these?

Legumes. Legume plants have the ability to fix atmospheric nitrogen, due to a mutualistic symbiotic relationship with bacteria found in root nodules of these plants.

The Nitrogen Cycle

Nitrogen makes up 78 percent of Earth's atmosphere. It's also an important part of living things. Nitrogen is found in proteins, nucleic acids, and chlorophyll. The **nitrogen cycle** moves nitrogen through the abiotic and biotic parts of ecosystems. **Figure** 9.3 shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes through a similar cycle in aquatic ecosystems.

Even though nitrogen gas makes up most of Earth's atmosphere, plants cannot use this nitrogen gas to make organic compounds for themselves and other organisms. The two nitrogen atoms in a molecule of nitrogen gas are held together by a very stable triple bond. This bond must be broken for the nitrogen to be used. The nitrogen gas must be changed to a form called nitrates, which plants can absorb through their roots. The process of changing nitrogen

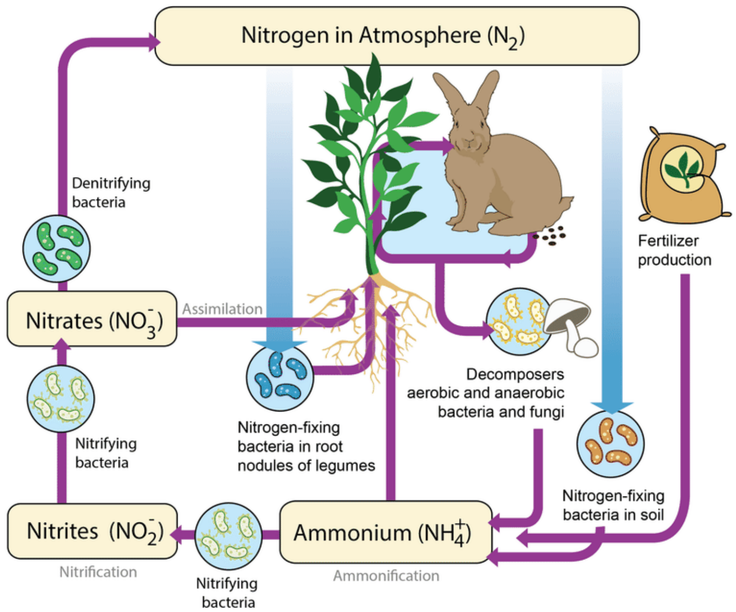
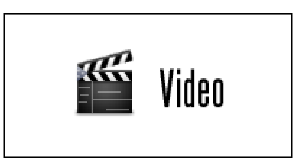


FIGURE 9.3

Nitrogen Cycle in a Terrestrial Ecosystem. Nitrogen cycles between the atmosphere and living things.

gas to nitrates is called **nitrogen fixation**. It is carried out by nitrogen-fixing bacteria. The bacteria live in soil and roots of legumes, such as peas.

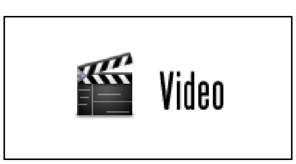
When plants and other organisms die, decomposers break down their remains. In the process, they release nitrogen in the form of ammonium ions. This process is called **ammonification.** Nitrifying bacteria change the ammonium ions into nitrites and nitrates. Some of the nitrates are used by plants. The process of converting ammonium ions to nitrites or nitrates is called **nitrification.** Still other bacteria, called denitrifying bacteria, convert some of the nitrates in soil back into nitrogen gas in a process called **denitrification.** The process is the opposite of nitrogen fixation. Denitrification returns nitrogen gas back to the atmosphere, where it can continue the nitrogen cycle.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/160878



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/160882

Summary

- The nitrogen cycle moves nitrogen back and forth between the atmosphere and organisms.
- Bacteria change nitrogen gas from the atmosphere to nitrogen compounds that plants can absorb.
- Other bacteria change nitrogen compounds back to nitrogen gas, which re-enters the atmosphere.

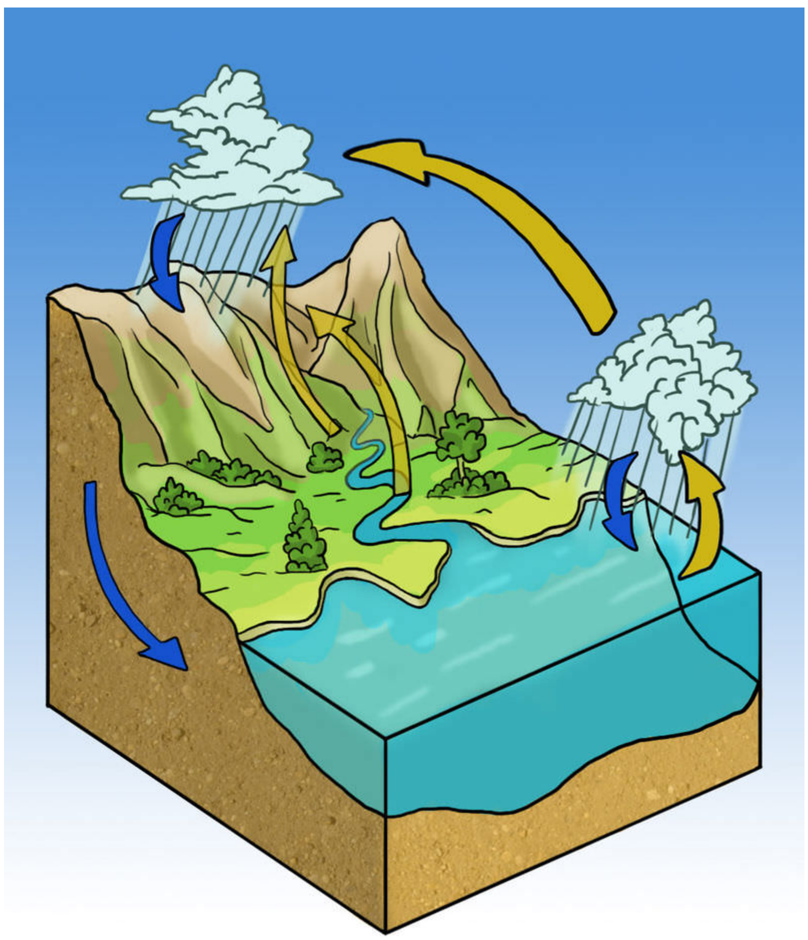
Review

1. Why can't plants use nitrogen gas directly?
2. What is nitrogen fixation?
3. Explain why bacteria are essential parts of the nitrogen cycle.
4. What is ammonification?

9.4 Water Cycle

Learning Objectives

- Define biogeochemical cycle.
- Compare an exchange pool to a reservoir.
- Describe the water cycle and its processes.
- Compare evaporation to sublimation and to transpiration.
- Explain the roles of condensation and precipitation in the water cycle.



Where does the water come from that is needed by your cells?

Unlike energy, matter is not lost as it passes through an ecosystem. Instead, matter, including water, is recycled. This recycling involves specific interactions between the biotic and abiotic factors in an ecosystem. Chances are, the water you drank this morning has been around for millions of years, or more.

The Water Cycle

The chemical elements and water that are needed by organisms continuously recycle in ecosystems. They pass through biotic and abiotic components of the biosphere. That's why their cycles are called **biogeochemical cycles**. For example, a chemical might move from organisms (*bio*) to the atmosphere or ocean (*geo*) and back to organisms again. Elements or water may be held for various periods of time in different parts of a cycle.

- Part of a cycle that holds an element or water for a short period of time is called an **exchange pool**. For example, the atmosphere is an exchange pool for water. It usually holds water (in the form of water vapor) for just a few days.
- Part of a cycle that holds an element or water for a long period of time is called a **reservoir**. The ocean is a reservoir for water. The deep ocean may hold water for thousands of years.

Water on Earth is billions of years old. However, individual water molecules keep moving through the water cycle. The **water cycle** is a global cycle. It takes place on, above, and below Earth's surface, as shown in **Figure** 9.4.

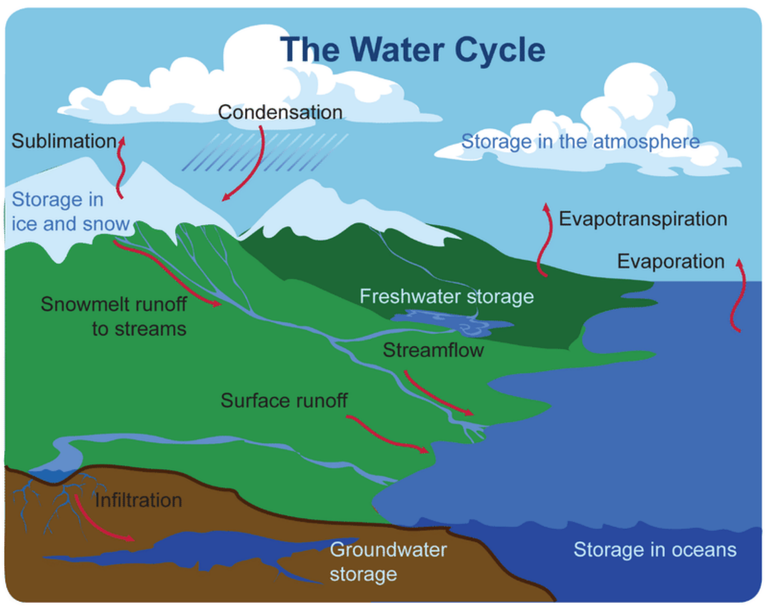


FIGURE 9.4
Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating.

During the water cycle, water occurs in three different states: gas (water vapor), liquid (water), and solid (ice). Many processes are involved as water changes state in the water cycle.

Evaporation, Sublimation, and Transpiration

Water changes to a gas by three different processes:

1. **Evaporation** occurs when water on the surface changes to water vapor. The sun heats the water and gives water molecules enough energy to escape into the atmosphere.
2. **Sublimation** occurs when ice and snow change directly to water vapor. This also happens because of heat from the sun.
3. **Transpiration** occurs when plants release water vapor through leaf pores called stomata (see **Figure** 9.5).

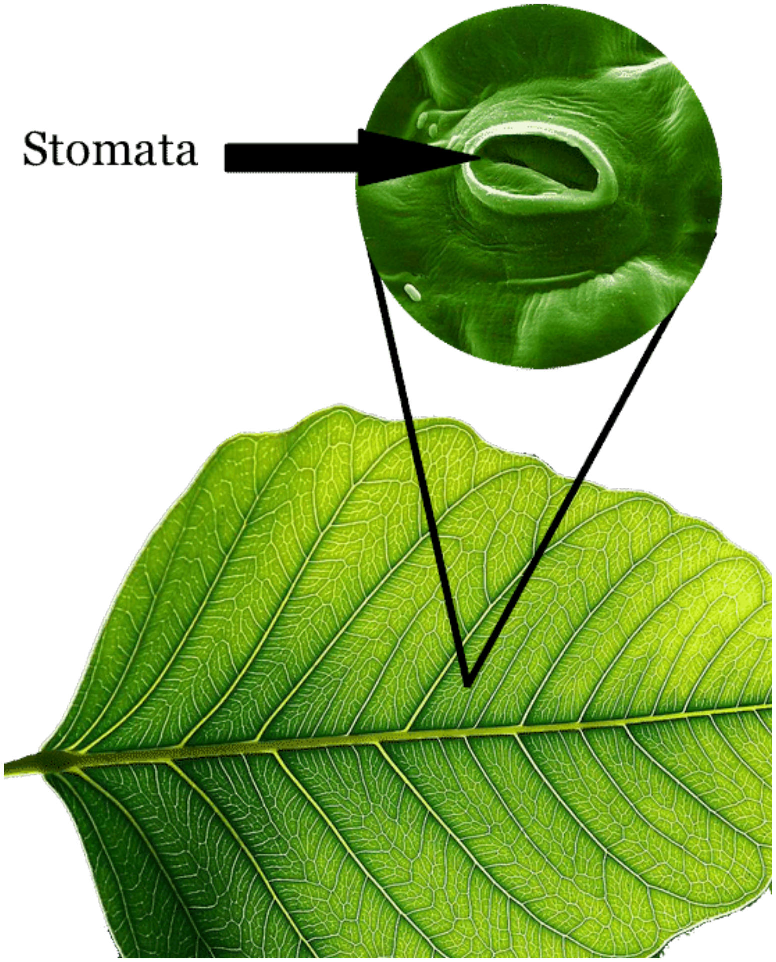


FIGURE 9.5
Plant leaves have many tiny stomata. They release water vapor into the air.

Condensation and Precipitation

Rising air currents carry water vapor into the atmosphere. As the water vapor rises in the atmosphere, it cools and condenses. **Condensation** is the process in which water vapor changes to tiny droplets of liquid water. The water droplets may form clouds. If the droplets get big enough, they fall as **precipitation**—rain, snow, sleet, hail, or freezing rain. Most precipitation falls into the ocean. Eventually, this water evaporates again and repeats the water cycle. Some frozen precipitation becomes part of ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or longer.

Groundwater and Runoff

Precipitation that falls on land may flow over the surface of the ground. This water is called **runoff**. It may eventually flow into a body of water. Some precipitation that falls on land may soak into the ground, becoming **groundwater**. Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater may be taken up by plant roots. Some may flow deeper underground to an **aquifer**. This is an underground layer of rock that stores water, sometimes for thousands of years.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/160886

Science Friday: Forecasting the Meltdown: The Aerial Snow Observatory

75% of Southern California's water supply comes from the snowpack in the Sierra Nevada Mountain Range. This video by Science Fridayexplains how NASA uses the Airborne Snow Observatory that uses specialized instrumentation to carefully measure the water content.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/194571

Summary

- Chemical elements and water are recycled through biogeochemical cycles. The cycles include both biotic and abiotic parts of ecosystems.
- The water cycle takes place on, above, and below Earth's surface. In the cycle, water occurs as water vapor, liquid water, and ice. Many processes are involved as water changes state in the cycle.
- The atmosphere is an exchange pool for water. Ice masses, aquifers, and the deep ocean are water reservoirs.

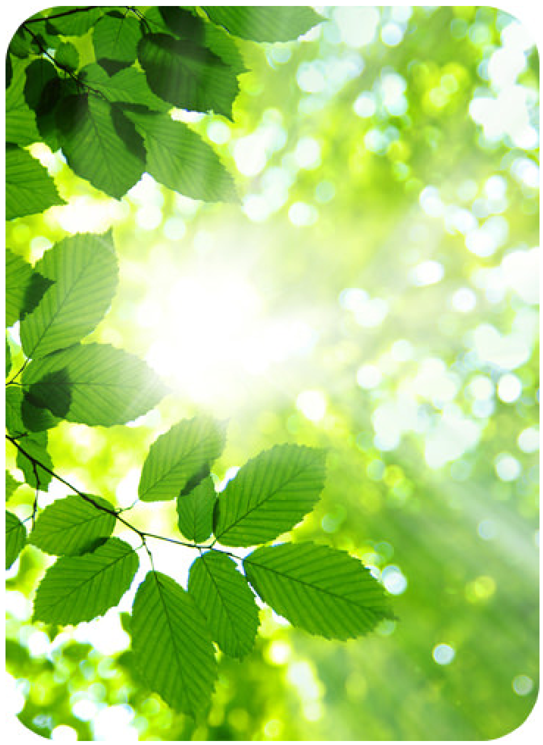
Review

1. What is a biogeochemical cycle? Name an example.
2. Identify and define two processes by which water naturally changes from a solid or liquid to a gas.
3. Define exchange pool and reservoir, and identify an example of each in the water cycle.
4. Assume you are a molecule of water. Describe one way you could go through the water cycle, starting as water vapor in the atmosphere.

9.5 Autotrophs and Heterotrophs

Learning Objectives

- Define photosynthesis.
- State the chemical reaction of photosynthesis.
- Describe how autotrophs and heterotrophs obtain energy.
- Explain the relationship between producers and consumers.
- Distinguish photosynthesis from chemosynthesis.



Name one major difference between a plant and an animal.

There are many differences, but in terms of energy, it all starts with sunlight. Plants absorb the energy from the sun and turn it into *food.* You can sit in the sun for hours and hours. You will feel warm, but you're not going to absorb any energy. You have to eat to obtain your energy.

Autotrophs vs. Heterotrophs

Living organisms obtain chemical energy in one of two ways.

Autotrophs, shown in **Figure** 9.6, store chemical energy in carbohydrate food molecules they build themselves. **Food** is chemical energy stored in organic molecules. Food provides both the energy to do work and the carbon to build bodies. Because most autotrophs transform sunlight to make food, we call the process they use **photosynthesis**. Only three groups of organisms - plants, algae, and some bacteria - are capable of this life-giving energy transformation. Autotrophs make food for their own use, but they make enough to support other life as well. Almost all other organisms depend absolutely on these three groups for the food they produce. The **producers**, as autotrophs are also known, begin **food chains** which feed all life. Food chains will be discussed in the "Food Chains and Food Webs" concept.

Heterotrophs cannot make their own food, so they must eat or absorb it. For this reason, heterotrophs are also known as **consumers**. Consumers include all animals and fungi and many protists and bacteria. They may consume autotrophs or other heterotrophs or organic molecules from other organisms. Heterotrophs show great diversity and may appear far more fascinating than producers. But heterotrophs are limited by our utter dependence on those autotrophs that originally made our food. If plants, algae, and autotrophic bacteria vanished from earth, animals, fungi, and other heterotrophs would soon disappear as well. All life requires a constant input of energy. Only autotrophs can transform that ultimate, solar source into the chemical energy in food that powers life, as shown in **Figure** 9.7.

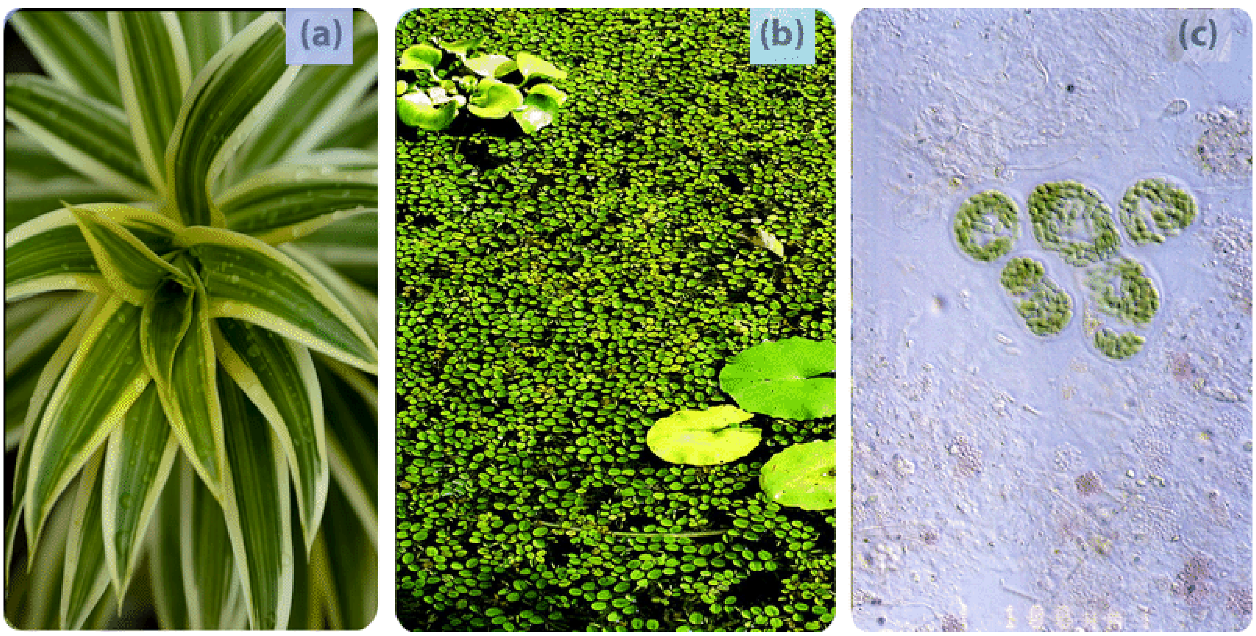


FIGURE 9.6

Photosynthetic autotrophs, which make food using the energy in sunlight, include (a) plants, (b) algae, and (c) certain bacteria.

Photosynthesis provides over 99 percent of the energy for life on earth. A much smaller group of autotrophs - mostly bacteria in dark or low-oxygen environments - produce food using the chemical energy stored in inorganic molecules such as hydrogen sulfide, ammonia, or methane. While photosynthesis transforms light energy to chemical energy, this alternate method of making food transfers chemical energy from inorganic to organic molecules. It is therefore called **chemosynthesis**, and is characteristic of the tubeworms shown in **Figure** 9.8. Some of the most recently discovered chemosynthetic bacteria inhabit deep ocean hot water vents or "black smokers." There, they use the energy in gases from the Earth's interior to produce food for a variety of unique heterotrophs: giant tube worms, blind shrimp, giant white crabs, and armored snails. Some scientists think that chemosynthesis may support life below the surface of Mars, Jupiter's moon, Europa, and other planets as well. Ecosystems based on chemosynthesis may seem rare and exotic, but they too illustrate the absolute dependence of heterotrophs on autotrophs for food.

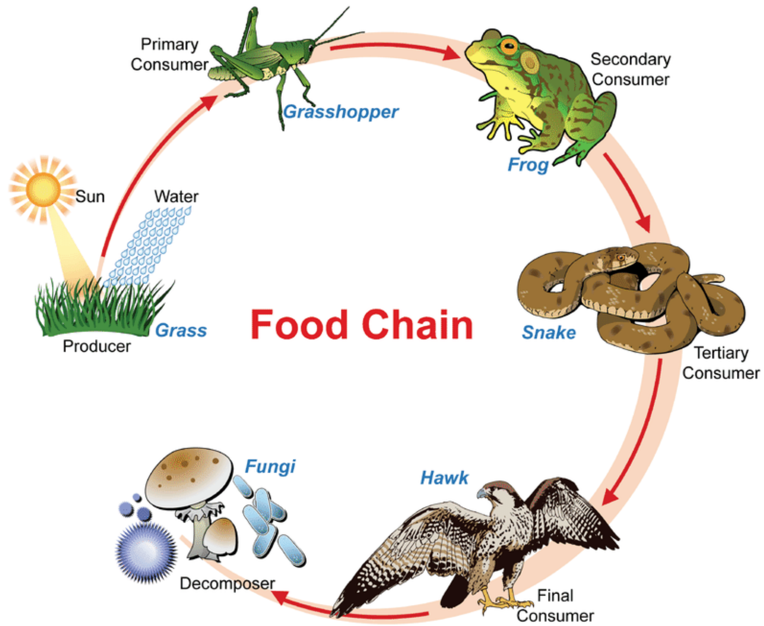


FIGURE 9.7
A food chain shows how energy and matter flow from producers to consumers. Matter is recycled, but energy must keep flowing into the system. Where does this energy come from? Though this food chains "ends" with decomposers, do decomposers, in fact, digest matter from each level of the food chain? (see the "Flow of Energy" concept.)

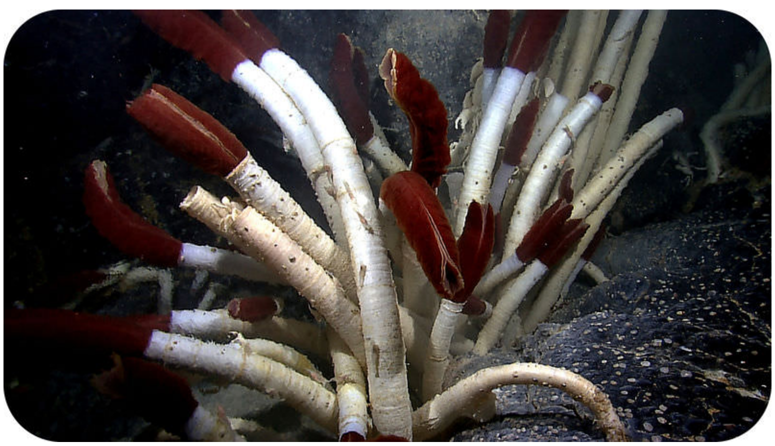


FIGURE 9.8
Tubeworms deep in the Galapagos Rift get their energy from chemosynthetic bacteria living within their tissues. No digestive systems needed!

Making and Using Food

The flow of energy through living organisms begins with photosynthesis. This process stores energy from sunlight in the chemical bonds of glucose. By breaking the chemical bonds in glucose, cells release the stored energy and make the ATP they need. The process in which glucose is broken down and ATP is made is called **cellular respiration**.

Photosynthesis and cellular respiration are like two sides of the same coin. This is apparent from **Figure** 9.9. The products of one process are the reactants of the other. Together, the two processes store and release energy in living organisms. The two processes also work together to recycle oxygen in Earth's atmosphere.

Photosynthesis

Photosynthesis is often considered to be the single most important life process on Earth. It changes light energy into chemical energy and also releases oxygen. Without photosynthesis, there would be no oxygen in the atmosphere.

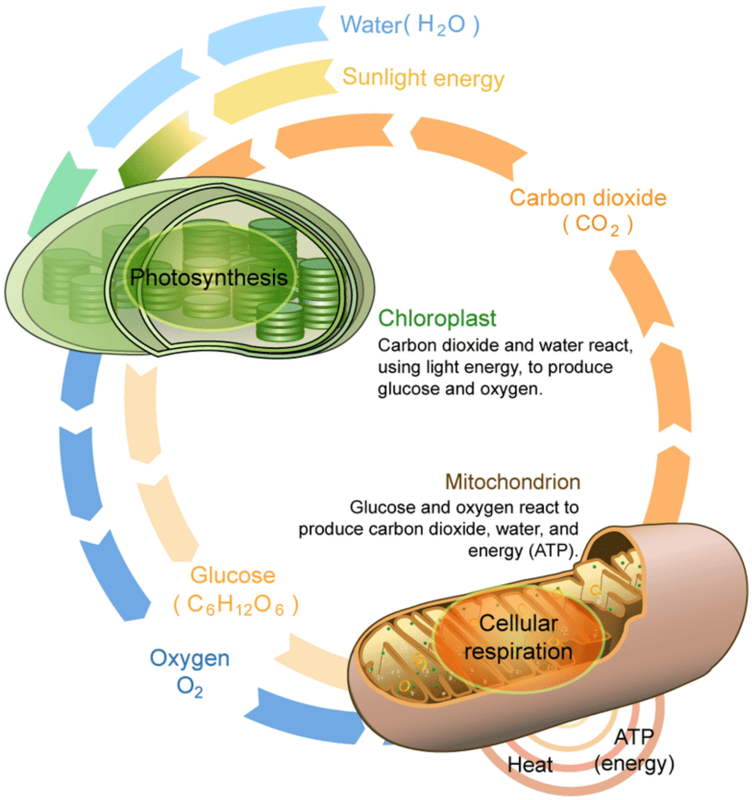


FIGURE 9.9
This diagram compares and contrasts photosynthesis and cellular respiration. It also shows how the two processes are related.

Photosynthesis involves many chemical reactions, but they can be summed up in a single chemical equation:

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

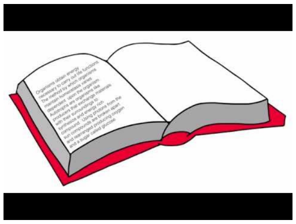
Photosynthetic autotrophs capture light energy from the sun and absorb carbon dioxide and water from their environment. Using the light energy, they combine the reactants to produce glucose and oxygen, which is a waste product. They store the glucose, usually as starch, and they release the oxygen into the atmosphere.

Cellular Respiration

Cellular respiration actually "burns" glucose for energy. However, it doesn't produce light or intense heat as some other types of burning do. This is because it releases the energy in glucose slowly, in many small steps. It uses the energy that is released to form molecules of ATP. Cellular respiration involves many chemical reactions, which can be summed up with this chemical equation:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Chemical Energy (in ATP)}$

Cellular respiration occurs in the cells of all living things. It takes place in the cells of both autotrophs and heterotrophs. All of them burn glucose to form ATP.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/188397

Summary

- Autotrophs store chemical energy in carbohydrate food molecules they build themselves. Most autotrophs make their "food" through photosynthesis using the energy of the sun.
- Heterotrophs cannot make their own food, so they must eat or absorb it.
- Chemosynthesis is used to produce food using the chemical energy stored in inorganic molecules.

Review

1. Compare autotrophs to heterotrophs, and describe the relationship between these two groups of organisms.
2. Name and describe the two types of food making processes found among autotrophs. Which is quantitatively more important to life on earth?
3. Describe the flow of energy through a typical food chain (describing "what eats what"), including the original source of that energy and its ultimate form after use.

9.6 Flow of Energy

Learning Objectives

- Describe energy flows through ecosystems.
- Distinguish photoautotrophs from chemoautotrophs.
- Distinguish herbivores from carnivores and omnivores.
- Explain the role of decomposers.
- Compare scavengers to detritivores and to saprotrophs.

What is happening inside each leaf and blade of grass?

Photosynthesis. Maybe the most important biochemical reaction of Earth. As sunlight shines down on this forest, the sunlight is being absorbed, and the energy from that sunlight is being transformed into chemical energy. That chemical energy is then distributed to all other living organisms in the ecosystem.

Flow of Energy

To survive, ecosystems need a constant influx of energy. Energy enters ecosystems in the form of sunlight or chemical compounds. Some organisms use this energy to make food. Other organisms get energy by eating the food.

Producers

Producers are organisms that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. The stability of producers is vital to ecosystems because all organisms need organic molecules. Producers are also called **autotrophs**. There are two basic types of autotrophs: photoautotrophs and chemoautotrophs.

1. **Photoautotrophs** use energy from sunlight to make food by photosynthesis. They include plants, algae, and certain bacteria (see **Figure** 9.10).
2. **Chemoautotrophs** use energy from chemical compounds to make food by chemosynthesis. They include some bacteria and also archaea. Archaea are microorganisms that resemble bacteria.

FIGURE 9.10
Different types of photoautotrophs are important in different ecosystems.

Consumers

Consumers are organisms that depend on other organisms for food. They take in organic molecules by essentially "eating" other living things. They include all animals and fungi. (Fungi don't really "eat"; they absorb nutrients from other organisms.) They also include many bacteria and even a few plants, such as the pitcher plant shown in **Figure** 9.11. Consumers are also called heterotrophs. Heterotrophs are classified by what they eat:

- **Herbivores** consume producers such as plants or algae. They are a necessary link between producers and other consumers. Examples include deer, rabbits, and mice.
- **Carnivores** consume animals. Examples include lions, polar bears, hawks, frogs, salmon, and spiders. Carnivores that are unable to digest plants and must eat only animals are called obligate carnivores. Other carnivores can digest plants but do not commonly eat them.

- **Omnivores** consume both plants and animals. They include humans, pigs, brown bears, gulls, crows, and some species of fish.

FIGURE 9.11
Pitcher Plant. Virtually all plants are producers. This pitcher plant is an exception. It consumes insects. It traps them in a sticky substance in its "pitcher." Then it secretes enzymes that break down the insects and release nutrients. Which type of consumer is a pitcher plant?

Decomposers

When organisms die, they leave behind energy and matter in their remains. **Decomposers** break down the remains and other wastes and release simple inorganic molecules back to the environment. Producers can then use the molecules to make new organic compounds. The stability of decomposers is essential to every ecosystem. Decomposers are classified by the type of organic matter they break down:

- **Scavengers** consume the soft tissues of dead animals. Examples of scavengers include vultures, raccoons, and blowflies.
- **Detritivores** consume **detritus**—the dead leaves, animal feces, and other organic debris that collects on the soil or at the bottom of a body of water. On land, detritivores include earthworms, millipedes, and dung beetles (see **Figure** 9.12). In water, detritivores include "bottom feeders" such as sea cucumbers and catfish.
- **Saprotrophs** are the final step in decomposition. They feed on any remaining organic matter that is left after other decomposers do their work. Saprotrophs include fungi and single-celled protozoa. Fungi are the only organisms that can decompose wood.

KQED: Banana Slugs: The Ultimate Recyclers

One of the most beloved and iconic native species within the old growth redwood forests of California is the Pacific Banana Slug. These slimy friends of the forest are the ultimate recyclers. Feeding on fallen leaves, mushrooms or even dead animals, they play a pivotal role in replenishing the soil. QUEST goes to Henry Cowell Redwoods State Park near Santa Cruz, California on a hunt to find *Ariolimax dolichophallus*, a bright yellow slug with a very big personality.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/440

FIGURE 9.12
Dung Beetle. This dung beetle is rolling a ball of feces to its nest to feed its young.

Summary

- Ecosystems require constant inputs of energy from sunlight or chemicals.
- Producers use energy and inorganic molecules to make food.
- Consumers take in food by eating producers or other living things.
- Decomposers break down dead organisms and other organic wastes and release inorganic molecules back to the environment.

Review

1. Identify three different types of consumers. Name an example of each type.
2. What are photoautotrophs? Give an example of one.
3. What can you infer about an ecosystem that depends on chemoautotrophs for food?
4. What is the role of decomposers?
5. What do scavengers do? Give an example of a scavenger.

9.7 Flow of Energy in Ecosystems

Learning Objectives

- 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** 9.13)?

Most of the energy at a trophic level - about 90% - is used at that trophic level. Organisms need it for growth, 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.

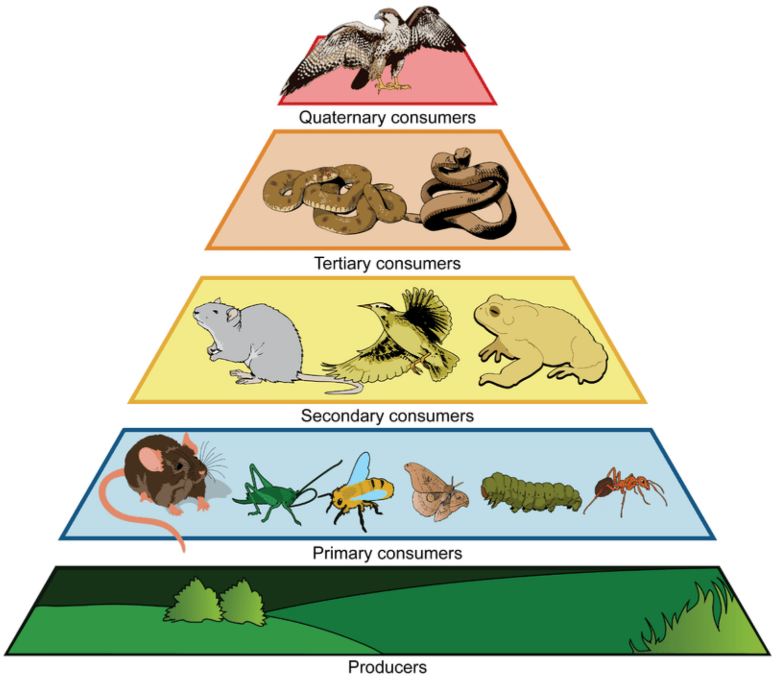
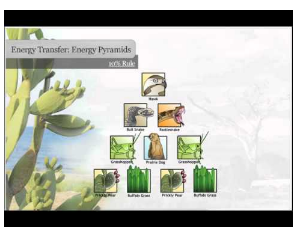


FIGURE 9.13
Producers are always the first trophic level, herbivores the second, the carnivores that eat herbivores the third, and so on.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186551

Food Chains

The set of organisms that pass energy from one trophic level to the next is described as the **food chain** (**Figure** 9.14). In this simple depiction, all organisms eat at only one trophic level (**Figure** 9.15).

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.

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** 9.16).

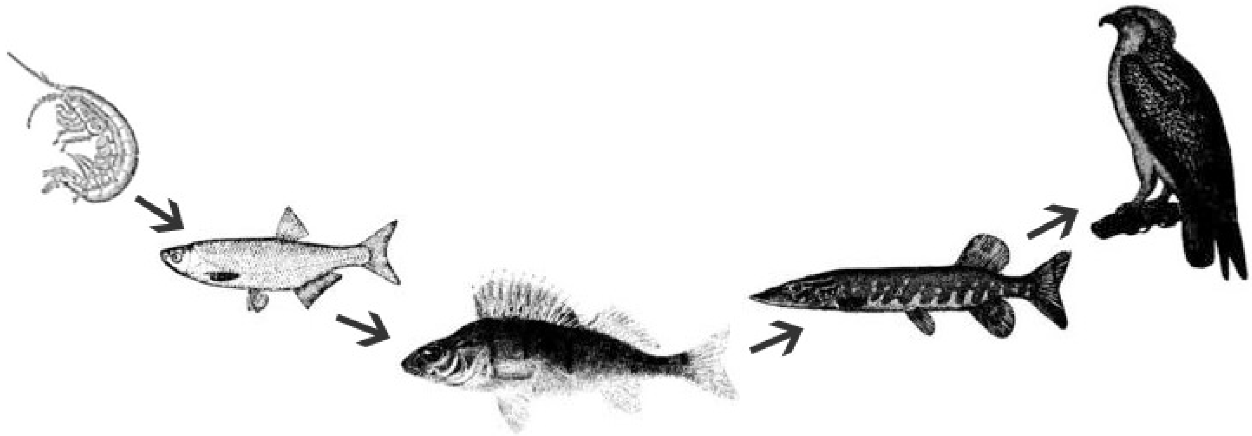


FIGURE 9.14
A simple food chain in a lake. The producers, algae, are not shown. For the predatory bird at the top, how much of the original energy is left?

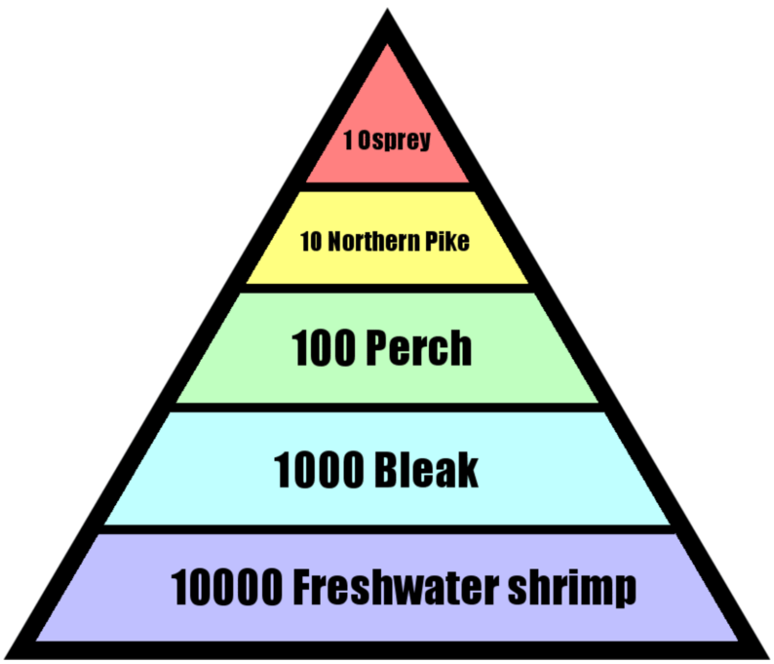


FIGURE 9.15
How many osprey are there relative to the number of shrimp?

Food Webs

What is a more accurate way to depict the passage of energy in an ecosystem? A **food web** (**Figure** 9.17) recognizes that many organisms eat at multiple trophic levels.

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.

FIGURE 9.16

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.

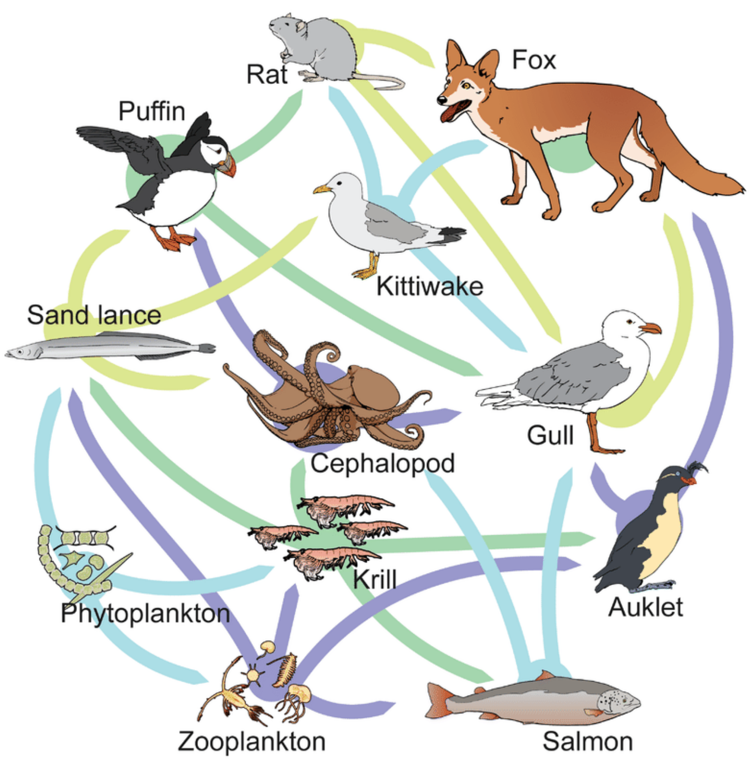


FIGURE 9.17

A food web includes the relationships between producers, consumers, and decomposers.

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.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186549

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.

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? Using energy as the factor, what case can be made for eating vegetarian.

9.8 References

1. Hana Zavadska. Nutrients cycle through ocean food webs . CC BY-NC 3.0
2. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. An illustration of the carbon cycle . CC BY-NC 3.0
3. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. An illustration of the nitrogen cycle in a terre strial ecosystem . CC BY-NC 3.0
4. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. The water cycle takes place on, above, and b elow Earth's surface . CC BY-NC 3.0
5. Stomata: Dartmouth Electron Microscope Facility; Leaf: Jon Sullivan. Tiny stomata are found on a plant leaf . Public Domain
6. (a) Corey Leopold; (b) Flickr:*higetiger (c) Courtesy of NASA. Examples of photosynthetic autotrophs . (a) CC BY 2.0; (b) CC BY 2.0; (c) Public Domain
7. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Energy flow in a food chain . CC BY-NC 3.0
8. Courtesy of the NOAA Okeanos Explorer Program, Galapagos Rift Expedition 2011. These tubeworms get their energy from chemosynthesis . CC BY 2.0
9. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
10. Tree: User:Haabet/Wikimedia Commons; Grass: User:Polishname/Wikipedia; Diatoms: Gordon T. Taylor/Stony Brook University/NOAA; Seaweed: User:Flyingdream/Wikipedia; Cyanobacteria: Barry H. Rosen/USGS; Purple bacteria: Janice Carr/CDC. Photoautotrophs include plants, algae, and bacteria and can be found in terrestrial and aquatic ecosystems . Public Domain
11. Tim Mansfield. A pitcher plant is different from other plants because it is not a producer, it is a consuemer . CC BY 2.0
12. Amy Goldstein. A dung beetle is an example of a detritivore . CC BY 2.0
13. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Trophic levels in an ecological pyramid . CC BY-NC 3.0
14. User:OlofE/Sv.Wikipedia. Example of a food chain . Public Domain
15. User:LeoNomis/Wikipedia. Example of an ecological pyramid . Public Domain
16. Courtesy of Doug Smith, National Park Service. A pack of wolves hunting a bison . Public Domain
17. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Example of a food web . CC BY-NC 3.0

CHAPTER 10 LS2-6

Chapter Outline

10.1 Extinction and Radiation of Life

Learning Objectives

- 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** 10.1).

FIGURE 10.1
An extinct *Tyrannosaurus rex*. This fossil resembles a living organism.

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 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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178261

1. What does a branch on a phylogenetic tree indicate?
2. What two things could have happened when a species disappears?
3. What is necessary regarding ability to mate for one species to become two different species?
4. What two things might a changing environment force to happen? What do each of these to things do to biodiversity?
5. How did natural selection take place in three-spined stickelbacks at Loberg Lake in Alaska? How is this an example of speciation?
6. Under what conditions does adaptive radiation take place? How are honeycreepers in Hawaii an example?
7. How many species that ever existed are now extinct?
8. How many mass extinctions have been identified according to the teacher? What is a mass extinction?
9. What is the K-T (Cretaceous-Tertiary) boundary?
10. What is found at the K-T boundary? What could that mean?

10.2 Origin of Species

Learning Objectives

- Define speciation.
- Compare and contrast allopatric and sympatric speciation.

How can a river influence evolution?

Imagine a group of small organisms, such as mice, that become separated by a mighty river. This group has now become isolated, and formed two separate groups. The groups are obviously no longer able to breed together. Over many generations, each group will evolve separately, eventually forming two completely new species of mice.

Origin of Species

Macroevolution is evolution over geologic time above the level of the species. One of the main topics in macroevolution is how new species arise. The process by which a new species evolves is called **speciation**. How does speciation occur? How does one species evolve into two or more new species?

To understand how a new species forms, it's important to review what a species is. A **species** is a group of organisms that can breed and produce fertile offspring together in nature. For a new species to arise, some members of a species must become reproductively isolated from the rest of the species. This means they can no longer interbreed with other members of the species. How does this happen? Usually they become geographically isolated first.

Allopatric Speciation

Assume that some members of a species become geographically separated from the rest of the species. If they remain separated long enough, they may evolve genetic differences. If the differences prevent them from interbreeding with members of the original species, they have evolved into a new species. Speciation that occurs in this way is called **allopatric speciation**. An example is described in the **Figure** 10.2.

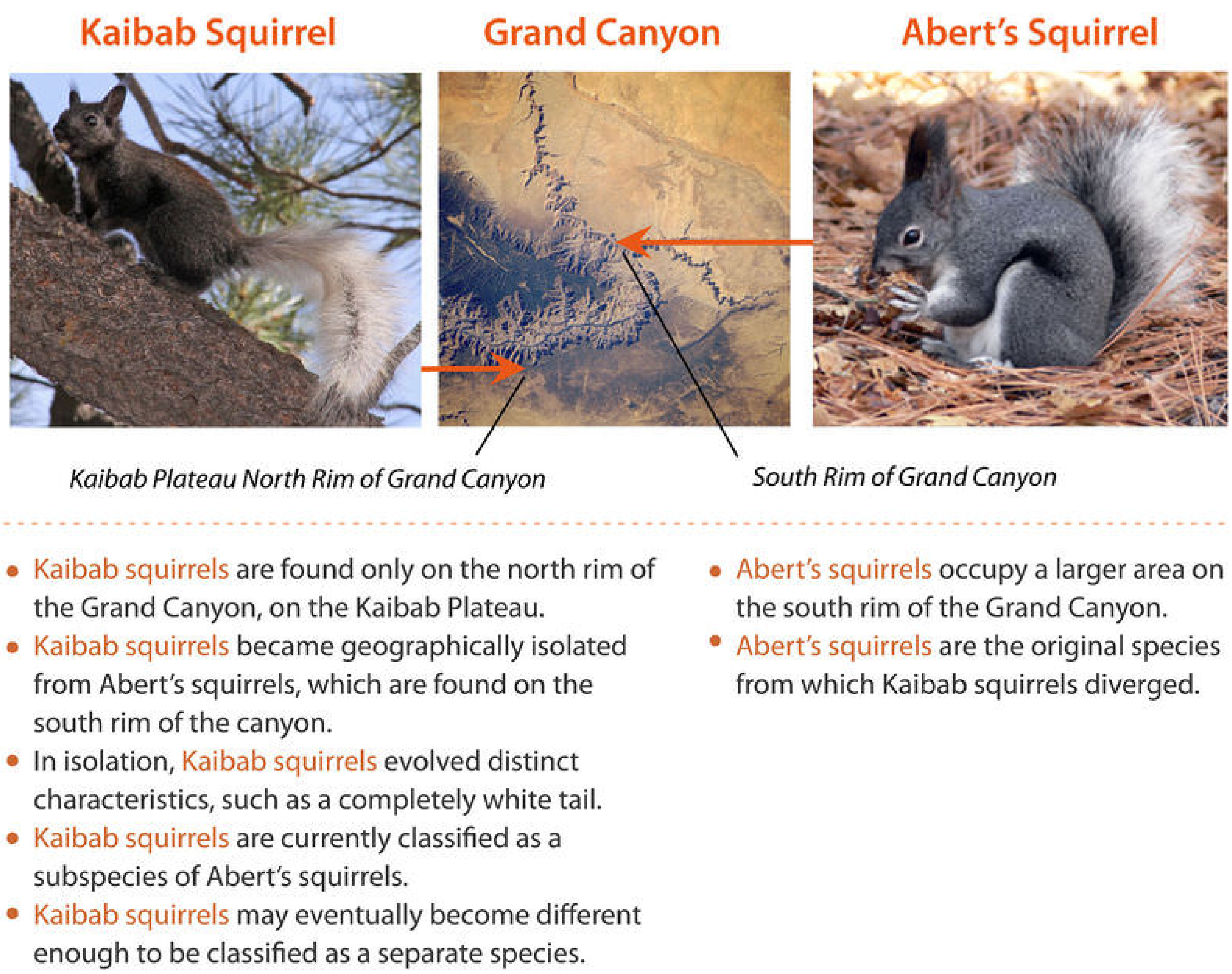


FIGURE 10.2

Allopatric Speciation in the Kaibab Squirrel. The Kaibab squirrel is in the process of becoming a new species.

Sympatric Speciation

Less often, a new species arises without geographic separation. This is called **sympatric speciation**. The following example shows one way this can occur.

1. Hawthorn flies lay eggs in hawthorn trees (see **Figure** 10.3). The eggs hatch into larvae that feed on hawthorn fruits. Both the flies and trees are native to the U.S.
2. Apple trees were introduced to the U.S. and often grow near hawthorn trees. Some hawthorn flies started to lay eggs in nearby apple trees. When the eggs hatched, the larvae fed on apples.
3. Over time, the two fly populations—those that fed on hawthorn trees and those that preferred apple trees—evolved reproductive isolation. Now they are reproductively isolated because they breed at different times. Their breeding season matches the season when the apple or hawthorn fruits mature.
4. Because they rarely interbreed, the two populations of flies are evolving other genetic differences. They appear to be in the process of becoming separate species.

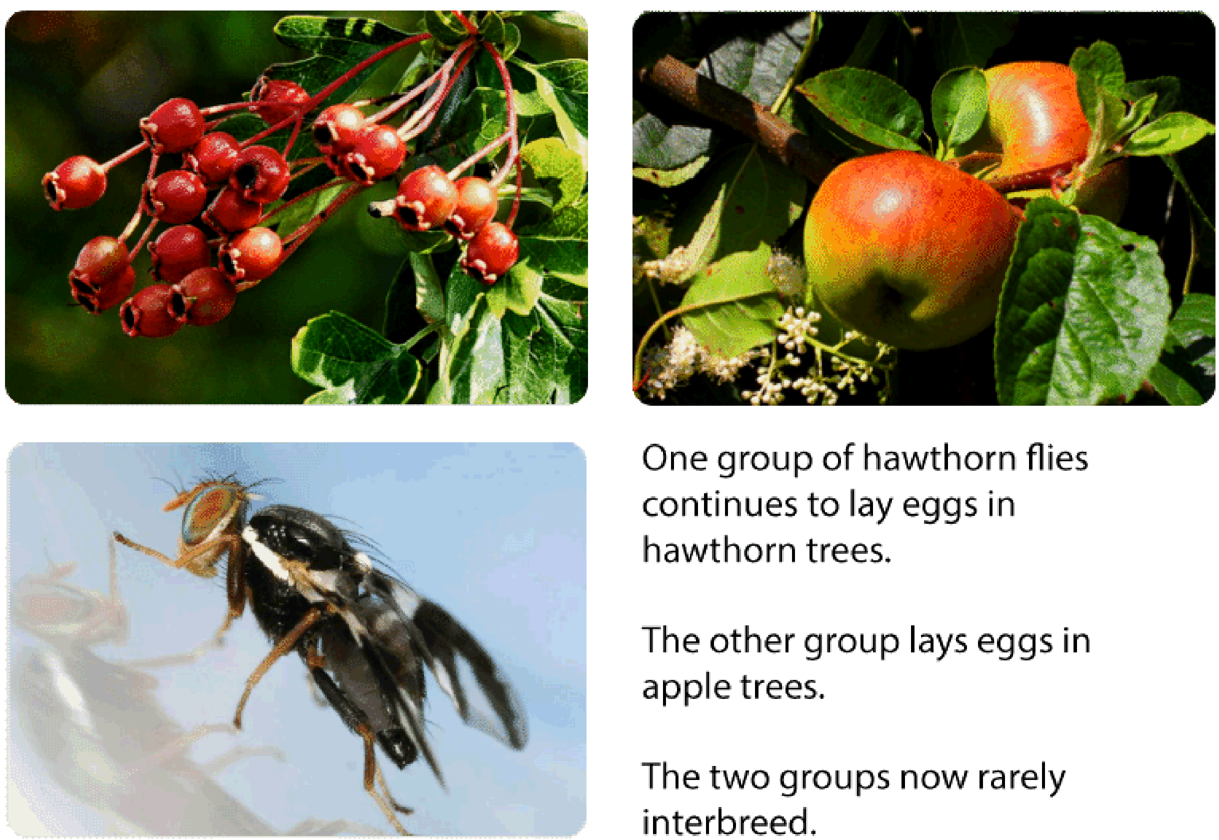


FIGURE 10.3

Sympatric Speciation in Hawthorn Flies. Hawthorn flies are diverging from one species into two. As this example shows, behaviors as well as physical traits may evolve and lead to speciation.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/157172

Summary

- New species arise in the process of speciation.
- Allopatric speciation occurs when some members of a species become geographically separated. They then evolve genetic differences. If the differences prevent them from interbreeding with the original species, a new species has evolved.
- Sympatric speciation occurs without geographic separation.

Review

1. Define speciation.
2. Describe how allopatric speciation occurs.
3. Why is sympatric speciation less likely to occur than allopatric speciation?

10.3 Global Climate Change

Learning Objectives

- Explain the greenhouse effect.
- Define global warming.
- Explain the effects of global climate change.

Is the Earth really fragile?

Maybe not the planet, but how about the ecosystems? It may soon be hard to argue that global climate change does not exist. Climate change can definitely be seen in numerous ecosystems. So what will we do about it?

Global Climate Change

Another major problem caused by air pollution is global climate change. Gases such as carbon dioxide from the burning of fossil fuels increase the natural greenhouse effect. This raises the temperature of Earth's surface.

What Is The Greenhouse Effect?

The **greenhouse effect** is a natural feature of Earth's atmosphere. It occurs when gases in the atmosphere radiate the sun's heat back down to Earth's surface (see **Figure** 10.4). Otherwise, the heat would escape into space. Without the greenhouse effect, Earth's surface temperature would be far cooler than it is. In fact, it would be too cold to support life as we know it.

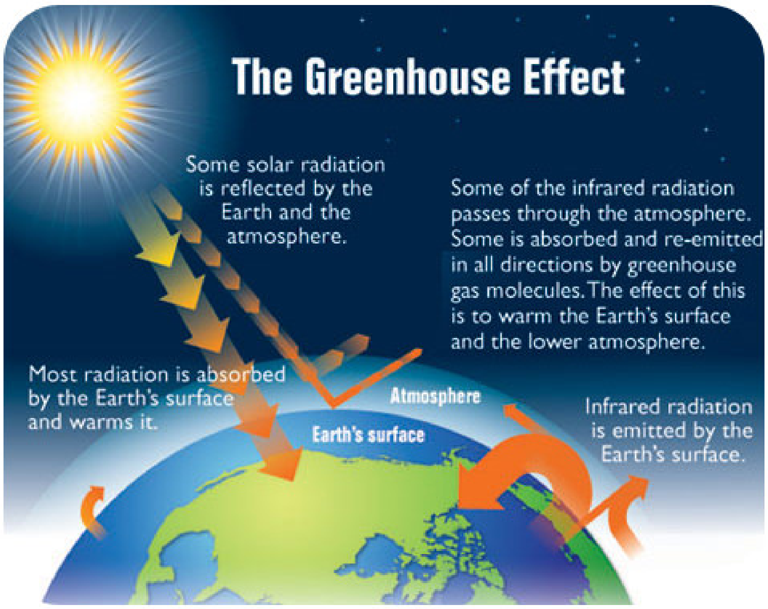


FIGURE 10.4
The Greenhouse Effect. Without greenhouse gases, most of the sun's energy would be radiated from Earth's surface back out to space.

Global Warming

Global warming refers to a recent increase in Earth's average surface temperature (see **Figure** 10.5). During the past century, the temperature has risen by almost 1°C (about 1.3°F). That may not seem like much. But consider that just 10°C is the difference between an ice-free and an ice-covered Earth.

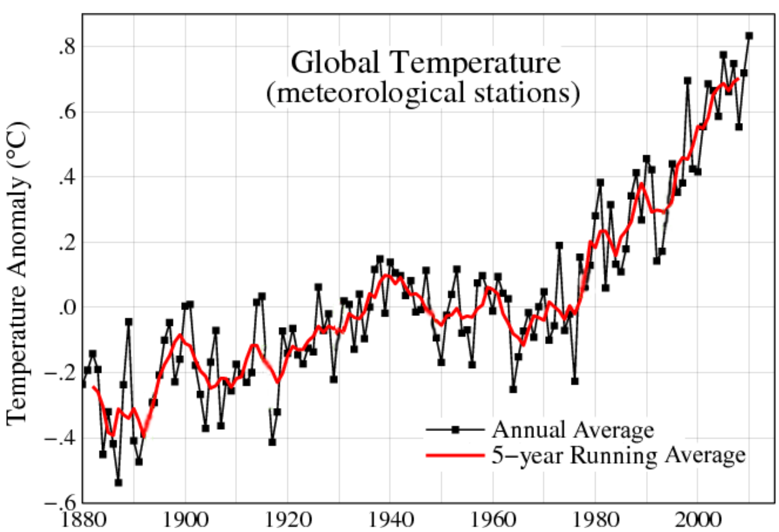


FIGURE 10.5
The average annual temperature on Earth has been rising for the past 100 years.

Most scientists agree that global warming is caused by more carbon dioxide in the atmosphere (see **Figure** 10.6). This increases the greenhouse effect. There is more carbon dioxide mainly because of the burning of fossil fuels. Destroying forests is another cause. With fewer forests, less carbon dioxide is removed from the atmosphere by photosynthesis.

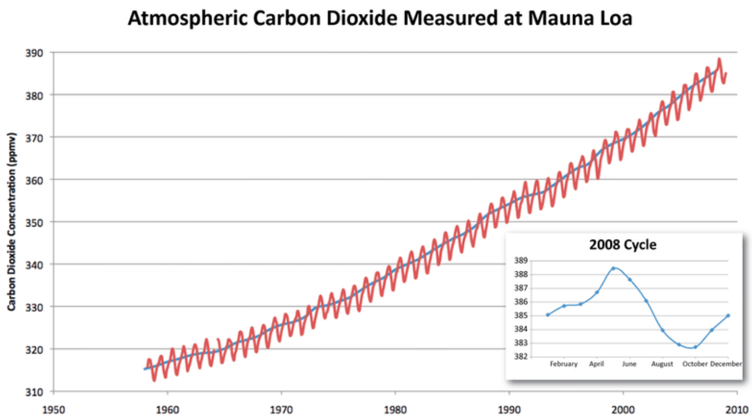


FIGURE 10.6
This graph shows the recent trend in carbon dioxide in the atmosphere.

Effects of Climate Change

How has global warming affected Earth and its life? Some of its effects include:

- Decline in cold-adapted species such as polar bears.
- Melting of glaciers and rising sea levels.
- Coastal flooding and shoreline erosion.
- Heat-related human health problems.
- More droughts and water shortages.
- Changing patterns of precipitation.
- Increasing severity of storms.
- Major crop losses.

KQED: Climate Watch: California at the Tipping Point

The world's climate is changing and California is now being affected in both dramatic and subtle ways. In 2008, scientists determined that California's temperatures increased by more than 2.1°F during the last century. What's more, the data showed that human activity has played a significant role in that climate change. "What's just 2 degrees?" you may wonder. But, as the science shows, just 2 degrees is extremely significant.

What does all this temperature change mean? For starters, declining mountain snowpack and prolonged drought conditions could pose a threat to limited water supplies. Heat waves are projected to be longer, bringing increased danger from wildfires and heat-related deaths. Rising sea levels due to temperature shifts jeopardize life in coastal areas, both for human communities and the plants and animals that rely on intertidal and rich wetland ecosystems. Also, more precipitation is expected to fall as rain rather than snow, thereby increasing the risk of floods. And, as heat increases the formation of smog, poor air quality could get even worse.

Climate change may also profoundly affect the economy in California and elsewhere. Shorter ski seasons and damage to the marine ecosystem mean a reduction in tourism. Water shortages mean issues with the commercial and recreational fishing industry, and higher temperatures will affect crop growth and quality, weakening the agricultural industry, to name just a few of the economic issues associated with climate change.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/414

Melting glaciers, rising temperatures and droughts are all impacts of global warming. But how does global warming actually affect the oceans? The sea, it turns out, absorbs carbon dioxide emissions. The ocean acts like a giant sponge, absorbing carbon dioxide emissions from the air. And as we add more and more carbon dioxide to air by burning fossil fuels, the ocean is absorbing it. On one level, it's done us a big favor. Scientists say that we would be experiencing much more extreme climate change were it not for the ocean's ability to remove the heat-trapping gas. However, these emissions are causing the oceans to become more acidic. Changing pH levels threaten entire marine food webs, from coral reefs to salmon.

As carbon dioxide levels increase in the atmosphere, the levels also increase in the oceans. What effects does this have? Can ocean acidification make it difficult for sea life to produce their hard exoskeletons?

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/108467

Efforts to reduce future global warming mainly involve energy use. We need to use less energy, for example, by driving more fuel-efficient cars. We also need to switch to energy sources that produce less carbon dioxide, such as solar and wind energy. At the same time, we can increase the amount of carbon dioxide that is removed from air. We can stop destroying forests and plant new ones.

Summary

- Gases such as carbon dioxide from the burning of fossil fuels increase the natural greenhouse effect. This is raising the temperature of Earth's surface, and is called global warming.

Review

1. How does air pollution contribute to global warming?
2. What is the greenhouse effect?
3. What are three effects of global warming?

10.4 Overpopulation and Over-Consumption

Learning Objectives

- 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 human resident of planet Earth and even more for a single 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** 10.7). 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 10.7
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** 10.8).

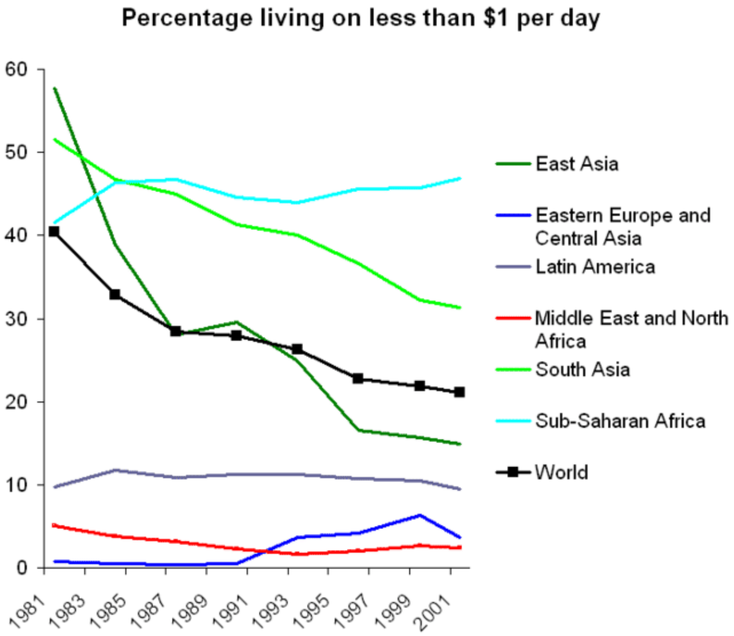


FIGURE 10.8

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.

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 decades ago. All of these require resources in order to be produced, and fossil fuels in order to be powered (**Figure** 10.9). 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.

MEDIA

Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186846

MEDIA

Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/152830

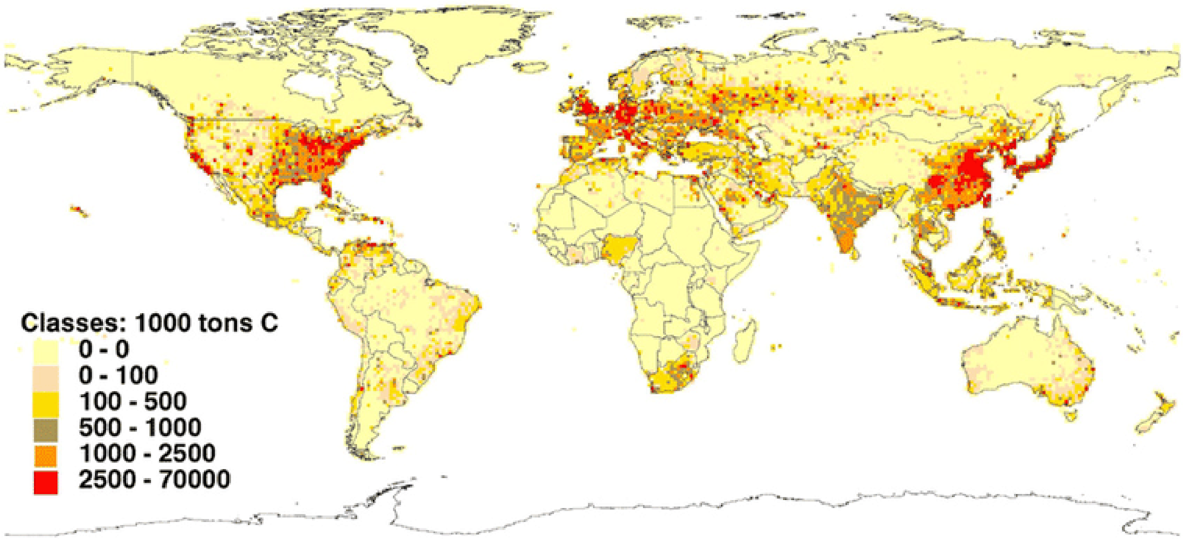


FIGURE 10.9

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.

Summary

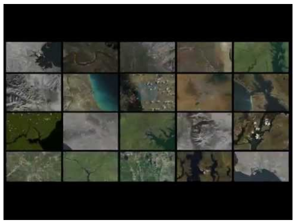
- The Green Revolution has allowed more people to be fed and the human population to increase. The consequences are land loss, pollution, and a tremendous use of fossil fuels.
- By keeping more people alive, the Green Revolution has put a strain on other needed resources like water and materials.
- Overpopulation 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.

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.?

Explore More

Use these resources to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/171326

1. What is the bank the announcer is referring to?
2. What are the two factors that our impact on this bank depend on?
3. Earth is now home to 7 billion people yet there is the statement that if everyone lived like an average European Earth could only support 2 billion in the long term, so what does that mean about the present?
4. What are ecosystem services? What are some examples?
5. What is overconsumpulation?
6. What does the speaker say will happen if we don't get population down to 2 billion?
7. What are the two options?
8. What will happen if population continue to grow or doesn't shrink?

10.5 Oil Spills

Learning Objectives

- Describe the damage that occurs from oil spills.

Will this oil spill victim live?

After every oil spill, photos are released of marine organisms covered with oil. Sometimes people are trying to clean them. Seabirds are especially vulnerable; they dive into a slick because the surface looks like calmer water. Oil-coated birds cannot regulate their body temperatures and will die. After cleanup, some birds will live and some will not.

Oil Spills

Large oil spills, like the Exxon Valdez in Alaska in 1989, get a lot of attention, as they should. Besides these large spills, though, much more oil enters the oceans from small leaks that are only a problem locally. In this concept, we'll take a look at a large recent oil spill in the Gulf of Mexico.

The Gulf of Mexico Oil Spill

New drilling techniques have allowed oil companies to drill in deeper waters than ever before. This allows us to access oil deposits that were never before accessible, but only with great technological difficulty. The risks from deepwater drilling and the consequences when something goes wrong are greater than those associated with shallower wells.

Explosion

Working on oil platforms is dangerous. Workers are exposed to harsh ocean conditions and gas explosions. The danger was never more obvious than on April 20, 2010, when 11 workers were killed and 17 injured in an explosion on a deepwater oil rig in the Gulf of Mexico (**Figure** 10.10). The drilling rig, operated by BP, was 77 km (48 miles) offshore and the depth to the well was more than 5,000 feet.

FIGURE 10.10
The U.S. Coast Guard tries to put out the fire and search for missing workers after the explosion on the Deepwater Horizon drilling rig. Eleven workers were killed.

Spill

Two days after the explosion, the drill rig sank. The 5,000-foot pipe that connected the wellhead to the drilling platform bent. Oil was free to gush into the Gulf of Mexico from nearly a mile deep (**Figure** 10.11). Initial efforts to cap or contain the spill at or near its source all failed to stop the vast oil spill. It was not until July 15, nearly three months after the accident, that the well was successfully capped.

Estimating the flow of oil into the Gulf from the well was extremely difficult because the leak was so far below the surface. The U.S. government estimates that about 4.9 million barrels entered the Gulf at a rate of 35,000 to 60,000 barrels a day. The largest previous oil spill in the United States was of 300,000 barrels by the Exxon Valdez in 1989 in Prince William Sound, Alaska.

Cleanup

Once the oil is in the water, there are three types of methods for dealing with it:

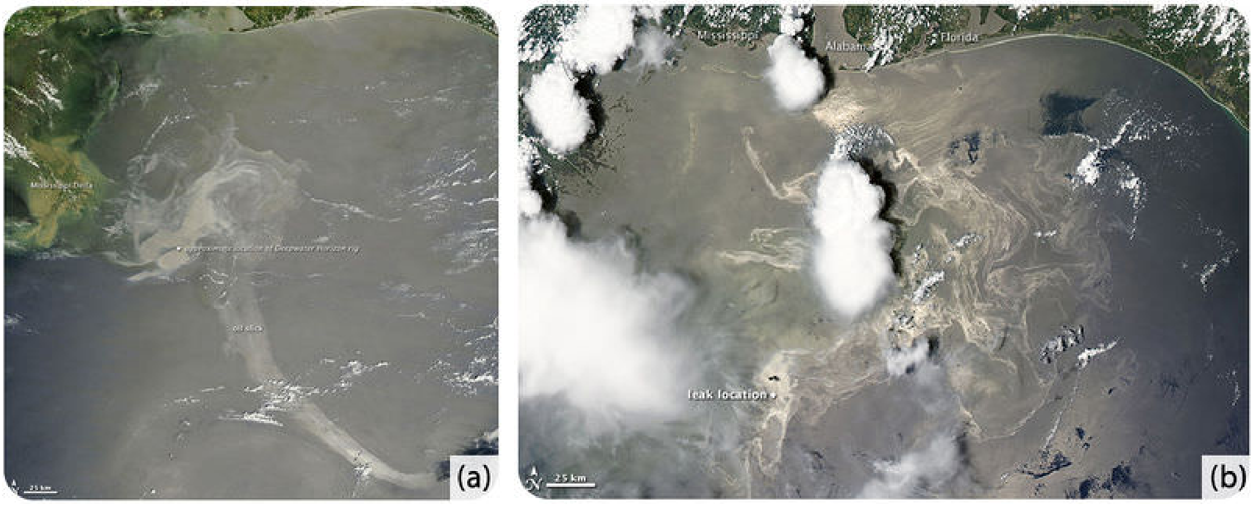


FIGURE 10.11
(a) On May 17, 2010, oil had been leaking into the Gulf for nearly one month. On that date government estimates put the maximum total oil leak at 1,600,000 barrels, according to the New York Times. (b) The BP oil spill on June 19, 2010. The government estimates for total oil leaked by this date was 3,200,000 barrels.

1. Removal: Oil is corralled and then burned; natural gas is flared off (**Figure** 10.12). Machines that can separate oil from the water are placed aboard ships stationed in the area. These ships cleaned tens of thousands of barrels of contaminated seawater each day.

FIGURE 10.12
Burning the oil can reduce the amount in the water.

2. Containment: Floating containment booms are placed on the surface offshore of the most sensitive coastal areas in an attempt to attempt to trap the oil. But the seas must be calm for the booms to be effective, and so were not very useful in the Gulf (**Figure** 10.13). Sand berms have been constructed off of the Louisiana coast to keep the oil from

reaching shore.

FIGURE 10.13
A containment boom holds back oil, but it is only effective in calm water.

3. Dispersal: Oil disperses naturally over time because it mixes with the water. However, such large amounts of oil will take decades to disperse. To speed the process up, BP has sprayed unprecedented amounts of chemical dispersants on the spill. That action did not receive support from the scientific community since no one knows the risks to people and the environment from such a large amount of these harmful chemicals. Some workers may have become ill from exposure to the chemicals.

Plugging the Well

BP drilled two relief wells into the original well. When the relief wells entered the original borehole, specialized liquids were pumped into the original well to stop the flow. Operation of the relief wells began in August 2010. The original well was declared effectively dead on September 19, 2010.

Impact

The economic and environmental impact of this spill will be felt for many years. Many people rely on the Gulf for their livelihoods or for recreation. Commercial fishing, tourism, and oil-related jobs are the economic engines of the region. Fearing contamination, NOAA imposed a fishing ban on approximately one-third of the Gulf (**Figure** 10.14). Tourism is down in the region as beach goers find other ways to spend their time. Real estate prices along the Gulf have declined precipitously.

The toll on wildlife is felt throughout the Gulf. Plankton, which form the base of the food chain, are killed by the oil, leaving other organisms without food. Islands and marshlands around the Gulf have many species that are already at risk, including four endangered species of sea turtles. With such low numbers, rebuilding their populations after the spill will be difficult.

The Gulf of Mexico is one of only two places in the world where bluefin tuna spawn and they are also already endangered. Marine mammals in the Gulf may come up into the slick as they come to the surface to breathe.

Eight national parks and seashores are found along the Gulf shores. Other locations may be ecologically sensitive habitats such as mangroves or marshlands.

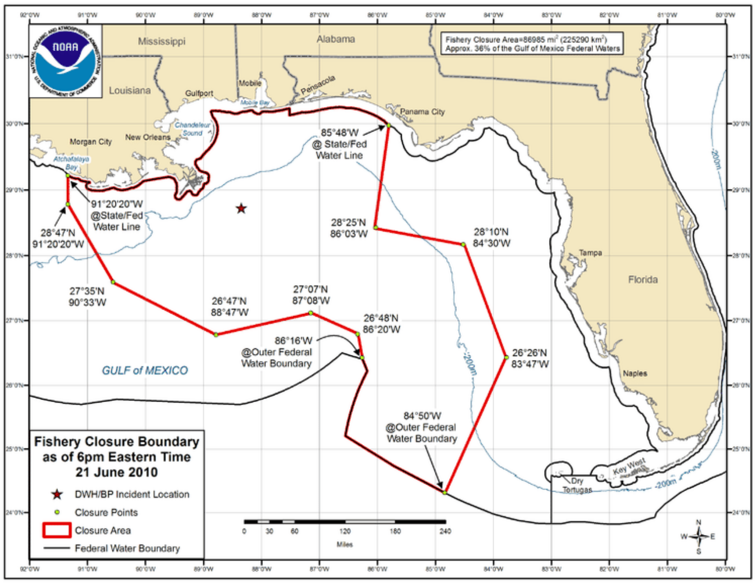


FIGURE 10.14

This was the extent of the banned area on June 21, 2010.

Long-Term Effects

There is still oil on beaches and in sediment on the seafloor in the region. Chemicals from the oil dispersants are still in the water. In October 2011 a report was issued that showed that whales and dolphins are dying in the Gulf at twice their normal rate. The long-term effects will be with us for a long time.

Multimedia

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186890

Summary

- As oil becomes scarcer, there are economic incentives to drill in deeper water, but this is a technologically difficult undertaking.
- There are still chemicals in the water that cause damage to wildlife.
- Massive amounts of oil that have been spilled into a water body can be removed, contained, or dispersed. These actions are difficult and may have negative consequences.
- Birds or beaches coated with oil are the most visible evidence of a spill, but there are many consequences that we can't see, like oil on the seabed or chemical dispersants in the water.

Review

1. What precautions should be made to be sure that there is little chance of negative consequences from an oil spill?
2. How do chemical dispersants work? Should they always be used?
3. What are the long-term effects of a major oil spill?

Explore More

Use the resource below to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178425

1. What were the causes of the Exxon Valdez disaster?
2. What were the oil industry's response plans?
3. What was the industry's response actually?
4. What were chemical dispersants used for?
5. What were the concerns brought about by the use of chemical dispersants?
6. How much of the oil was recovered?
7. Who was assigned responsibility for the spill? What was lost?
8. When plan for the Alaska pipeline was drawn up, how was the environment to be protected? What was the mistake made by the state?
9. What happened when the state passed its own safety law?
10. How did the passage of ships change from when the oil first was passing through the area to when the Exxon Valdez spill happened?
11. What was supposed to be done during the time the ship was going through the channel, who was supposed to do it, and what was actually happening?
12. What was the long-term damage?
13. What are the safeties now in place?
14. What does it mean that the offense got ahead of the defense in the Gulf of Mexico?
15. How had cleanup changed in two decades?
16. Have we really learned the lessons of Exxon Valdez and Gulf of Mexico spills?

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186892

10.6 References

1. Jeff. Fossil of a Tyrannosaurus Rex . CC BY 2.0
2. From left to right: Allyson Mathis/National Park Service; NASA; Sally King/National Park Service; Composite created by CK-12 Foundation. From left to right: http://www.flickr.com/photos/grand_canyon_nps/6171345968/; http://commons.wikimedia.org/wiki/File:Grand_Canyon_autumn_STS61A-48-91.jpg; http://bandelier.areaparks.com/parkinfo.html?pid=1789 . Public Domain
3. Hawthorn berries: Brian Clift; Apples: Jennifer C.; Hawthorn fly: Joseph Berger; Composite created by CK-12 Foundation. Sympatric speciation in Hawthorn flies . Hawthorn berries and apples: CC BY 2.0; Hawthorn fly: CC BY 3.0
4. U.S. Environmental Protection Agency. Diagram of the greenhouse effect . Public Domain
5. NASA, modified by Zachary Wilson/CK-12 Foundation. Annual temperature over the last 100 years . Public Domain
6. Steven Lai and Zachary Wilson, based on data from the Carbon Dioxide Information Analysis Center (http://cdiac.ornl.gov/ Carbon dioxide concentration in the atmosphere over time . CC BY-NC 3.0
7. Courtesy of Charles O'Rear/US Department of Agriculture. Plane releasing pesticides over a field . Public Domain
8. User:Ultramarine/Wikipedia. Graph showing percentage of people in the world that live in poverty . Public Domain
9. Richard Olson and Holly Gibbs, ORNL/ESD. Map of carbon dioxide emissions in the world . Public Domain
10. Courtesy of the US Coast Guard. The Deepwater Horizon oil rig on fire in the Gulf of Mexico . Public Domain
11. (a) Courtesy of Jeff Schmaltz, MODIS Rapid Respond Team, and NASA; (b) Courtesy of MODIS Rapid Response Team and NASA. Satellite image of oil spill in the Gulf of Mexico . Public Domain
12. Courtesy of John Kepsimelis, US Coast Guard. Burning the oil can reduce the amount in the water . Public Domain
13. Courtesy of the Minerals Management Service. Picture of a containment boom . Public Domain
14. Courtesy of the US National Oceanic and Atmospheric Administration. Map of the fishing ban as a result of the Deepwater Horizon oil spill . Public Domain

CHAPTER 11 LS2-7

Chapter Outline

11.1 Hazardous Waste

Learning Objectives

- Define hazardous waste.
- Explain how hazardous wastes negatively affect humans and the environment.

Are these hazardous wastes safely stored?

Hazardous wastes must be stored, used and disposed of properly. Some wastes are extremely corrosive and can get through steel drums over time. How can we be sure that hazardous wastes are actually stored safely for the time necessary?

What Is Hazardous Waste?

Hazardous waste is any waste material that is dangerous to human health or that degrades the environment. Hazardous waste includes substances that are:

1. Toxic: causes serious harm or death, or is poisonous.
2. Chemically active: causes dangerous or unwanted chemical reactions, such as explosions.
3. Corrosive: destroys other things by chemical reactions.
4. Flammable: easily catches fire and may send dangerous smoke into the air.

All sorts of materials are hazardous wastes and there are many sources. Many people have substances that could become hazardous wastes in their homes. Several cleaning and gardening chemicals are hazardous if not used properly. These include chemicals like drain cleaners and pesticides that are toxic to humans and many other creatures. While these chemicals are fine if they are stored and used properly, if they are used or disposed of improperly, they may become hazardous wastes. Others sources of hazardous waste are shown in **Table** 11.1.

TABLE 11.1: Hazardous Waste

Type of Hazardous Waste	Example	Why it is Hazardous
Chemicals from the automobile industry	Gasoline, used motor oil, battery acid, brake fluid	Toxic to humans and other organisms; often chemically active; often flammable.
Batteries	Car batteries, household batteries	Contain toxic chemicals; are often corrosive.
Medical wastes	Surgical gloves, wastes contaminated with body fluids such as blood, x-ray equipment	Toxic to humans and other organisms; may be chemically active.
Paints	Paints, paint thinners, paint strippers, wood stains	Toxic; flammable.
Dry cleaning chemicals	Many various chemicals	Toxic; many cause cancer in humans.
Agricultural chemicals	Pesticides, herbicides, fertilizers	Toxic to humans; can harm other organism; pollute soils and water.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186860

Summary

- Hazardous waste is material that is toxic, chemically active, corrosive, or flammable.
- Hazardous wastes are damaging to the environment or human health.
- Hazardous materials are found in a variety of settings, including industry, agriculture, and people's homes.

Review

1. If pesticides are toxic, why do we spray them on food crops?
2. Why are some medical wastes hazardous?
3. What is hazardous waste? Is it always clear whether something is hazardous or not?

11.2 Preventing Hazardous Waste Problems

Learning Objectives

- Explain how to prevent pollution by hazardous wastes.

What should be done about hazardous waste sites?

Cleaning up toxic wastes has incredible costs in time and money. Laws now protect lands from contamination, but many sites were damaged before those laws were passed. No other organization is big enough, so it is the government's job to clean up a toxic site if the company that caused the damage no longer exists or cannot afford cleanup.

Preventing Hazardous Waste Pollution

Nations that have more industry produce more hazardous waste. Currently, the United States is the world's largest producer of hazardous wastes, but China, which produces so many products for the developed world, may soon take over the number-one spot.

Countries with more industry produce more hazardous wastes than those with little industry. Problems with hazardous wastes and their disposal became obvious sooner in the developed world than in the developing world. As a result, many developed nations, including the United States, have laws to help control hazardous waste disposal and to clean toxic sites.

As mentioned in the "Impacts of Hazardous Waste" concept, the Superfund Act requires companies to clean up contaminated sites that are designated as Superfund sites (**Figure** 11.1). If a responsible party cannot be identified, because the company has gone out of business or its culpability cannot be proven, the federal government pays for the cleanup out of a trust fund with money put aside by the petroleum and chemical industries. As a result of the Superfund Act, companies today are more careful about how they deal with hazardous substances.

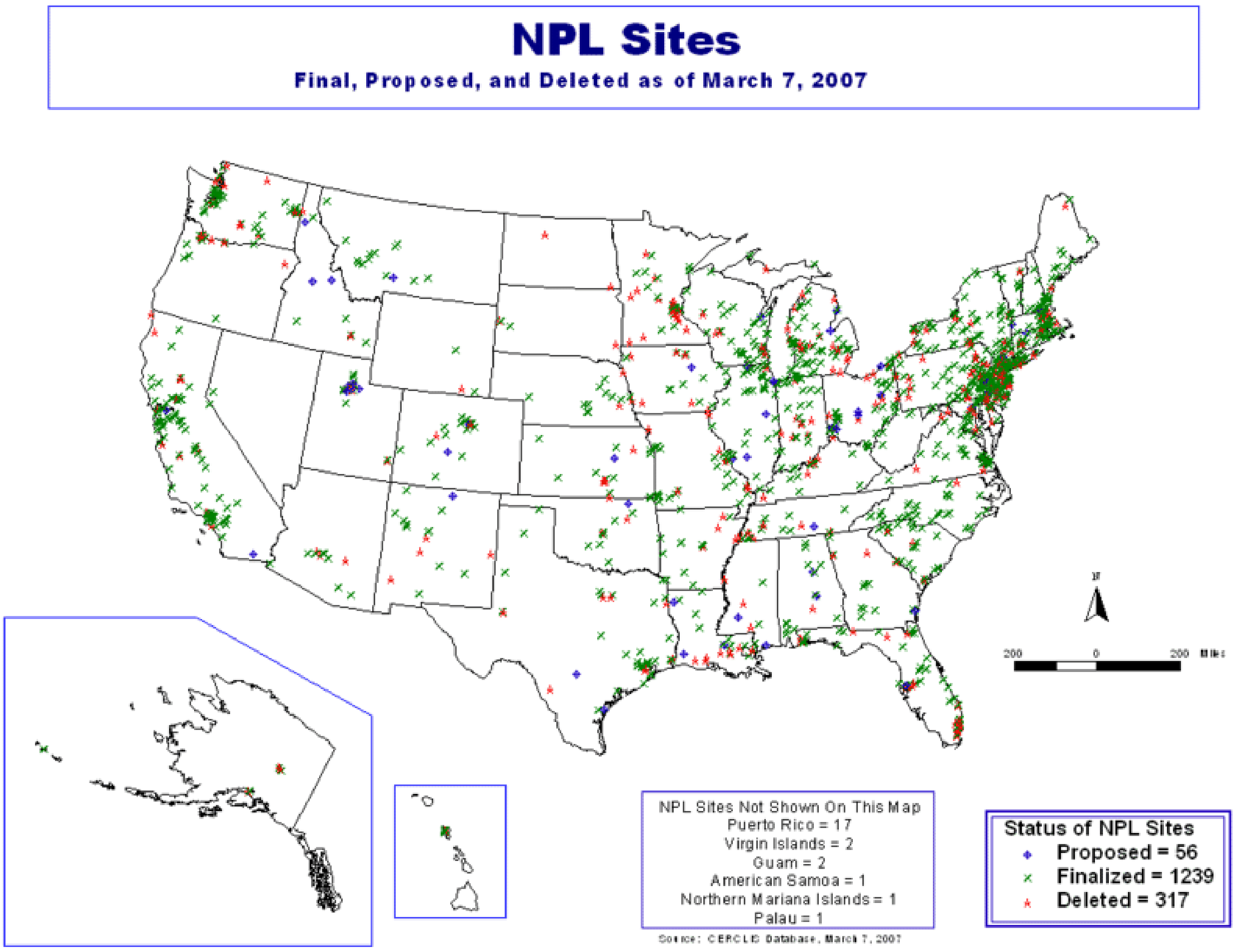


FIGURE 11.1

Superfund sites are located all over the nation and many are waiting to be cleaned up.

The Resource Conservation and Recovery Act of 1976 requires that companies keep track of any hazardous materials they produce. These materials must be disposed of using government guidelines and records must be kept to show the government that the wastes were disposed of safely. Workers must be protected from the hazardous materials.

To some extent, individuals can control the production and disposal of hazardous wastes. We can choose to use materials that are not hazardous, such as using vinegar as a cleanser. At home, people can control the amount of pesticides that they use (or they can use organic methods of pest control). It is also necessary to dispose of hazardous materials properly by not pouring them over the land, down the drain or toilet, or into a sewer or trashcan.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186861

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186863

Summary

- Government regulations, like the Superfund Act, hold companies accountable for the hazardous materials they produce.
- Developed nations have seen the consequences of hazardous waste and are more likely to have protections in place than developing countries.
- People can lessen the hazardous waste problem by using materials that are not hazardous or by disposing of wastes properly.

Review

1. How do the Superfund Act and other government regulations prevent lands from being contaminated?
2. What can you do to prevent or lessen the generation of hazardous wastes?
3. Why does the United States have so many Superfund sites compared with other nations?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178376

1. Why can't hazardous wastes be thrown in the trash?
2. What does proper disposal of hazardous waste prevent?

3. Although this video is made for a specific location, how can you use the information to dispose of hazardous waste in your own region?
4. What typical household wastes are hazardous?
5. What should you do with the hazardous wastes?
6. What should you do with leftover pharmaceuticals?
7. How does the hazardous waste facility in Contra Costa County meet the motto reduce, reuse, recycle?
8. How can you find a hazardous waste facility in your area? Does your facility take all toxic waste items? How about pharmaceuticals?

11.3 Impacts of Hazardous Waste

Learning Objectives

- Describe the impacts of hazardous waste on humans and the environment.
- Trace how these impacts led to the Superfund Act.

What role do citizens play in protecting their environment?

Sometimes it's up to the residents in an area to recognize the effects of hazardous waste and to get the government to find the responsible party and initiate cleanup. Here, a resident of Love Canal protests the hazardous waste contamination in her neighborhood.

Love Canal

The story of Love Canal, New York, begins in the 1950s, when a local chemical company placed hazardous wastes in 55-gallon steel drums and buried them. Love Canal was an abandoned waterway near Niagara Falls and was thought to be a safe site for hazardous waste disposal because the ground was fairly impermeable (**Figure** 11.2). After burial, the company covered the containers with soil and sold the land to the local school system for $1. The company warned the school district that the site had been used for toxic waste disposal.

FIGURE 11.2
Steel drums were used to contain 21,000 tons of hazardous chemicals at Love Canal.

Soon a school, a playground, and 100 homes were built on the site. The impermeable ground was breached when sewer systems were dug into the rock layer. Over time, the steel drums rusted and the chemicals were released into the ground. In the 1960s people began to notice bad odors. Children developed burns after playing in the soil, and they were often sick. In 1977 a swamp created by heavy rains was found to contain 82 toxic chemicals, including 11 suspected cancer-causing chemicals.

A Love Canal resident, Lois Gibbs, organized a group of citizens called the Love Canal Homeowners Association to try to find out what was causing the problems (See opening image). When they discovered that toxic chemicals were buried beneath their homes and school, they demanded that the government take action to clean up the area and remove the chemicals.

Superfund Act

In 1978, people were relocated to safe areas. The problem of Love Canal was instrumental in the passage of the the **Superfund Act** in 1980. This law requires companies to be responsible for hazardous chemicals that they put into the environment and to pay to clean up polluted sites, which can often cost hundreds of millions of dollars. Love Canal became a **Superfund site** in 1983 and as a result, several measures were taken to secure the toxic wastes. The land was capped so that water could not reach the waste, debris was cleaned from the nearby area, and contaminated soils were removed.

Impacts of Hazardous Waste

The pollution at Love Canal was not initially visible, but it became visible. The health effects from the waste were also not initially visible, but they became clearly visible. The effects of the contamination that were seen in human health included sickness in children and a higher than normal number of miscarriages in pregnant women. Toxic chemicals may cause cancer and birth defects. Why do you think children and fetuses are more susceptible? Because young organisms grow more rapidly, they take in more of the toxic chemicals and are more affected.

Cancer Clusters

Sometimes the chemicals are not so easily seen as they were at Love Canal. But the impacts can be seen statistically. For example, contaminated drinking water may cause an increase in some types of cancer in a community.

Why is one person with cancer not enough to suspect contamination by toxic waste? One is not a statistically valid number. A certain number of people get cancer all the time. To identify contamination, a number of cancers above the normal rate, called a cancer cluster, must be discovered. A case that was made into a book and movie called *A Civil Action* involved the community of Woburn, Massachusetts. Groundwater contamination was initially suspected because of an increase in childhood leukemia and other illnesses. As a result of concern by parents, the well water was analyzed and shown to have high levels of TCE (trichloroethylene).

Toxic Metals

Lead and mercury are two chemicals that are especially toxic to humans. Lead was once a common ingredient in gasoline and paint, but it was shown to damage human brains and nervous systems. Since young children are growing rapidly, lead is especially harmful in children under the age of six (**Figure** 11.3). In the 1970s and 1980s, the United States government passed laws completely banning lead in gasoline and paint. Homes built before the 1970s may contain lead paint. Paint so old is likely to be peeling and poses a great threat to human health. About 200 children die every year from lead poisoning.

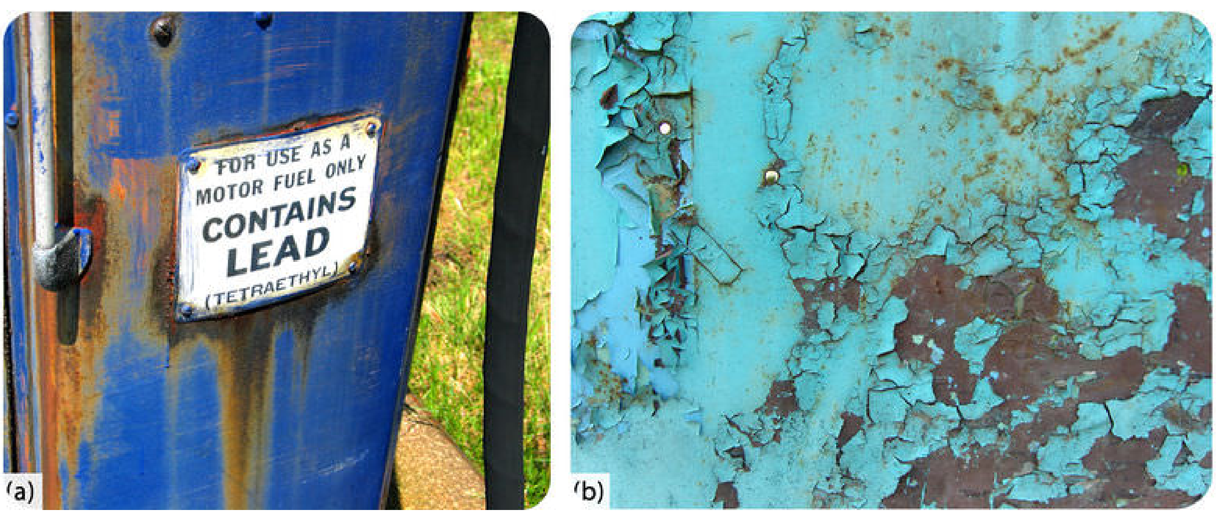


FIGURE 11.3

(a) Leaded gasoline. (b) Leaded paint.

Mercury is a pollutant that can easily spread around the world. Sources of mercury include volcanic eruptions, coal burning, and wastes such as batteries, electronic switches, and electronic appliances such as television sets. Like lead, mercury damages the brain and impairs nervous system function. More about the hazards of mercury pollution can be found later in this concept.

Summary

- The Superfund Act of 1980 requires that companies safely dispose of hazardous chemicals they generate and clean up sites they pollute.
- The effects of hazardous wastes on human populations include miscarriages, birth defects, brain damage, and cancer, particularly in children.
- An individual may develop a disease, like cancer, but when the number of cases of the disease exceeds what is found in other areas, it is cause for concern.

Review

1. If waste is to remain hazardous for a long period of time, how can society protect itself from problems as occurred at Love Canal?
2. What is the Superfund Act and how did Love Canal lead to it?
3. What is a cancer cluster? What should be done if one is found?

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/169944

11.4 Air Quality

Learning Objectives

- 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** 11.4).

FIGURE 11.4
The 2012 Olympic Games in London opening ceremony contained a reen-actment 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** 11.5). Photochemical smog consists of more than 100 compounds, most importantly ozone.

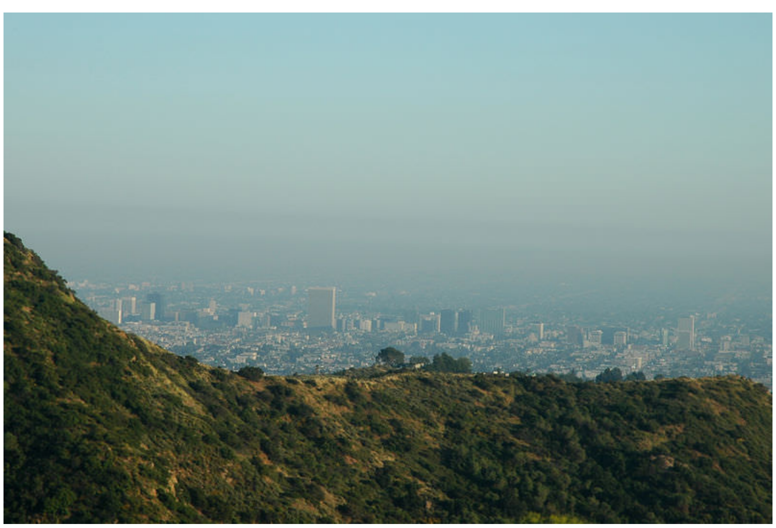


FIGURE 11.5
Smog over Los Angeles as viewed from the Hollywood Hills.

The Clean Air Act

Terrible air pollution events in Pennsylvania and London, in which many people died, 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 11.2 lists the smoggiest cities in 2013: 7 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 11.2: Smoggiest U.S. Cities, 2013

Rank	City, State
1	Los Angeles area, California
2	Visalia-Porterville, California
3	Bakersfield-Delano, California
4	Fresno-Madera, California
5	Hanford-Corcoran, California
6	Sacramento area, California
7	Houston area, Texas
8	Dallas-Fort Worth, Texas
9	Washington D.C. area
10	El Centro, California

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.

Review

1. How does photochemical smog differ from other types of air pollution?
2. What does the Clean Air Act regulate? what are the most important pollutants it regulates?
3. Why do parts of California have such bad air pollution?

11.5 Effects of Air Pollution on the Environment

Learning Objectives

- 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** 11.6).

FIGURE 11.6
Smog in New York City.

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.

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.

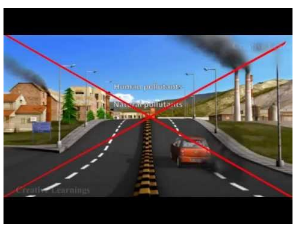
Some crop plants show ozone damage (**Figure** 11.7). When exposed to ozone, spinach leaves become spotted. Soybeans and other crops have reduced productivity. In developing nations, where getting every last bit of food energy out of the agricultural system is critical, any loss is keenly felt.

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.

FIGURE 11.7
The spots on this leaf are caused by ozone damage.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186903

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.

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 happened to air temperature when jet airplanes could not fly over the United States for three days? Why? If smog were reduced, what effect might that have on temperature?

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186905

11.6 Reducing Air Pollution

Learning Objectives

- 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** 11.8). 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 11.8

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** 11.9). 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.

FIGURE 11.9
A hydrogen fuel-cell car looks like a gasoline-powered car.

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** 11.10). Gases, such as nitrogen oxides, can be broken down at very high temperatures.

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.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186915

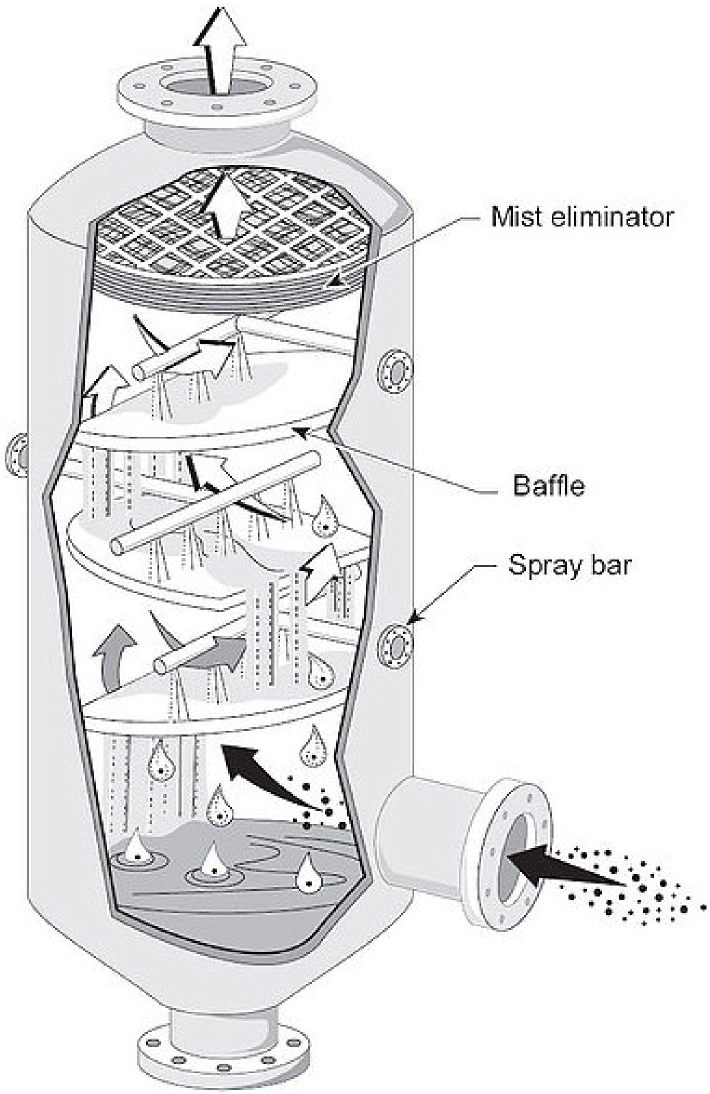


FIGURE 11.10
Scrubbers remove particles and waste gases from exhaust.

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.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/164837

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.

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?

11.7 Reducing Greenhouse Gas Pollution

Learning Objectives

- 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** 11.11). 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 11.11
A bus that runs on soybean oil shows the potential of biofuels.

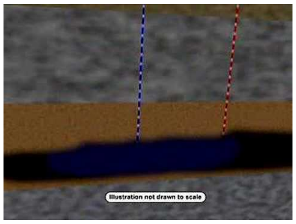
Carbon Capture and Sequestration

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.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186927

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.

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?

Explore More

Use this resource (watch from 2:12 to 4:25) to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/178443

1. What are the four strategies that California will use together to meet their greenhouse gas reduction target?
2. What does cap and trade do?
3. What does the cap in cap-and-trade refer to?
4. How will California meet its cap?
5. What does the trade in cap-and-trade refer to? What is the incentive to reduce emissions?

6. Why is cap-and-trade a good system?
7. Has this system worked in another environmental area?

11.8 Water Pollution

Learning Objectives

- 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. 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** 11.12). 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 11.12
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.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/116516

Industrial Pollution

Factories and hospitals spew pollutants into the air and waterways (**Figure** 11.13). 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.

FIGURE 11.13
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.

Agricultural Pollution

Runoff from crops, livestock, and poultry farming carries contaminants such as fertilizers, pesticides, and animal waste into nearby waterways (**Figure** 11.14). Soil and silt also run off farms. Animal wastes may carry harmful diseases, particularly in the developing world.

FIGURE 11.14
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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/160889

1. What is an example of point source pollution?
2. What is our biggest threat to clean water, at least in Indiana?
3. What are the common pollutants carried in non-source pollution?
4. Why does non-point source pollution have the greatest impact on water quality?
5. How does non-point source pollution end up in our water sources?
6. What are some of the common causes of non-point source pollution?

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/164831

11.9 Protecting Water From Pollution

Learning Objectives

- 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** 11.15).

FIGURE 11.15
Scientists control water pollution by sampling the water and studying the pollutants that are in the water.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186876

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.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186878

Science Friday: Poop and Paddle: An Eco-Friendly Floating Toilet

How do wetlands filter water? In this video by Science Friday, inventor Adam Katzman describes how his toilet-boat converts human waste into cattails and clean water.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/194516

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/164824

1. What has the Clean Water Act been doing for the past four decades?
2. What has changed in the past 15 years?
3. What is keeping water clean about, according to the EPA Administrator?
4. Who depends on clean water?
5. Who had input into the new rules governing the Clean Water Act?
6. Does the proposal protect waters that were previously unprotected? What does it do?

11.10 Hydroelectric Power

Learning Objectives

- 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** 11.16).

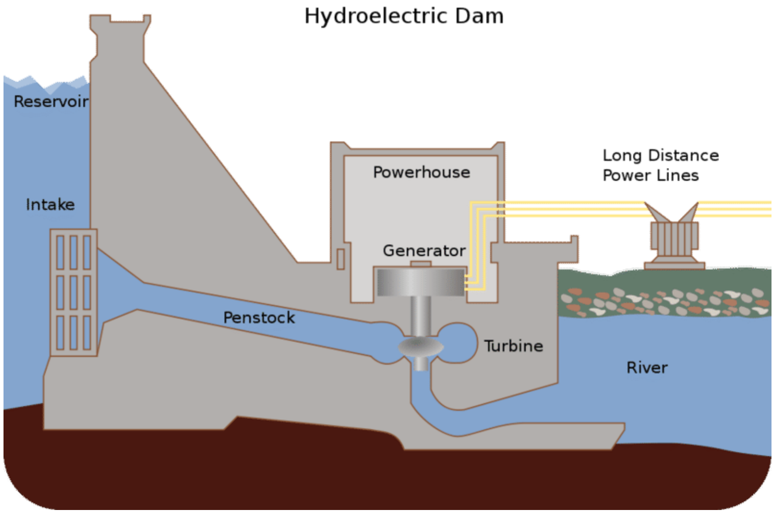
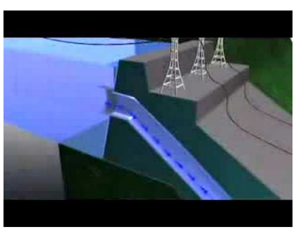


FIGURE 11.16
A cross-section of a hydroelectric plant.

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 state's nearly 400 hydropower plants are mostly located in the eastern mountain ranges, where large streams descend down a steep grade.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186817

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** 11.17).

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.

FIGURE 11.17
Glen Canyon Dam in Arizona created Lake Powell. The dam was controversial because it flooded Glen Canyon, a beautiful desert canyon.

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.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186815

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178361

1. How does a hydropower facility generate electricity?
2. How much of the energy in the US is generated by hydropowr?
3. What makes hydropower renewable?
4. How does an impoundment generate electricity?
5. How does a diversion generate electricity?
6. What is pumped storage hydropower?
7. What is new in hydropower technology?

11.11 References

1. Courtesy of the EPA. Map of Superfund sites in the United States . Public Domain
2. Courtesy of the US Environmental Protection Agency. Steel drums used to contain hazardous chemicals at L ove Canal . Public Domain
3. (a) Taber Andrew Bain; (b) Image copyright Mike Red, 2014. Lead is found in leaded gasoline and paint . (a) CC BY 2.0; (b) Used under license from Shutterstock.com
4. Shimelle Laine. Representation of the Industrial Revolution during the 2012 London Olympic Games . CC BY 2.0
5. Clinton Steeds. Smog over Los Angeles . CC BY 2.0
6. Courtesy of Edwin P Ewin, Jr/Centers for Disease and Control Prevention. Smog in New York City . Public Domain
7. Courtesy of Pat Temple, US Forest Service. The spots on this leaf are caused by ozone damage . Public Domain
8. User:Ahanix1989/Wikimedia Commons. Picture of a catalytic converter on a car . Public Domain
9. User:Bbqjunkie/Wikipedia. Picture of a hydrogen fuel-cell car . CC BY 3.0
10. Courtesy of US Environmental Protection Agency. Diagram of a scrubber that removes particles and waste g ases from exhaust . Public Domain
11. Courtesy of US Department of Energy. Bus that runs on soybean oil, a biofuel . Public Domain
12. Courtesy of the US Environmental Protection Agency. Municipal and agricultural pollution . Public Domain
13. Calexico New River Committee. Polluted water pouring into a stream coming from a factory in Mexico . Public Domain
14. Image copyright mosista, 2014. This chicken farm means that runoff from the area is full of pollutants . Used under license from Shutterstock.com
15. 176th Wing, Alaska Air National Guard. Scientists control water pollution by sampling the water and studyin g the pollutants that are in the water . CC BY 2.0
16. User:Tomia/Wikimedia Commons. A cross-section of a hydroelectric plant . CC BY 2.5
17. Image copyright Manamana, 2014. Glen Canyon Dam in Arizona created Lake Powell . Used under license from Shutterstock.com

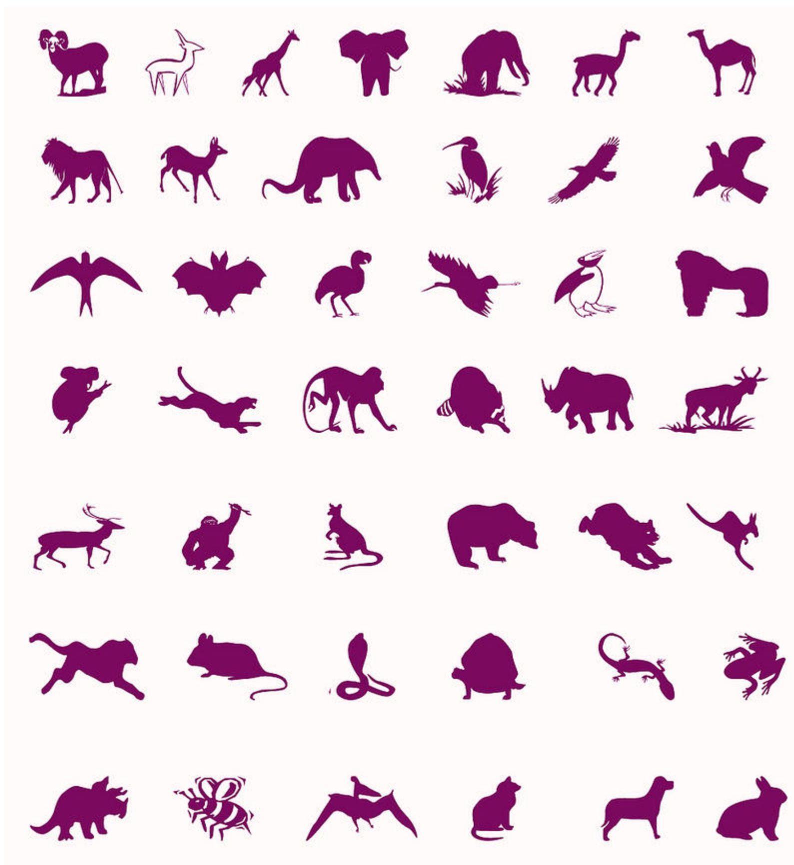
CHAPTER 12 LS4-1

Chapter Outline

12.1 Phylogenetic Classification

Learning Objectives

- Define clade.
- Describe phylogenetic classification.
- Interpret a phylogenetic tree and cladogram.
- Distinguish phylogenetic classification from Linnaean classification.



Can two different species be related?

Of course they can. For example, there are many different species of mammals, or of one type of mammal, such as mice. And they are all related. In other words, how close or how far apart did they separate from a common ancestor during evolution? Determining how different species are evolutionarily related can be a tremendous task.

Phylogenetic Classification

Linnaeus classified organisms based on obvious physical traits. Basically, organisms were grouped together if they looked alike. After Darwin published his theory of evolution in the 1800s, scientists looked for a way to classify organisms that showed phylogeny. **Phylogeny** is the evolutionary history of a group of related organisms. It is represented by a **phylogenetic tree**, like the one in **Figure** 12.1.

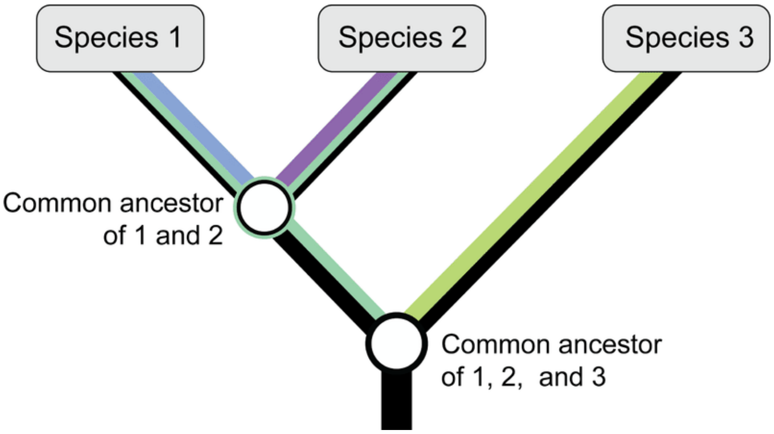


FIGURE 12.1
Phylogenetic Tree. This phylogenetic tree shows how three hypothetical species are related to each other through common ancestors. Do you see why Species 1 and 2 are more closely related to each other than either is to Species 3?

One way of classifying organisms that shows phylogeny is by using the clade. A **clade** is a group of organisms that includes an ancestor and all of its descendants. Clades are based on **cladistics**. This is a method of comparing traits in related species to determine ancestor-descendant relationships. Clades are represented by **cladograms**, like the one in **Figure** 12.2. This cladogram represents the mammal and reptile clades. The reptile clade includes birds. It shows that birds evolved from reptiles. Linnaeus classified mammals, reptiles, and birds in separate classes. This masks their evolutionary relationships.

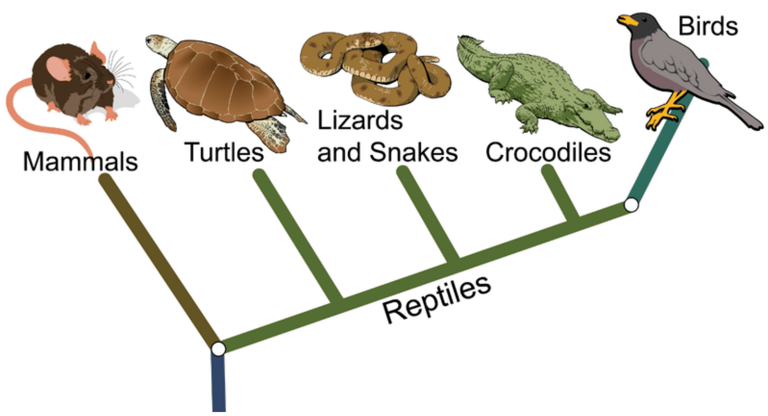


FIGURE 12.2
This cladogram classifies mammals, reptiles, and birds in clades based on their evolutionary relationships.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/154139

Summary

- Phylogeny is the evolutionary history of group of related organisms. It is represented by a phylogenetic tree that shows how species are related to each other through common ancestors.
- A clade is a group of organisms that includes an ancestor and all of its descendants. It is a phylogenetic classification, based on evolutionary relationships.

Review

1. What is a clade?
2. What is cladistics, and what is it used for?
3. Explain why reptiles and birds are placed in the same clade.
4. Dogs and wolves are more closely related to each other than either is to cats. Draw a phylogenetic tree to show these relationships.

12.2 Fossils

Learning Objectives

- Define fossil.
- Describe how fossils help us understand the past.

Would this be evidence of evolution?

Fossils, like this dinosaur fossil, provide evidence of species that lived in the past and have since gone extinct. In other words, these fossils are evidence of evolution.

Fossil Evidence

In his book *On the Origin of Species*, Darwin included evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin's time, much more evidence has been gathered. The evidence includes a huge number of fossils. It also includes more detailed knowledge of living things, right down to their DNA.

Fossils are a window into the past. They provide clear evidence that evolution has occurred. Scientists who find and study fossils are called **paleontologists**. How do they use fossils to understand the past? Consider the example of the horse, shown in the **Figure** 12.3. The fossil record shows how the horse evolved.

The oldest horse fossils show what the earliest horses were like. They were about the size of a fox, and they had four long toes. Other evidence shows they lived in wooded marshlands, where they probably ate soft leaves. Through time, the climate became drier, and grasslands slowly replaced the marshes. Later fossils show that horses changed as well.

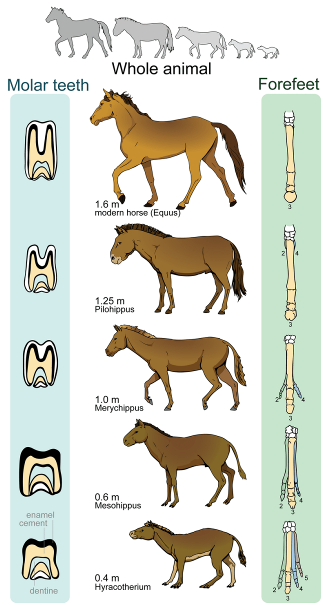
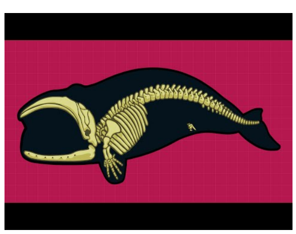


FIGURE 12.3

Evolution of the horse. Fossil evidence, depicted by the skeletal fragments, demonstrates evolutionary milestones in this process. Notice the 57 million year evolution of the horse leg bones and teeth. Especially obvious is the transformation of the leg bones from having four distinct digits to that of today's horse.

- They became taller, which would help them see predators while they fed in tall grasses.
- They evolved a single large toe that eventually became a hoof. This would help them run swiftly and escape predators.
- Their molars (back teeth) became longer and covered with cement. This would allow them to grind tough grasses and grass seeds without wearing out their teeth.

Similar fossil evidence demonstrates the evolution of the whale, moving from the land into the sea.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/183488

Science Friday: Millions of Fossils Can't Be Wrong

What's in a tar pit? In this video by Science Friday, Dr. John Harris describes how the La Brea Tar Pit has come to accumulate so many fossils.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/194515

Summary

- Fossils provide a window into the past. They are evidence for evolution.
- Scientists who find and study fossils are called paleontologists.

Review

1. What is a fossil?
2. How do paleontologists learn about evolution?
3. Describe what fossils reveal about the evolution of the horse.

12.3 Living Species

Learning Objectives

- Explain the significance of homologous structures, analogous structures, and vestigial structures.
- Describe the meaning of similar DNA sequences between two species.

Is this evidence of evolution?

Take a close look at this gorilla hand. The similarities to a human hand are remarkable. Comparing anatomy, and characterizing the similarities and differences, provides evidence of evolution.

Evidence from Living Species

Just as Darwin did many years ago, today's scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

Comparative Anatomy

Comparative anatomy is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

Homologous structures are structures that are similar in related organisms because they were inherited from a common ancestor. These structures may or may not have the same function in the descendants. **Figure** 12.4 shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However, their forelimbs now have different functions.

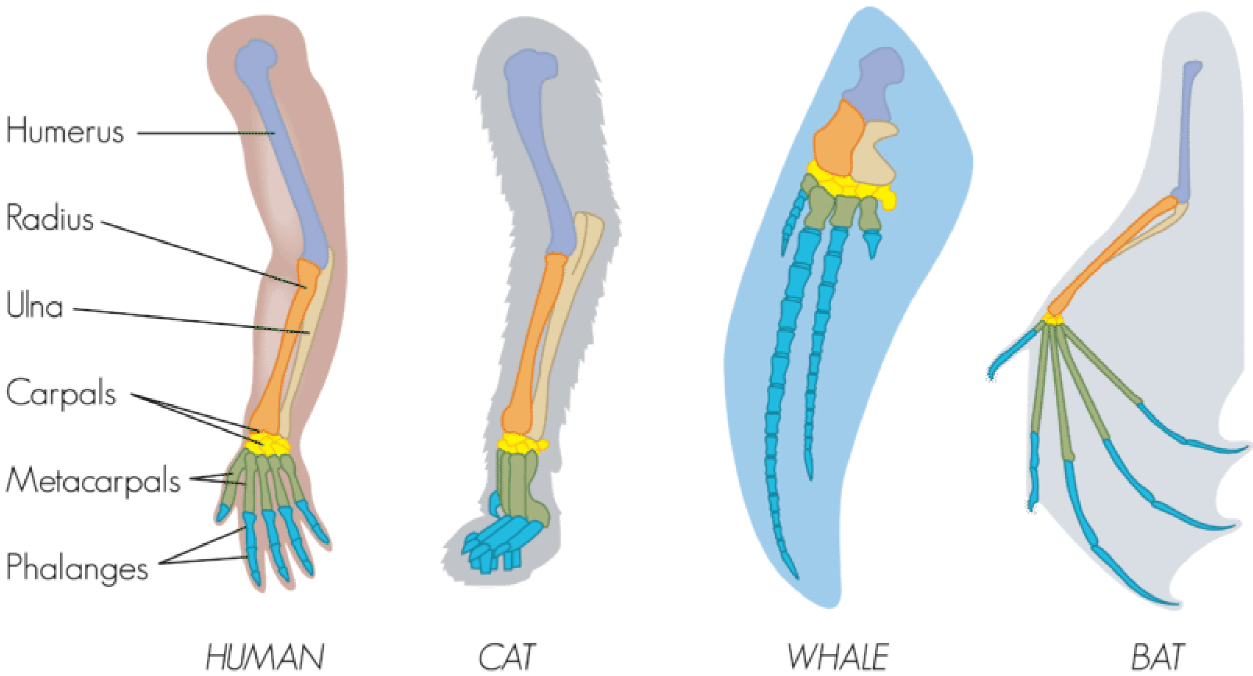
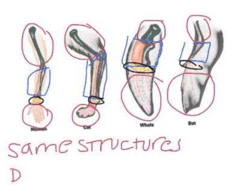


FIGURE 12.4
The forelimbs of all mammals have the same basic bone structure.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185005

Analogous structures are structures that are similar in unrelated organisms. The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds, shown in **Figure** 12.5, look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

Comparative Embryology

Comparative embryology is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails. Most vertebrates, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tail bone. Thus, similarities organisms share as embryos may be gone by adulthood.

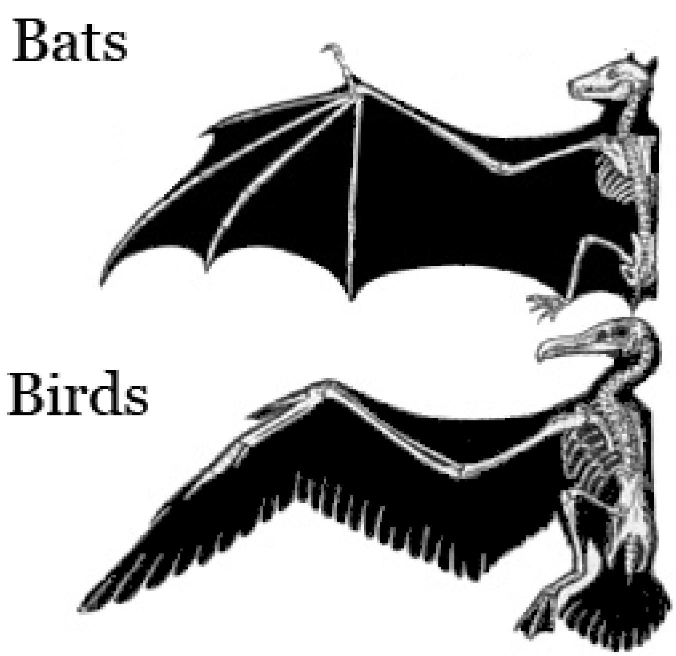
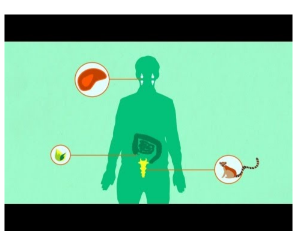


FIGURE 12.5
Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.

This is why it is valuable to compare organisms in the embryonic stage.

Vestigial Structures

Structures like the human tail bone and whale pelvis are called **vestigial structures**. Evolution has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism's fitness?



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185002

Comparing DNA

Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. More similarities in the

DNA sequence is evidence for a closer evolutionary relationship. Look at the cladogram in the **Figure** 12.6. It shows how humans and apes are related based on their DNA sequences.

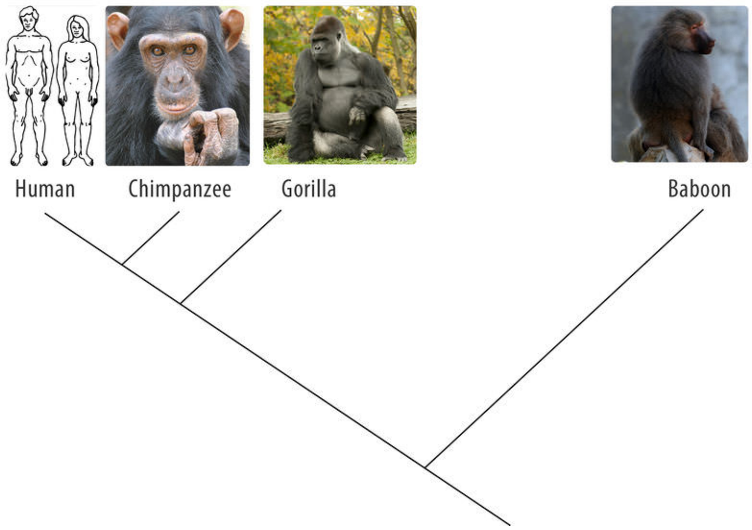


FIGURE 12.6
Cladogram of Humans and Apes. This cladogram is based on DNA comparisons. It shows how humans are related to apes by descent from common ancestors.

Summary

- Scientists compare the anatomy, embryos, and DNA of living things to understand how they evolved.
- Evidence for evolution is provided by homologous structures. These are structures shared by related organisms that were inherited from a common ancestor.
- Other evidence for evolution is provided by analogous structures. These are structures that unrelated organisms share because they evolved to do the same job.
- Comparing DNA sequences provided some of the strongest evidence of evolutionary relationships.

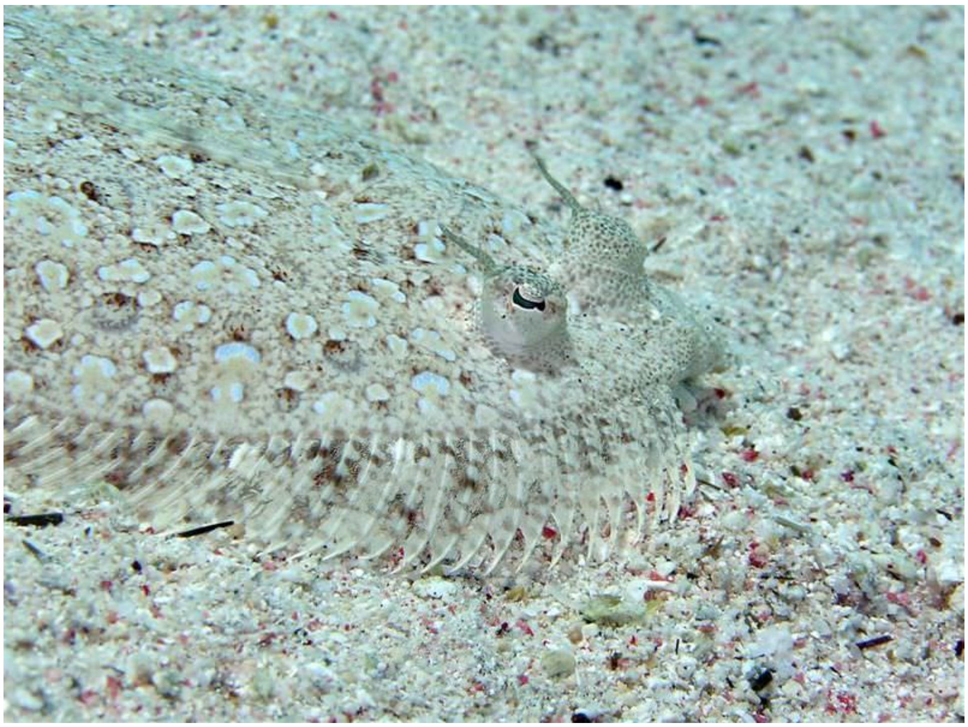
Review

1. What are vestigial structures? Give an example.
2. Compare homologous and analogous structures.
3. Why do vertebrate embryos show similarities between organisms that do not appear in the adults?
4. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.
5. What is the strongest evidence of evolution from a common ancestor?

12.4 Adaptation and Evolution of Populations

Learning Objectives

- 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** 12.7). 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.

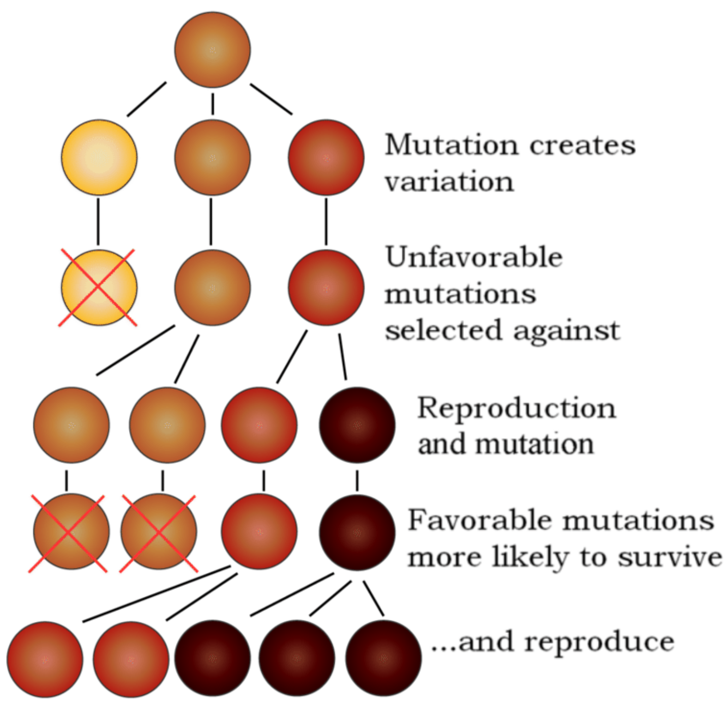
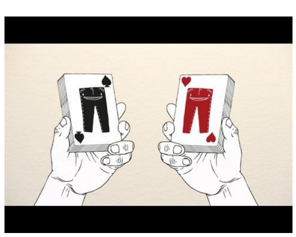


FIGURE 12.7
An explanation of how adaptations develop.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/186575

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/186577

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.

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?
4. What will cause evolution to proceed rapidly?

Explore More

Use these resources to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178257

1. What is an adaptation? What does an adaptation do?
2. What adaptation does the rock pocket mouse have for living over desert sand and gravel? What adaptation does it have for living over lava?
3. How could bacteria become resistant to antibiotics.
4. As climate warms what may happen to polar bears?
5. How does natural selection change the rock pocket mouse population from brown to black?
6. How do new species form?
7. What are the four factors of natural selection so that a species is better adapted to its environment?
8. What is adaptation? What is the mechanism?

12.5 Comparative Anatomy and Embryology - Advanced

Learning Objectives

- Compare and contrast homologous structures and analogous structures as evidence for evolution.
- Give examples of evidence from embryology which supports common ancestry.
- Explain how vestigial structures support evolution by natural selection.

Is this evidence of evolution?

Take a close look at this gorilla hand. The similarities to a human hand are remarkable. Comparing anatomy and characterizing the similarities and differences provides evidence of evolution.

Comparative Anatomy and Embryology

The evidence Darwin presented in *The Origin of Species* included not only fossils but also detailed comparisons of living species at all stages of life. Naturalists in Darwin's time were experts in **comparative anatomy**, the study of the similarities and differences in organisms' structures (body parts). At different times during his life, Darwin studied the comparative anatomy of closely related species of marine mammals, barnacles, orchids, insectivorous plants, and earthworms.

Species which share many similarities are closely related by a relatively recent common ancestor. For example, all orchids share parallel-veined leaves, two-sided flowers with a "lip," and small seeds (**Figures A and B** 12.8). Species which share fewer similarities, sharing only basic features, are related by relatively distant ancestor. The sundew, one of the insectivorous plants Darwin studied, shares leaves and petals with orchids, but the leaves are wide with branching veins and the flowers are radially symmetrical rather than two-sided (**Figure C** 12.8). The many species of orchids, then, share a recent common ancestor, but they also share a more distant ancestor with the sundew.

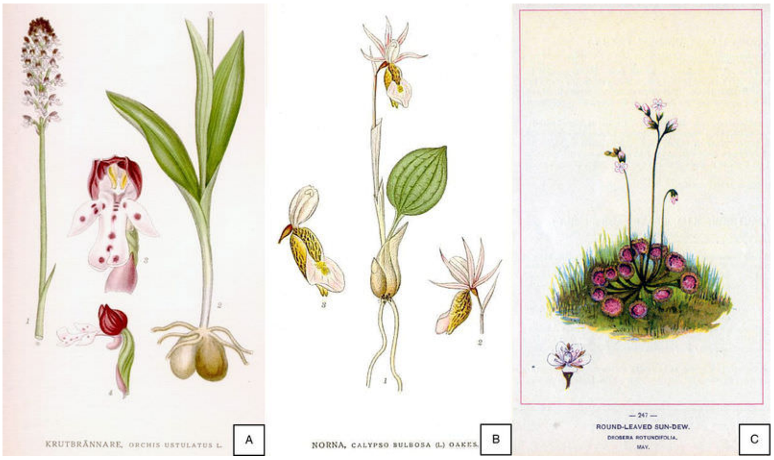


FIGURE 12.8

Darwin's Theory of Evolution explains both the similarities and the differences among living things. All flowering plants share leaves, petals, stamens, and pistils, but orchids have parallel-veined leaves, flowers with lips, and fused stamens and pistils, while sundews have leaves with branching veins, flowers with equal petals, and separate stamens and pistils. The two species of orchid (A and B) share a recent common ancestor, whereas all three species share a more distant common ancestor.

Homologous and Analogous Structures

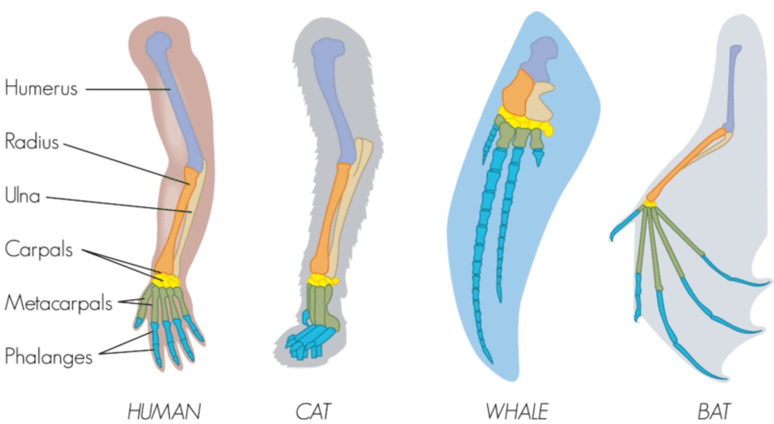


FIGURE 12.9

Homologous structures are similarities throughout a group of closely related species. The similar bone patterns in bat's wings, dolphin's flippers, and horse's legs support their descent from a common mammalian ancestor.

Similarities among different species can show two different kinds of relationships, both of which support evolution and natural selection. These similar structures are known as **homologous structures** and **analogous structures**.

Similarities shared by closely related species (species who share many characteristics) are homologous, because the species have descended from a common ancestor which had that trait. Homologous structures may or may not serve the same function. **Figure** 12.9 shows the forelimbs of mammals, considered homologous because all mammals show the same basic pattern: a single proximal bone joins a pair of more distal bones, which connect to bones of the wrist, "hand," and digits. With this basic pattern, bats build wings for their lives in the air, whales form fins for their lives in the sea, and horses construct long, hoofed legs for speed on land. Therefore, homologous structures support common ancestry.

Similarities shared by distantly related species may have evolved separately because they live in similar habitats. These structures are analogous because they serve similar functions, but evolved independently. **Figure** 12.10 compares the wings of bats, bird, and pterosaurs. Bats evolved wings as mammals, pterosaurs as dinosaurs, and birds from a separate line of reptiles. Their wings are analogous structures, each of which evolved independently, but all of which suit a lifestyle in the air. Note that although the wings are analogous, their bones are homologous:

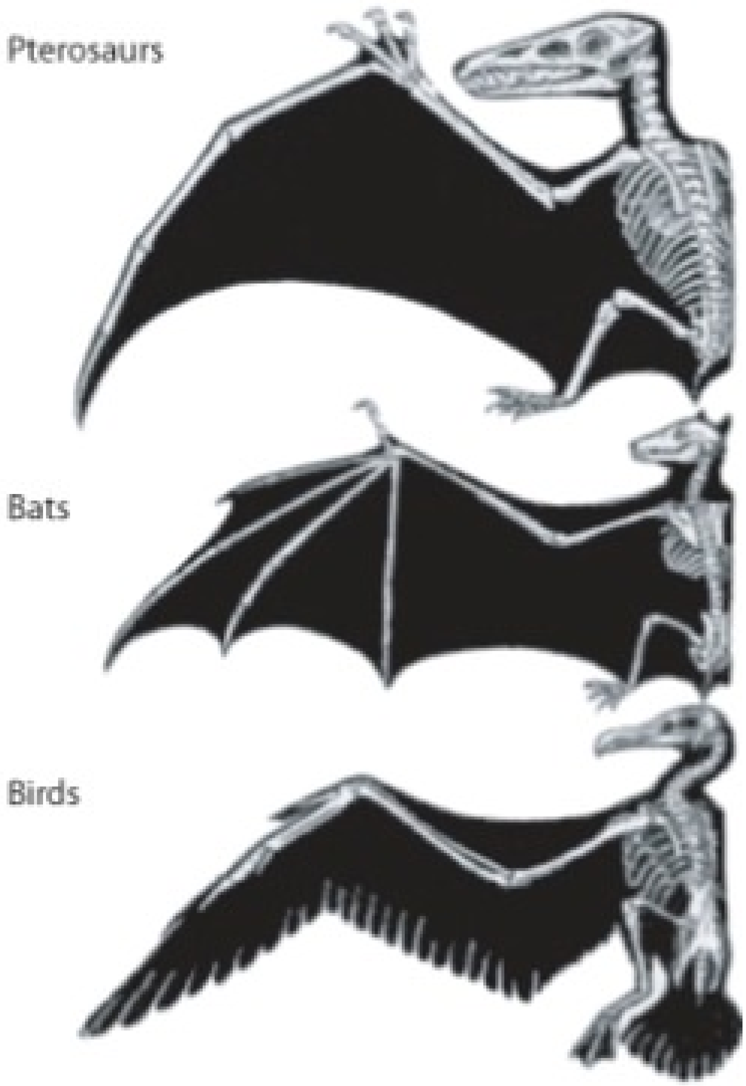
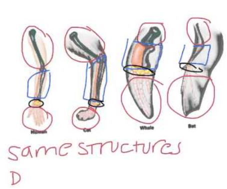


FIGURE 12.10

The wings of pterosaurs, bats, and birds illustrate both homologous and analogous structures. Similarities in the patterns of bones are due to descent from a common vertebrate (reptilian) ancestor, so they are homologous. However, the wings of each evolved independently, in response to similar environments, so they are analogous and provide evidence for natural selection.

all three share a common but more distant vertebrate ancestor, in which the basic forelimb pattern evolved. Because analogous structures are independent adaptations to a common environment, they support natural selection.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/185005

Embryology

Embryology is a branch of comparative anatomy which studies the development of vertebrate animals before birth or hatching. Like adults, embryos show similarities which can support common ancestry. For example, all vertebrate embryos have gill slits and tails, as shown in **Figure** 12.11. The "gill slits" are not gills, however. They connect the throat to the outside early in development but eventually close in many species; only in fish and larval amphibians do they contribute to the development of gills. In mammals, the tissue between the first gill slits forms part of the lower jaw and the bones of the inner ear. The embryonic tail does not develop into a tail in all species; in humans, it is reduced during development to the coccyx, or tailbone. Similar structures during development support common ancestry.

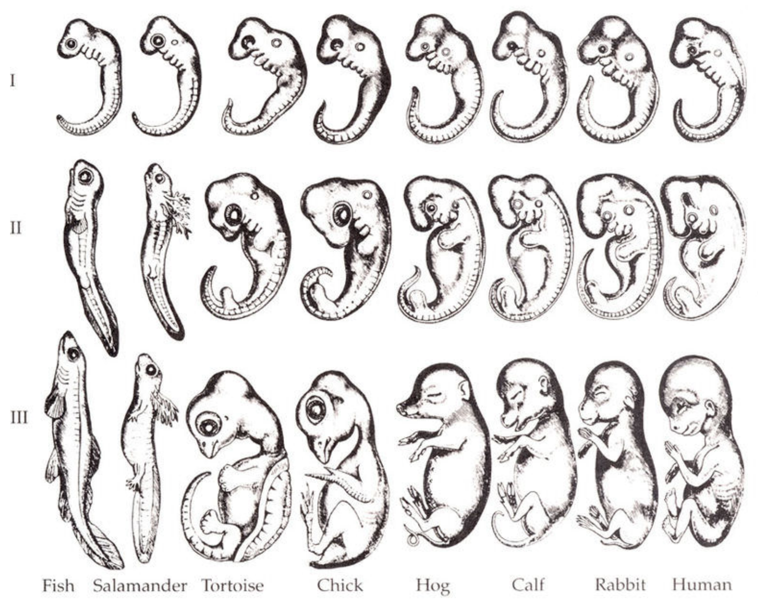


FIGURE 12.11

Comparative embryology reveals homologies which form during development but may later disappear. All vertebrate embryos develop tails, though adult humans retain only the coccyx. All vertebrate embryos show gill slits, though these develop into gill openings only in fish and larval amphibians. In humans, gills slits form the lower jaw and Eustachian tube. Many scientists consider developmental homologies evidence for ancestry, although some embryologists believe that these particular drawings exaggerate the similarities.

Vestigial Structures

Structures which are reduced and are perhaps even nonfunctional, such as the human tail and the human appendix, are considered **vestigial structures**. The tail, of course, functions for balance in many mammals, and the human appendix may have served digestive functions in herbivorous ancestors. Whales, which evolved from land mammals, do not have legs or hair as adults; both begin to develop in embryos, but then recede. Vestigial leg bones remain, buried deep in their bodies, shown in **Figure A** 12.12.

True flies have reduced the second pair of wings found in most insects to halteres for balance shown in **Figure B** 12.12. Cavefish lose both eyes and pigment, because both would require energy to create, and they are useless in the lightless habitats of caves, as shown in **Figure C** 12.12. You are probably very familiar with this fine example of a vestigial behavior: goosebumps raise the sparse hairs on your arms even though they are no longer sufficiently dense to insulate you from the cold by trapping warm air next to your skin; in most mammals, this reflex is still quite functional, as shown in **Figure D** 12.12. Most vestigial structures are homologous to similar, functioning structures in closely related species and, as such, support both common ancestry and natural selection.

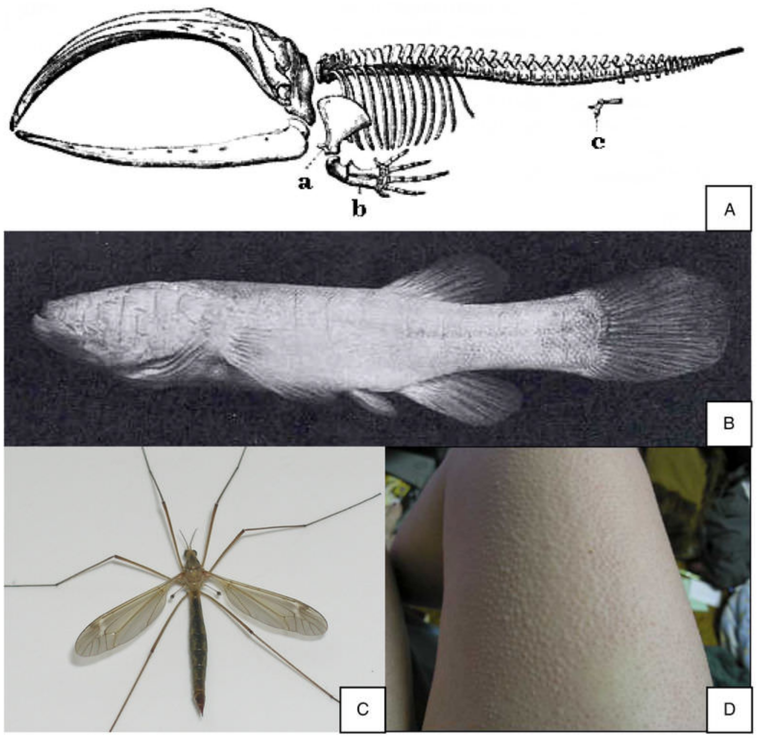
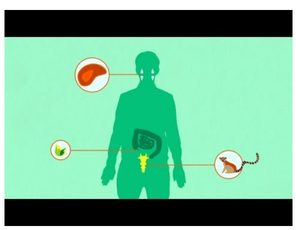


FIGURE 12.12

Vestigial structures show evolutionary reduction or loss of unneeded structures which were useful to ancestors. A: Whales retain remnants of their mammalian ancestors' leg bones (c). B: Cavefish lack the eyes and pigments important to their relatives who live in lighted habitats. C: True flies have reduced insects' second pair of wings to balancing knobs. D: We still show the reflex which raises hairs for insulation in cold air in our furry relatives, but all we have to show for our follicle's efforts are goosebumps.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/185002

Summary

- Many basic similarities in comparative anatomy support recent common ancestry.
- Similarities in structure for closely related species are homologous.
- Similarities in structure among distantly related species are analogous if they evolved independently in similar environments. They provide good evidence for natural selection.
- Examples of evidence from embryology which supports common ancestry include the tail and gill slits present in all early vertebrate embryos.
- Vestigial structures are reduced and perhaps even nonfunctional, but homologous to fully developed and functional similar structures in a closely related species; these support the idea of natural selection.
- Cavefish without sight or pigment and humans with goose bumps illustrate the concept of vestigiality.

Review

1. Compare and contrast homologous and analogous structures as evidence for evolution.
2. Give two examples of evidence from embryology which support common ancestry.

3. Use an example to show how vestigial structures support evolution by natural selection.
4. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.

12.6 References

1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
2. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
3. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Evolution of the horse . CC BY-NC 3.0
4. Christopher Auyeung. Bone structure of various animal forelimbs shows they are homologous structures . CC BY-NC 3.0
5. John Romanes, modified by CK-12 Foundation. Wings of bats and birds are analogous structures . Public Domain
6. Human: User:MrKimm/Wikimedia Commons; Chimpanzee: Afrika Force; Gorilla: Roger Luijten; Baboon: Birdseye Maple. Cladogram of humans, chimpanzees, gorillas, and babbons . Human: Public Domain; Chimpanzee, Gorilla, Baboon: CC BY 2.0
7. Hana Zavadska. An explanation of how adaptations develop . CC BY-NC 3.0
8. Carl A. M. Lindman of the Botanical Fine Art Weekly. http://commons.wikimedia.org/wiki/Image:Orchis_ustulata_Nordens_Flora_403.jpg; http://commons.wikimedia.orgwiki/Image:Calypso_bulbosa_Nordens_Flora_416.jpg; http://commons.wikimedia.org/wiki/Image:Drosera_rotundifolia_chromolithograph.jpg . Public Domain
9. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
10. John Romanes. http://commons.wikimedia.org/wiki/Image:Homology.jpg . Public Domain
11. Romanes, G. J.. http://commons.wikimedia.org/wiki/File:Haeckel_drawings.jpg . public domain
12. (A) Meyers Konversionlexikon; (B) University of Washington Libraries/Freshwater and Marine Image Bank; (C) User:Pinzo/Wikipedia; (D) User:Chemicalpink/Wikimedia Commons. (A) http://commons.wikimedia.org/wiki/Image:Whale_skeleton.png; (B) http://commons.wikimedia.org/wiki/Image:Amblyopsis_spelaeus.jpg; (C) http://en.wikipedia.org/wiki/Image:Crane_fly_halteres.jpg; (D) http://commons.wikimedia.org/wiki/Image:Cold_urticaria.jpg . Public Domain

CHAPTER 13 LS4-6

Chapter Outline

13.1 Human Actions and the Sixth Mass Extinction

Learning Objectives

- Describe the sixth mass extinction.
- Relate human actions to the sixth mass extinction.
- Define habitat loss and exotic species.
- Give examples of the effects of extinction.
- Describe how biodiversity can be protected.

This is one of the most powerful birds in the world. Could it go extinct?

The Philippine Eagle, also known as the Monkey-eating Eagle, is among the rarest, largest, and most powerful birds in the world. It is critically endangered, mainly due to massive loss of habitat due to deforestation in most of its range. Killing a Philippine Eagle is punishable under Philippine law by twelve years in jail and heavy fines.

Human Actions and the Sixth Mass Extinction

Over 99 percent of all species that ever lived on Earth have gone extinct. Five mass extinctions are recorded in the fossil record. They were caused by major geologic and climatic events. Evidence shows that a **sixth mass extinction** is occurring now. Unlike previous mass extinctions, the sixth extinction is due to human actions.

Some scientists consider the sixth extinction to have begun with early hominids during the Pleistocene. They are blamed for over-killing big mammals such as mammoths. Since then, human actions have had an ever greater impact on other species. The present rate of extinction is between 100 and 100,000 species per year. In 100 years, we could lose more than half of Earth's remaining species.

Causes of Extinction

The single biggest cause of extinction today is **habitat loss**. Agriculture, forestry, mining, and urbanization have disturbed or destroyed more than half of Earth's land area. In the U.S., for example, more than 99 percent of tall-grass prairies have been lost. Other causes of extinction today include:

- **Exotic species** introduced by humans into new habitats. They may carry disease, prey on native species, and disrupt food webs. Often, they can out-compete native species because they lack local predators. An example is described in **Figure** 13.1.
- Over-harvesting of fish, trees, and other organisms. This threatens their survival and the survival of species that depend on them.
- Global climate change, largely due to the burning of fossil fuels. This is raising Earth's air and ocean temperatures. It is also raising sea levels. These changes threaten many species.
- Pollution, which adds chemicals, heat, and noise to the environment beyond its capacity to absorb them. This causes widespread harm to organisms.
- Human overpopulation, which is crowding out other species. It also makes all the other causes of extinction worse.

FIGURE 13.1
The brown tree snake is an exotic species that has caused many extinctions on Pacific islands such as Guam.

Effects of Extinction

The results of a study released in the summer of 2011 have shown that the decline in the numbers of large predators like sharks, lions and wolves is disrupting Earth's ecosystem in all kinds of unusual ways. The study, conducted by scientists from 22 different institutions in six countries, confirmed the sixth mass extinction. The study states that this mass extinction differs from previous ones because it is entirely driven by human activity through changes in land use, climate, pollution, hunting, fishing and poaching. The effects of the loss of these large predators can be seen in the oceans and on land.

- Fewer cougars in the western US state of Utah led to an explosion of the deer population. The deer ate more vegetation, which altered the path of local streams and lowered overall biodiversity.
- In Africa, where lions and leopards are being lost to poachers, there is a surge in the number of olive baboons, who are transferring intestinal parasites to humans living nearby.
- In the oceans, industrial whaling led a change in the diets of killer whales, who eat more sea lions, seals, and otters and have dramatically lowered the population counts of those species.

The study concludes that the loss of big predators has likely driven many of the pandemics, population collapses and ecosystem shifts the Earth has seen in recent centuries.

Disappearing Frogs

Around the world, frogs are declining at an alarming rate due to threats like pollution, disease, and climate change. Frogs bridge the gap between water and land habitats, making them the first indicators of ecosystem changes.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/443

Nonnative Species

Scoop a handful of critters out of the San Francisco Bay and you'll find many organisms from far away shores. Invasive kinds of mussels, fish, and more are choking out native species, challenging experts around the state to change the human behavior that brings them here.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/444

How You Can Help Protect Biodiversity

There are many steps you can take to help protect biodiversity. For example:

- Consume wisely. Reduce your consumption wherever possible. Re-use or recycle rather than throw out and buy new. When you do buy new, choose products that are energy efficient and durable.
- Avoid plastics. Plastics are made from petroleum and produce toxic waste.
- Go organic. Organically grown food is better for your health. It also protects the environment from pesticides and excessive nutrients in fertilizers.
- Save energy. Unplug electronic equipment and turn off lights when not in use. Take mass transit instead of driving.

Lost Salmon

Why is the salmon population of Northern California so important? Salmon do not only provide food for humans, but also supply necessary nutrients for their ecosystems. Because of a sharp decline in their numbers, in part due to human interference, the entire salmon fishing season off California and Oregon was canceled in both 2008 and 2009. The species in the most danger of extinction is the California coho salmon.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/445

Summary

- Evidence shows that a sixth mass extinction is occurring. The single biggest cause is habitat loss caused by human actions.
- There are many steps you can take to help protect biodiversity. For example, you can use less energy.

Review

1. How is human overpopulation related to the sixth mass extinction?
2. Why might the brown tree snake or the Philippine Eagle serve as "poster species" for causes of the sixth mass extinction?
3. Describe a hypothetical example showing how rising sea levels due to global warming might cause extinction.
4. Create a poster that conveys simple tips for protecting biodiversity.

Resources

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/164843

13.2 Genetic Variation

Learning Objectives

- Explain why sexual reproduction leads to variation in offspring.
- Define crossing-over.
- Summarize the process of crossing-over.
- Explain the importance of independent assortment and random fertilization.

What helps ensure the survival of a species?

Genetic variation. It is this variation that is the essence of evolution. Without genetic differences among individuals, "survival of the fittest" would not be likely. Either all survive, or all perish.

Genetic Variation

Sexual reproduction results in infinite possibilities of genetic variation. In other words, sexual reproduction results in offspring that are genetically unique. They differ from both parents and also from each other. This occurs for a number of reasons.

- When homologous chromosomes form pairs during prophase I of meiosis I, crossing-over can occur. **Crossing-over** is the exchange of genetic material between homologous chromosomes. It results in new combinations of genes on each chromosome.
- When cells divide during meiosis, homologous chromosomes are randomly distributed to daughter cells, and different chromosomes segregate independently of each other. This called is called **independent assortment**. It results in gametes that have unique combinations of chromosomes.

- In sexual reproduction, two gametes unite to produce an offspring. But which two of the millions of possible gametes will it be? This is likely to be a matter of chance. It is obviously another source of genetic variation in offspring. This is known as **random fertilization.**

All of these mechanisms working together result in an amazing amount of potential variation. Each human couple, for example, has the potential to produce more than 64 trillion genetically unique children. No wonder we are all different!

Crossing-Over

Crossing-over occurs during prophase I, and it is the exchange of genetic material between non-sister chromatids of homologous chromosomes. Recall during prophase I, homologous chromosomes line up in pairs, gene-for-gene down their entire length, forming a configuration with four chromatids, known as a **tetrad**. At this point, the chromatids are very close to each other and some material from two chromatids switch chromosomes, that is, the material breaks off and reattaches at the same position on the homologous chromosome (**Figure** 13.2). This exchange of genetic material can happen many times within the same pair of homologous chromosomes, creating unique combinations of genes. This process is also known as **recombination**.

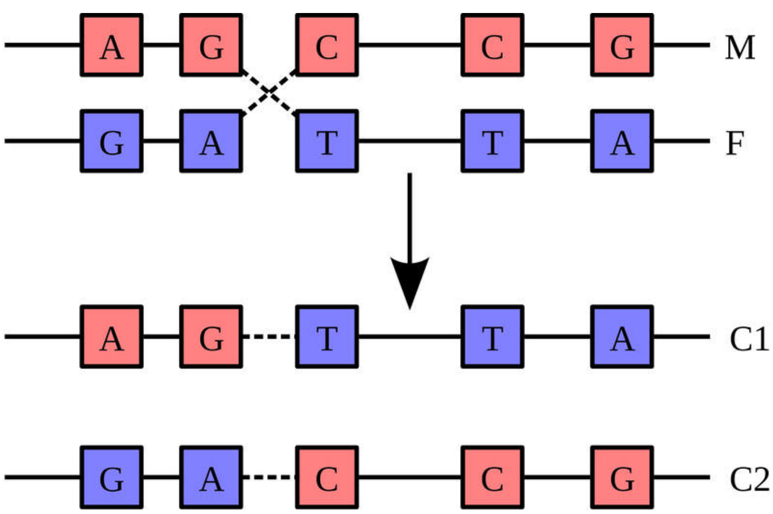


FIGURE 13.2

Crossing-over. A maternal strand of DNA is shown in red. A paternal strand of DNA is shown in blue. Crossing over produces two chromosomes that have not previously existed. The process of recombination involves the breakage and rejoining of parental chromosomes (M, F). This results in the generation of novel chromosomes (C1, C2) that share DNA from both parents.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/184640

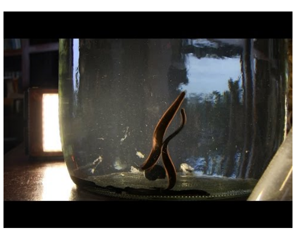
Independent Assortment and Random Fertilization

In humans, there are over 8 million configurations in which the chromosomes can line up during metaphase I of meiosis. It is the specific processes of meiosis, resulting in four unique haploid cells, that result in these many combinations. This independent assortment, in which the chromosome inherited from either the father or mother can sort into any gamete, produces the potential for tremendous genetic variation. Together with random fertilization, more possibilities for genetic variation exist between any two people than the number of individuals alive today. Sexual reproduction is the random fertilization of a gamete from the female using a gamete from the male. In humans, over 8 million (2^{23}) chromosome combinations exist in the production of gametes in both the male and female. A sperm cell, with over 8 million chromosome combinations, fertilizes an egg cell, which also has over 8 million chromosome combinations. That is over 64 trillion unique combinations, not counting the unique combinations produced by crossing-over. In other words, each human couple could produce a child with over 64 trillion unique chromosome combinations!

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/184638

Science Friday: True BloodSuckers - Leeches

Leeches seem like disgusting creatures with little intelligence. But, in this video by Science Friday, Dr. Mark Siddall discusses his research on leeches and some of their interesting properties.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/194493

Summary

- Sexual reproduction has the potential to produce tremendous genetic variation in offspring.
- This variation is due to independent assortment and crossing-over during meiosis, and random union of gametes during fertilization.

Review

1. What is crossing-over and when does it occur?

2. Describe how crossing-over, independent assortment, and random fertilization lead to genetic variation.
3. How many combinations of chromosomes are possible from sexual reproduction in humans?
4. Create a diagram to show how crossing-over occurs and how it creates new gene combinations on each chromosome.

13.3 References

1. National Park Service. A brown tree snake . Public Domain
2. David Eccles. Crossing-over in meiosis . CC BY 2.5

CHAPTER 14 PS2-1

Chapter Outline

14.1 Newton's First and Second Laws of Motion

Learning Objectives

- Define force.
- State the fundamental units for the Newton.
- State Newton's First Law of Motion.
- Given two of the three values in $F = ma$, calculate the third.

This image is of Buzz Aldrin, one of the first men to walk on the moon. Apollo 11 was the spaceflight that landed the first humans, Neil Armstrong and Buzz Aldrin, on the moon on July 20, 1969. Armstrong became the first to step onto the lunar surface 6 hours later on July 21. As you probably already know, men weigh less on the moon than on Earth; this is because the force of gravity is less on the moon than on Earth.

Newton's First and Second Laws of Motion

A **force** is a push or a pull on an object. When you place a book on a table, the book pushes downward on the table and the table pushes upward on the book. The two forces are equal and there is no resulting motion of the book. If, on the other hand, you hold the book in the air and let go, the force of gravity will pull the book to the ground.

If you slide a book across the floor or a table, the book will experience a frictional force, which acts in the opposite direction of the motion. This force will slow down the motion of the book and eventually bring it to rest. A smoother surface has a smaller force of friction, which will allow the book to slide further before coming to rest. If a perfectly smooth floor could be created, there would be no friction and the book would slide forever at constant speed.

Newton's First Law of Motion states that an object at rest will stay at rest and an object in motion will remain in motion. It describes a phenomenon called **inertia**. Inertia is the tendency of an object to resist change in its state of motion. In the absence of any force, an object will continue to move at the same constant speed and in the same straight line. If the object is at rest, in the absence of any force, it will remain at rest. Newton's First Law states that an object with no force acting on it moves with constant velocity. (The constant velocity could, of course, be 0 m/s.)

Newton's First Law is equivalent to saying that "if there is no net force on an object, there will be no acceleration." In the absence of acceleration, an object will remain at rest or will move with constant velocity in a straight line. The acceleration of an object is the result of an unbalanced force. If an object undergoes two forces, the motion of the object is determined by the net force. The magnitude of the acceleration is directly proportional to the magnitude of the unbalanced force. The direction of the acceleration is the same direction as the direction of the unbalanced force. The magnitude of the acceleration is inversely proportional to the mass of the object; the more massive the object, the smaller the acceleration produced by the same force.

These relationships are stated in **Newton's Second Law of Motion**: "the acceleration of an object is directly proportional to the net force on the object and inversely proportional to the mass of the object."

Newton's Second Law can be summarized in an equation:

$a = \frac{F}{m}$ or more commonly, $F = ma$

According to Newton's Second Law, a new force on an object causes it to accelerate. However, the larger the mass, the smaller the acceleration. We say that a more massive object has a greater inertia.

The units for force are defined by the equation for Newton's Second Law. Suppose we wish to express the force that will give a 1.00 kg object an acceleration of 1.00 m/s^2.

$F = ma = (1.00\ \mathbf{kg})(1.00\ \mathbf{m/s}^2) = 1.00\ \mathbf{kg} \cdot \mathbf{m/s}^2$

This unit is defined as 1.00 newton or 1.00 N.

$\frac{kg \cdot m}{s^2} = \text{newton}$

Examples

Example 1

What force is required to accelerate a 2000. kg car at 2.000 m/s^2?

$F = ma = (2000.\ \text{kg})(2.000\ \text{m/s}^2) = 4000.\ \text{N}$

Example 2

A net force of 150 N is exerted on a rock. The rock has an acceleration of 20. m/s^2 due to this force. What is the mass of the rock?

$m = \frac{F}{a} = \frac{(150\ \text{N})}{(20.\ \text{m/s}^2)} = 7.5\ \text{kg}$

Example 3

A net force of 100. N is exerted on a ball. If the ball has a mass of 0.72 kg, what acceleration will it undergo?

$a = \frac{F}{m} = \frac{(100.\ \text{N})}{(0.72\ \text{kg})} = 140\ \text{m/s}^2$

Summary

- A force is a push or pull on an object.

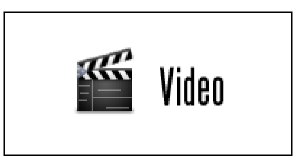
- Newton's First Law states that an object with no net force acting on it remains at rest or moves with constant velocity in a straight line.
- Newton's Second Law states that the acceleration of an object is directly proportional to the net force on the object and inversely proportional to the mass of the object.
- Newton's Second Law is expressed as an equation, $F = ma$.

Review

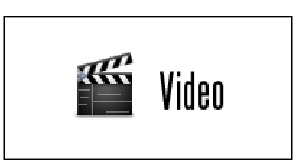
1. A car of mass 1200 kg traveling westward at 30. m/s is slowed to a stop in a distance of 50. m by the car's brakes. What was the braking force?
2. Calculate the average force that must be exerted on a 0.145 kg baseball in order to give it an acceleration of 130 m/s^2.
3. After a rocket ship going from the Earth to the moon leaves the gravitational pull of the Earth, it can shut off its engine and the ship will continue on to the moon due to the gravitational pull of the moon.
    1. True
    2. False
4. If a space ship traveling at 1000 miles per hour enters an area free of gravitational forces, its engine must run at some minimum level in order to maintain the ships velocity.
    1. True
    2. False
5. Suppose a space ship traveling at 1000 miles per hour enters an area free of gravitational forces and free of air resistance. If the pilot wishes to slow the ship down, he can accomplish that by shutting off the engine for a while.
    1. True
    2. False

Explore More

Use the resource below to answer the questions that follow.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/112409



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/112411

1. What is a Hero's Engine?
2. How does Newton's First Law of Motion have to do with the Hero's Engine?
3. Why does the yellow ball go further?

Vocabulary

- **force:** A push or pull on an object.

14.2 Newton's Second Law

Learning Objectives

- Describe Newton's Second Law and explain the relationship between acceleration, applied force, and mass.
- Determine the net force when multiple forces act on an object.

The acceleration experienced by an object will be proportional to the applied force and inversely proportional to its mass. If there are multiple forces, they can be added as vectors and it is the *net* force that matters.

Newton's Second Law describes his famous equation for the motion of an object:

> *The change of motion is proportional to the motive force impressed; and is made in the direction of the right* (straight) *line in which that force is impressed.*

The "motion" Newton mentions in the Second Law is, in his language, the product of the mass and velocity of an object — we call this quantity momentum — so the Second Law is actually the famous equation**:**

$$\vec{F} = \frac{\Delta(m\vec{v})}{\Delta t} = \frac{m\Delta\vec{v}}{\Delta t} = m\vec{a} \qquad [1]$$

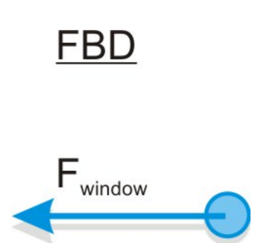
$$\text{Force Sums}\begin{cases} \vec{F}_{\text{net}} = \sum_i F_i = m\vec{a} & \text{Net force is the vector sum of all the forces} \\ F_{\text{net},x} = \sum_i F_{ix} = ma_x & \text{Horizontal components add also} \\ F_{\text{net},y} = \sum_i F_{iy} = ma_y & \text{As do vertical ones} \end{cases}$$

To calculate the net force on an object, you need to calculate all the individual forces acting on the object and then add them as vectors. This requires some mathematical skill.

Examples

Example 1

A 175-g bluebird slams into a window with a force of 19.0 N. What is the bird's acceleration?



$a =? [m/s^2]$

Given: $m = 175\ grams = 0.175\ kg$

$F = 19.0\ N$

Equation: $a = \frac{F_{net}}{m}$

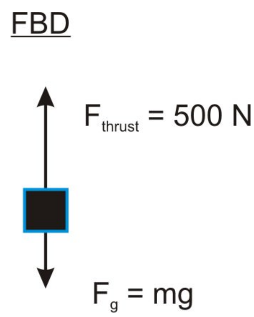
Plug n' Chug: $a = \frac{F_{net}}{m} = \frac{19.0\ N}{0.175\ kg} = \frac{19.0 \frac{kg \cdot m}{s^2}}{0.175\ kg} = 109 \frac{m}{s^2}$

The answer is 109 m/s^2.

$$\boxed{\mathbf{109\ m/s^2}}$$

Example 2

Calculate the acceleration of a rocket that has 500N of thrust force and a mass of 10kg.



$a = ?\,[m/s^2]$

Given: $m = 10\ kg$

$F_{\text{thrust}} = 500\ N$

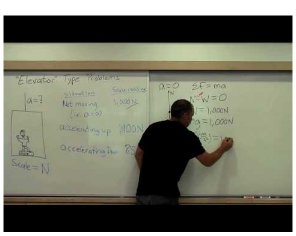
$g = 10.0\ m/s^2$

Equations: $\sum F_{\text{individual forces}} = ma$

or, in this case, $\sum F_{y-\text{direction forces}} = ma_y$

Plug n' Chug: Use FBD to "fill in" Newton's second law equation:

$$\begin{aligned} \sum F_{y-\text{direction forces}} &= ma_y \\ F - Mg &= Ma \\ 500N - 10\ kg(10\ m/s^2) &= 10kg(a) \\ a &= 40\ m/s^2 \end{aligned}$$



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/386

Interactive Simulation

SIMULATION

Understand the relationship between normal force gravity net force and acceleration in the context of a ride in an elevator.

URL: http://www.ck12.org/physics/Velocity-and-Acceleration/simulationint/Elevator

Review

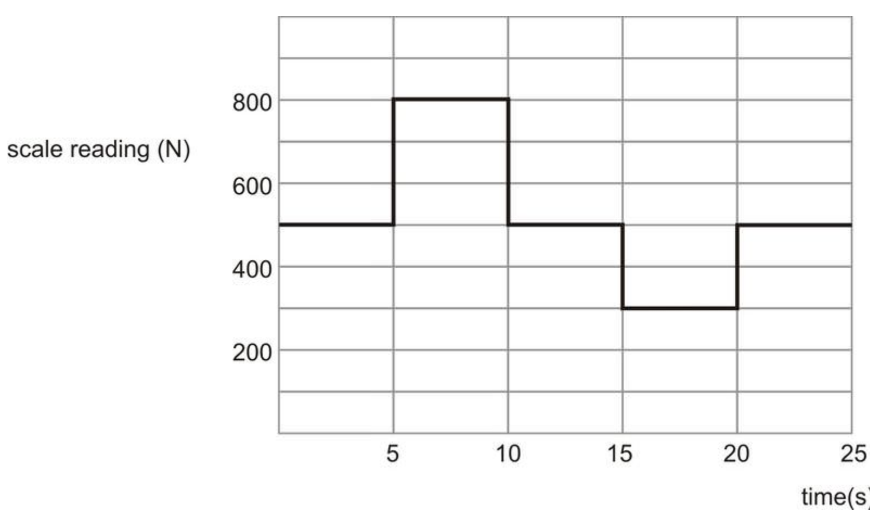
1. During a rocket launch, the rocket's acceleration increases greatly over time. Explain, using Newton's Second Law. (Hint: most of the mass of a rocket on the launch pad is fuel).
2. When pulling a paper towel from a paper towel roll, why is a quick jerk more effective than a slow pull?
3. You pull a wagon with a force of 20 N. The wagon has a mas of 10 kg. What is the wagon's acceleration?
4. The man is hanging from a rope wrapped around a pulley and attached to both of his shoulders. The pulley is fixed to the wall. The rope is designed to hold 500 N of weight; at higher tension, it will break. Let's say he has a mass of 80 kg. Draw a free body diagram and explain (using Newton's Laws) whether or not the rope will break.

5. Now the man ties one end of the rope to the ground and is held up by the other. Does the rope break in this situation? What precisely is the difference between this problem and the one before?

6. A crane is lowering a box of mass 50 kg with an acceleration of 2.0 m/s^2.

a. Find the tension F_T in the cable.
b. If the crane lowers the box at a constant speed, what is the tension F_T in the cable?

7. A physics student weighing 500 N stands on a scale in an elevator and records the scale reading over time. The data are shown in the graph below. At time $t = 0$, the elevator is at rest on the ground floor.



a. Draw a FBD for the person, labeling all forces.
b. What does the scale read when the elevator is at rest?
c. Calculate the acceleration of the person from 5-10 sec.
d. Calculate the acceleration of the person from 10-15 sec. Is the passenger at rest?
e. Calculate the acceleration of the person from 15-20 sec. In what direction is the passenger moving?
f. Is the elevator at rest at $t = 25\ s$? Justify your answer.

Review (Answers)

Using $g = 10\ m/s^2$.

1. According to Newton's second law: the acceleration of an object is inversely proportional to it's mass, so if you decrease it's mass while keeping the net force the same, the acceleration will increase.
2. When you jerk the paper towel, the paper towel that you are holding onto will accelerate much more quickly than the entire roll causing it to rip. Again, acceleration is inversely proportional to the mass of the object.
3. $2m/s^2$
4. The rope will not break because his weight of 800 N is distributed between the two ropes.
5. Yes, because his weight of 800 N is greater than what the rope can hold.
6. a. 400 N b. 500 N
7. b. 500 N c. 6 m/s^2 d. 0 e. $-4\ m/s^2$

14.3 Acceleration Due to Gravity

Learning Objectives

- Solve problems of the motion of objects uniformly accelerated by gravity.

In the absence of air resistance, all objects fall toward the Earth with the same acceleration. Parachutists, like the one from the U.S. Army Parachute Team shown above, make maximum use of air resistance in order to limit the acceleration of the fall.

Acceleration Due to Gravity

One of the most common examples of uniformly accelerated motion is that an object allowed to drop will fall vertically to the Earth due to gravity. In treating falling objects as uniformly accelerated motion, we must ignore air resistance. Galileo's original statement about the motion of falling objects is:

> *At a given location on the Earth and in the absence of air resistance, all objects fall with the same uniform acceleration.*

We call this **acceleration due to gravity** on the Earth and we give it the symbol g. The value of g is 9.81 m/s^2 in the downward direction. All of the equations involving constant acceleration can be used for falling bodies but we insert g wherever "a" appeared and the value of g is always 9.81 m/s^2.

Example: A rock is dropped from a tower 70.0 m high. How far will the rock have fallen after 1.00 s, 2.00 s, and 3.00 s? Assume the distance is positive downward.

Solution: We are looking for displacement and we have time and acceleration. Therefore, we can use $d = \frac{1}{2}at^2$.

Displacement after 1.00 s: $\left(\frac{1}{2}\right)(9.81 \text{ m/s}^2)(1.00 \text{ s})^2 = 4.91 \text{ m}$

Displacement after 2.00 s: $\left(\frac{1}{2}\right)(9.81 \text{ m/s}^2)(2.00 \text{ s})^2 = 19.6 \text{ m}$

Displacement after 3.00 s: $\left(\frac{1}{2}\right)(9.81 \text{ m/s}^2)(3.00 \text{ s})^2 = 44.1 \text{ m}$

Example: (a) A person throws a ball upward into the air with an initial velocity of 15.0 m/s. How high will it go before it comes to rest? (b) How long will the ball be in the air before it returns to the person's hand?

Solution: In part (a), we know the initial velocity (15.0 m/s), the final velocity (0 m/s), and the acceleration (-9.81 m/s^2). We wish to solve for the displacement, so we can use ${v_f}^2 = {v_i}^2 + 2ad$ and solve for d.

$d = \frac{{v_f}^2 - {v_i}^2}{2a} = \frac{(0 \text{ m/s})^2 - (15.0 \text{ m/s})^2}{(2)(-9.81 \text{ m/s}^2)} = 11.5 \text{ m}$

There are a number of methods by which we can solve part (b). Probably the easiest is to divide the distance traveled by the average velocity to get the time going up and then double this number since the motion is symmetrical—that is, time going up equals the time going down.

The average velocity is half of 15.0 m/s, or 7.5 m/s, and dividing this into the distance of 11.5 m yields 1.53 s. This is the time required for the ball to go up and the time for the ball to come down will also be 1.53 s, so the total time for the trip up and down is 3.06 s.

Example: A car accelerates with uniform acceleration from 11.1 m/s to 22.2 m/s in 5.0 s. (a) What was the acceleration and (b) how far did it travel during the acceleration?

Solution:

(a) $a = \frac{\Delta v}{\Delta t} = \frac{22.2 \text{ m/s} - 11.1 \text{ m/s}}{5.0 \text{ s}} = 2.22 \text{ m/s}^2$

(b) We can find the distance traveled by $d = v_i t + \frac{1}{2}at^2$, or we could find the distance traveled by determining the average velocity and multiply it by the time.

$$\begin{aligned} d &= v_i t + \frac{1}{2}at^2 \\ &= (11.1 \text{ m/s})(5.0 \text{ s}) + \left(\frac{1}{2}\right)(2.22 \text{ m/s}^2)(5.0 \text{ s})^2 \\ &= 55.5 \text{ m} + 27.8 \text{ m} \\ &= 83 \text{ m} \end{aligned}$$

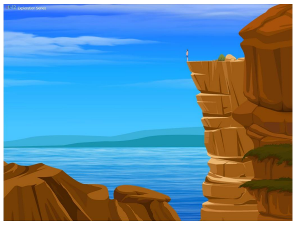
$d = (v_{\text{avg}})(t) = (16.6 \text{ m/s})(5.0 \text{ s}) = 83 \text{ m}$

Example: A stone is dropped from the top of a cliff. It is hits the ground after 5.5 s. How high is the cliff?

Solution:

$d = v_i t + \frac{1}{2}at^2 = (0 \text{ m/s})(5.5 \text{ s}) + \left(\frac{1}{2}\right)(9.81 \text{ m/s}^2)(5.5 \text{ s})^2 = 150 \text{ m}$

Interactive Simulations



SIMULATION

Learn about the relationship between position and velocity for a diver accelerating under the influence of gravity and air resistance.

URL: http://www.ck12.org/physics/Acceleration-Due-to-Gravity/simulationint/Cliff-Diver

SIMULATION

Learn about the relationship between position and velocity for a model rocket during launch and in free-fall.

URL: http://www.ck12.org/physics/Motion/simulationint/Model-Rocket

Summary

- At any given location on the Earth and in the absence of air resistance, all objects fall with the same uniform acceleration.
- We call this acceleration the acceleration due to gravity on the Earth and we give it the symbol g.
- The value of g is 9.81 m/s^2.

Review

1. A baseball is thrown vertically into the air with a speed of 24.7 m/s.
   a. How high does it go?
   b. How long does the round trip up and down require?
2. A salmon jumps up a waterfall 2.4 m high. With what minimum speed did the salmon leave the water below to reach the top?
3. A kangaroo jumps to a vertical height of 2.8 m. How long will it be in the air before returning to Earth?

Explore More

This video offers a discussion and demonstration of the acceleration due to gravity.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/60001

1. What is the gravitational acceleration given in the video? Why does it differ from that given in this text?
2. Why does the ball travel further in later time intervals than in the earlier ones?

Vocabulary

- **acceleration due to gravity:** The acceleration experienced by a body in free fall in a gravitational field.

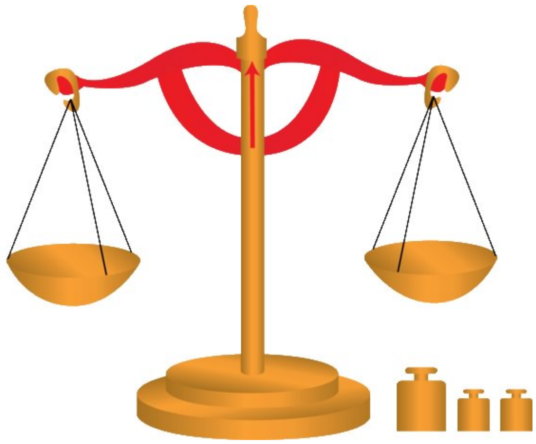
14.4 Mass vs Weight

- Distinguish between mass and weight.
- Given the acceleration due to gravity and either the mass or the weight of an object, calculate the other one.

Astronauts in training often fly in the KC-135 training aircraft to experience near-weightlessness. Three Japan Aerospace Exploration Agency astronauts—Akihiko Hoshide, Satoshi Furukawa, and Naoko Yamazaki—are shown here during such an exercise. Though they experience near-weightlessness, we can see that their mass has not changed. What is the relationship between mass and weight?

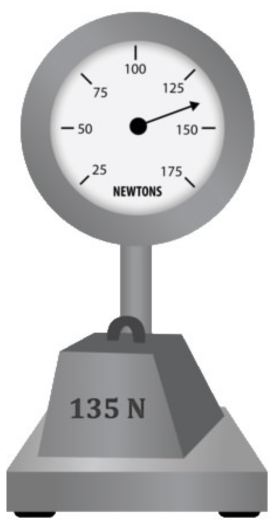
Mass and Weight

The **mass** of an object is defined as the amount of matter in the object. The amount of mass an object has does not change; a moon rock that has been returned to Earth has the same mass on the Earth's surface as it had on the moon. The amount of mass in an object is measured by comparing the object to known masses on an instrument called a balance.



Using the balance shown here, the object would be placed in one pan and known masses would be placed in the other pan until the pans were exactly balanced. When balanced, the mass of the object would be equal to the sum of the known masses in the other pan. A balance will work in any location; whether on the moon or on Earth, the moon rock mentioned earlier will have the same mass.

The **weight** of an object is the force pulling the object downward. On Earth, this would be the gravitational force of the Earth on the object. On the moon, this would be the gravitational force of the moon on the object. The gravitational force of the moon is one-sixth the magnitude of the gravitational force of the Earth; the weight of the moon rock on the moon will be one-sixth the weight of the moon rock on the Earth's surface. Weight is measured in force units—newtons—by a calibrated spring scale as shown here.



The force of gravity is given by Newton's Second Law, $F = ma$, where F is the force of gravity in newtons, m is the mass of the object in kilograms, and a is the acceleration due to gravity, 9.81 m/s^2. When the formula is used specifically for finding weight from mass or vice versa, it may appear as $W = mg$.

Example Problem: What is the weight of an object sitting on the Earth's surface if the mass of the object is 43.7 kg?

Solution: $W = mg = (43.7 \text{ kg})(9.81 \text{ m/s}^2) = 429 \text{ N}$

Example Problem: What is the mass of an object whose weight sitting on the Earth is 2570 N?

$m = \frac{W}{a} = \frac{2570 \text{ N}}{9.81 \text{ m/s}^2} = 262 \text{ kg}$

Summary

- The mass of an object is measured in kilograms and is defined as the amount of matter in an object.
- Mass is determined by comparing an object to known masses on a balance.
- The weight of an object on the Earth is defined as the force acting on the object by the Earth's gravity.
- Weight is measured by a calibrated spring scale.
- The formula relating mass and weight is $W = mg$.

Practice

Questions

A song about the difference between mass and weight sung by Mr. Edmunds to the tune of Sweet Caroline. Remember to make allowances for the fact that he is a teacher, not a professional singer. Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=1whMAIGNq7E

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/60010

1. What is used to measure mass?
2. What is used to measure weight?
3. What units are used to measure mass?
4. What units are used to measure weight?

Review

Questions

1. The mass of an object on the Earth is 100. kg.
   1. What is the weight of the object on the Earth?
   2. What is the mass of the object on the moon?
   3. Assuming the acceleration due to gravity on the moon is exactly one-sixth of the acceleration due to gravity on Earth, what is the weight of the object on the moon?
2. A man standing on the Earth can exert the same force with his legs as when he is standing on the moon. We know that the mass of the man is the same on the Earth and the moon. We also know that $F = ma$ is true on both the Earth and the moon. Will the man be able to jump higher on the moon than the Earth? Why or why not?

- **mass:** The mass of an object is measured in kilograms and is defined as the amount of matter in an object.
- **weight:** The weight of an object on the earth is defined as the force acting on the object by the earth's gravity.

14.5 References

1. Courtesy of Neil A. Armstrong, NASA. http://spaceflight.nasa.gov/gallery/images/apollo/apollo11/html/as11-40-5873.html .
2. Courtesy of Donna Dixon/U.S. Military. http://commons.wikimedia.org/wiki/File:Flickr_-_The_U.S._Army_-_U.S._Army_Parachute_Team_graduates_first_wounded_warrior_and_largest_female_class_%282%29.jpg .
3. Courtesy of NASA. http://spaceflight.nasa.gov/gallery/images/behindthescenes/training/html/jsc2004e45082.html .
4. Christopher Auyeung. CK-12 Foundation .
5. Christopher Auyeung. CK-12 Foundation .

CHAPTER 15 PS2-5

Chapter Outline

15.1 Current and Magnetism

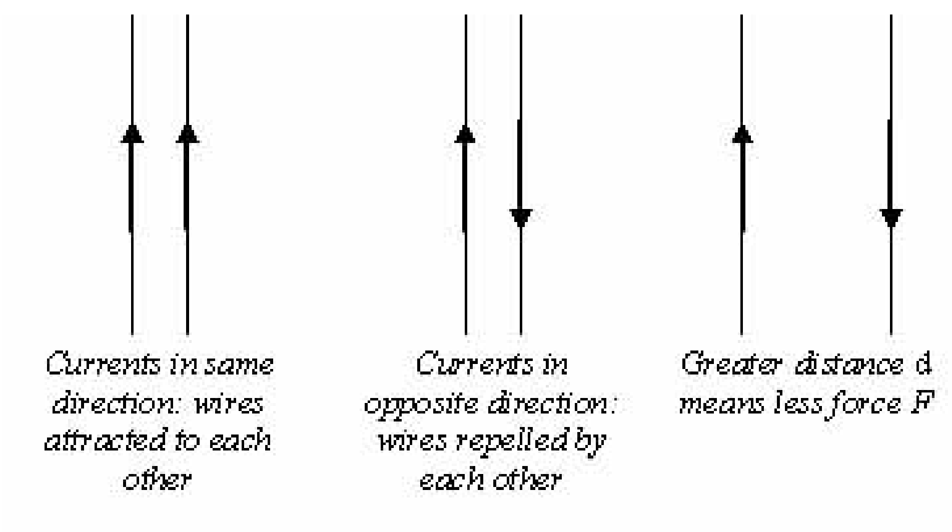
Learning Objectives

- Analyze and solve problems involving current carrying wires in magnetic fields.

Force on a Wire

Since a wire is nothing but a collection of moving charges, the force it will experience in a magnetic field will simply be the vector sum of the forces on the individual charges. If the wire is straight — that is, all the charges are moving in the same direction — these forces will all point in the same direction, and so will their sum. Then, the direction of the force can be found using the second right hand rule, while its magnitude will depend on the length of the wire (denoted L), the strength of the current, the strength of the field, and the angle between their directions:

Two current-carrying wires next to each other each generate magnetic fields and therefore exert forces on each other:



Key Equations

$$F_{\text{wire}} = LIB\sin(\theta) \quad \text{Force on a Current Carrying Wire}$$

In this equation, L refers to the length of the wire, I to the electric current, B the magnitude of the magnetic field and θ is the angle between the direction of the current and the direction of the magnetic field.

$$B_{\text{wire}} = \frac{\mu_0 I}{2\pi r} \quad \text{Magnetic field at a distance } r \text{ from a current-carrying wire}$$

$$\text{Where } \mu_0 = 4\pi \times 10^{-7}\ \text{Tm/A} \quad \text{Permeability of Vacuum (approximately same for air also)}$$

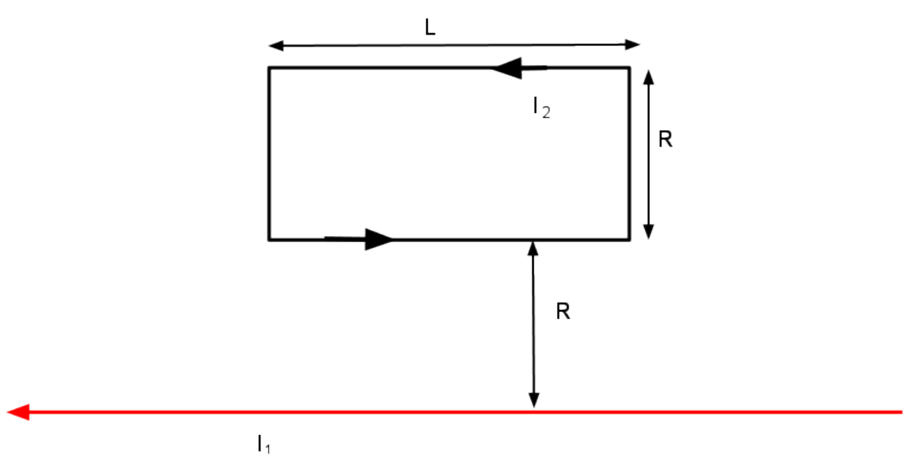
MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/329

Example

A wire loop and an infinitely long current carrying cable are placed a distance r apart. The infinitely long wire is carrying a current I_1 to the left and the loop is carrying a current I_2 CCW. The dimensions of the wire loop are shown in the diagram illustrating the situation below. What is the magnitude and direction of the net force on the loop (the mass of the wires are negligible)?



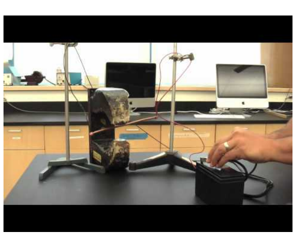
In this problem, it is best to start by determining the direction of the force on each segment of the loop. Based on the first right hand rule, the magnetic field from the infinite cable points into the page where the loop is. This means that the force on the top segment of the loop will be down toward the bottom of the page, the force on the left segment will be to right, the force on the bottom segment will be toward the top of the page, and the force on the right segment will be to the left. The forces on the left and right segments will balance out because both segments are the same distance from the cable. The forces from the top and bottom section will not balance out because the wires are different distances from the cable. The force on the bottom segment will be stronger than the one on the top segment because the magnetic field is stronger closer to the cable, so the net force on the loop will be up, toward the top of the page.

Now we will begin to calculate the force's magnitude by first determining the strength of the magnetic field at the bottom and top segments. All we really have to do is plug in the distances to each segment into the equation we already know for the magnetic field due to a current carrying wire.

$$B = \frac{\mu_o I}{2\pi r}$$
$$B_{bottom} = \frac{\mu_o I_1}{2\pi R}$$
$$B_{top} = \frac{\mu_o I_1}{2\pi 2R}$$

Now we will calculate the net force on the loop using the equation given above. We'll consider up the positive direction.

$\Sigma F = F_{bottom} - F_{top}$	start by summing the forces on the loop
$\Sigma F = I_2 L B_{bottom} - I_2 L B_{top}$	substitute in the values for each of the force terms
$\Sigma F = I_2 L (B_{bottom} - B_{top})$	factor the equation
$\Sigma F = I_2 L (\frac{\mu_o I_1}{2\pi R} - \frac{\mu_o I_1}{2\pi 2R})$	substitute in the values for the magnetic field
$\Sigma F = \frac{\mu_o I_1 I_2 L}{2\pi R}(1 - \frac{1}{2})$	factor the equation again
$\Sigma F = \frac{\mu_o I_1 I_2 L}{4\pi R}$	simplify to get the answer

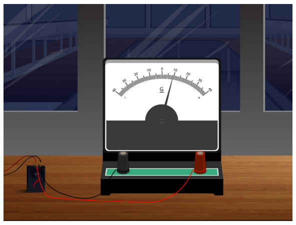


MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/327

Interactive Simulation



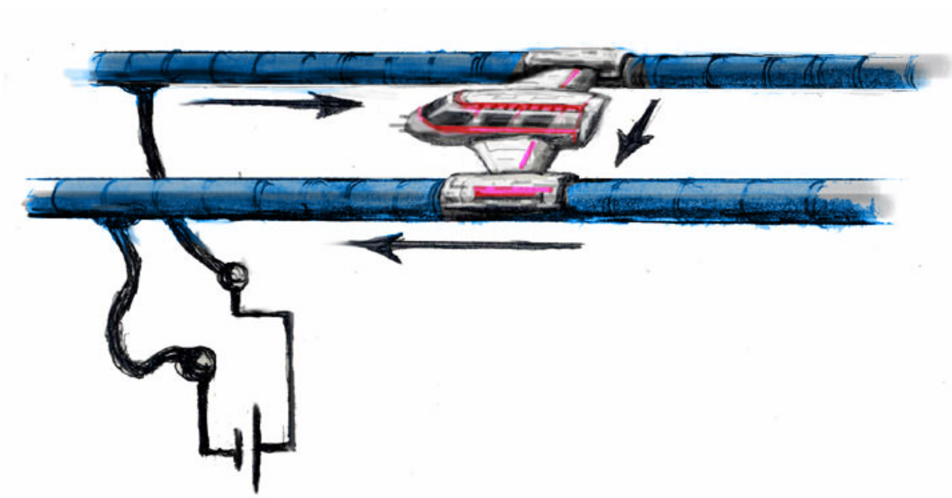
SIMULATION

Understand how the magnetic field generated by loops of current-carrying wire is used to create measuring devices like voltmeters and ammeters.

URL: http://www.ck12.org/physics/Current-and-Magnetism/simulationint/Galvanometer

Review

1. A vertical wire, with a current of 6.0 A going towards the ground, is immersed in a magnetic field of 5.0 T pointing to the right. What is the value and direction of the force on the wire? The length of the wire is 2.0 m.



2. A futuristic magneto-car uses the interaction between current flowing across the magneto car and magnetic fields to propel itself forward. The device consists of two fixed metal tracks and a freely moving metal car (see illustration above). A magnetic field is pointing downward with respect to the car, and has the strength of 5.00 T. The car is 4.70 m wide and has 800 Aof current flowing through it. The arrows indicate the direction of the current flow.
   a. Find the direction and magnitude of the force on the car.
   b. If the car has a mass of 2050 kg, what is its velocity after 10 s, assuming it starts at rest?
   c. If you want double the force for the same magnetic field, how should the current change?
3. A horizontal wire carries a current of 48 A towards the east. A second wire with mass 0.05 kg runs parallel to the first, but lies 15 cm below it. This second wire is held in suspension by the magnetic field of the first wire above it. If each wire has a length of half a meter, what is the magnitude and direction of the current in the lower wire?
4. Show that the formula for the force between two current carrying wires is $F = \frac{\mu_o L i_1 i_2}{2\pi d}$, where d is the distance between the two wires, i_1 is the current of first wire and L is the segment of length of the second wire carrying a current i_2. (Hint: find magnetic field emanating from first wire and then use the formula for a wire immersed in that magnetic field in order to find the force on the second wire.)

5. Two long thin wires are on the same plane but perpendicular to each other. The wire on the $y-$axis carries a current of 6.0 A in the $-y$ direction. The wire on the $x-$axis carries a current of 2.0 A in the $+x$ direction. Point, P has the co-ordinates of $(2.0, 2, 0)$ in meters. A charged particle moves in a direction of 45^o away from the origin at point, P, with a velocity of 1.0×10^7 m/s.
   a. Find the magnitude and direction of the magnetic field at point, P.
   b. If there is a magnetic force of 1.0×10^{-6} N on the particle determine its charge.
   c. Determine the magnitude of an electric field that will cancel the magnetic force on the particle.
6. A long straight wire is on the $x-$axis and has a current of 12 A in the $-x$ direction. A point P, is located 2.0 m above the wire on the $y-$axis.
   a. What is the magnitude and direction of the magnetic field at P.
   b. If an electron moves through P in the$-x$ direction at a speed of 8.0×10^7 m/s what is the magnitude and direction of the force on the electron?

Review (Answers)

1. Down the page; 60 N
2. a. To the right, 1.88×10^4 N b. 91.7 m/s c. It should be doubled
3. 7812.5 A
4.

$$F_{wire} = \frac{\mu_0 L I_{\text{wire 1}} I_{\text{wire 2}}}{2\pi d} = \frac{\mu_0 L i_1 i_2}{2\pi d}$$

FIGURE 15.1

5. a. 8×10^{-7} T b. 1.3×10^{-6} C c. 8 N/C
6. a. 1.2×10^{-6} T, $+z$ b. 1.5×10^{-17} N, $-y$

15.2 Electric Currents and Magnetic Fields

Learning Objectives

- Understand the shape of magnetic fields produced by moving current.
- Understand the effect of a magnetic field on a moving charged particle.
- Explain the direction of the force on a current-carrying wire in a magnetic field.
- Solve problems involving using the right and left hand rules.

Powerful electromagnets are commonly used for industrial lifting. Here, a magnet is lifting scrap iron and loading it onto a railroad car for transporting to a scrap iron recovery plant. Other uses for lifting magnets include moving cars in a junk yard, lifting rolls of steel sheeting, and lifting large steel parts for various machines. Electromagnets are usually used for these jobs because they are magnets only when the electric current is on. The magnet will hold the iron object when the current is on and release it when the current is off.

Electric Currents and Magnetic Fields

Electricity and magnetism are inextricably linked. Under certain conditions, electric current causes a magnetic field. Under other conditions, a magnetic field can cause an electric current. A moving charged particle creates a magnetic field around it. Additionally, when a moving charged particle moves through a different magnetic field, the two magnetic fields will interact. The result is a force exerted on the moving charged particle.

Magnetic Field Around a Current Carrying Wire

In sketch (a) above, a current is being pushed through a straight wire. Small compasses placed around the wire point in a circle, instead of all towards the north pole. This demonstrates the presence of a magnetic field around the wire.

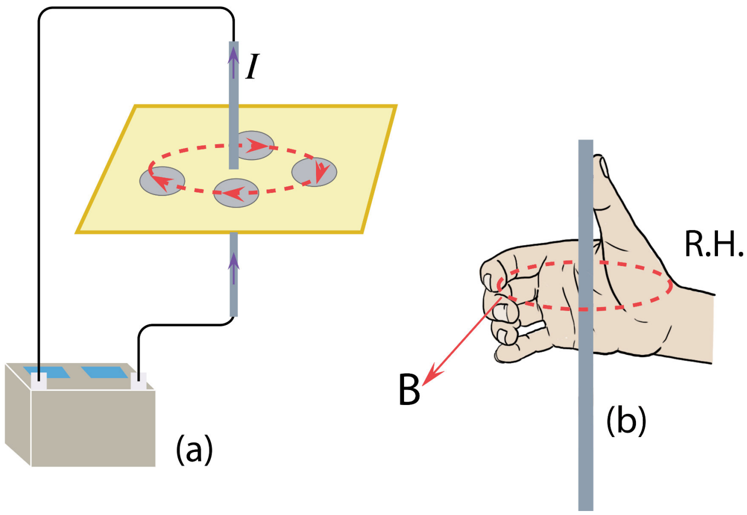


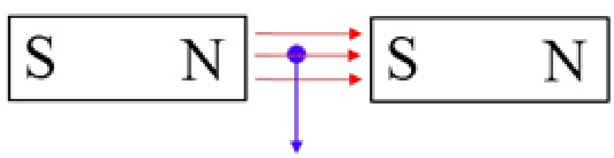
FIGURE 15.2

If the current is turned off, the compass points return to pointing north.

The current moving in a straight wire produces a circular magnetic field around the wire. When using conventional current, the direction of the magnetic field is determined by using the **right hand rule**. The rule says to curl your right hand around the wire such that your thumb points in the direction of the conventional current. Having done this, your fingers will curl around the wire in the direction of the magnetic field. Note that the right hand rule is for conventional current. If you are dealing with an electron flow current, the charges are flowing in the opposite direction, so you must use your left hand. That is, curl your left hand around the wire with your thumb pointing in the direction of the electron flow and your fingers will point in the direction of the magnetic field.

Charged Particles Moving Through a Magnetic Field

When a charged particle moves through a magnetic field at right angles to the field, the field exerts a force on the charged particle in a different direction.



In the case sketched above, an electron is moving downward through a magnetic field. The motion of the electron is perpendicular to the magnetic field. The force exerted on the electron can be calculated by the equation,

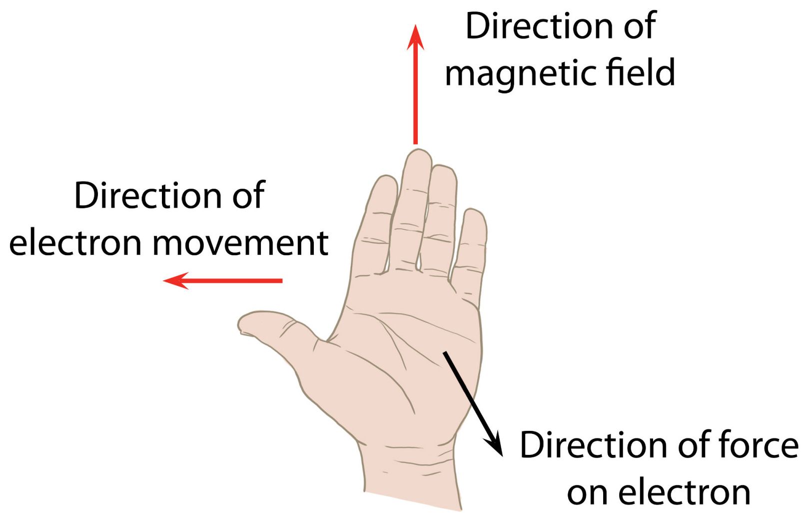
$F = Bqv$ is the velocity of the particle.v is the charge on the particle and q is the strength of the field, B, where

B is expressed in $\frac{Newtons}{Amp \cdot meter} \frac{N}{A \cdot m}$, after the Serbian physicist Nikola Tesla.**Tesla** is also known as a is expressed in m/s. The unit v is expressed in coulombs and q ,while

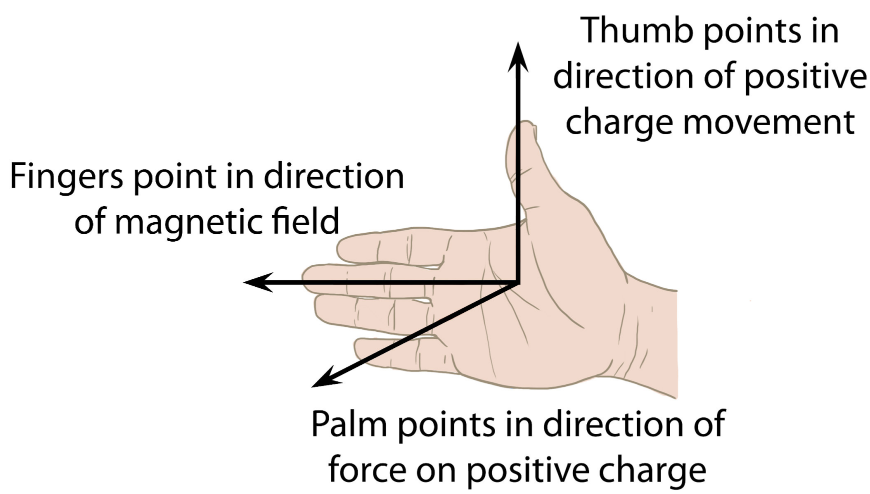
You can see that the product of these three units is Newtons, the appropriate unit for force.

$F = Bqv = \frac{Newtons}{Amp \cdot meter} \cdot coulomb \cdot \frac{meter}{s} \frac{coulomb}{second}$, amps cancels coulombs/second and meters cancels meters. The only unit remaining is Newtons. and since amperes are

Again, we can determine the direction of the force acting upon the electron using a hand rule. Since the electron has a negative charge, the **left hand rule** is used. The fingers of the left hand are pointed in the direction of the magnetic field and the thumb points in the direction of the initial electron movement. The direction of the force acting on the electron is the direction the palm of the left hand faces. The direction of the magnetic field, the direction of the moving charge, and the direction of the force on the particle are all perpendicular to each other.



In most situations, a positive test charged is used, instead of an electron. In these circumstances, the **right hand rule** is used. The right hand rule is the same as the left hand rule; the thumb is the direction of initial charge movement, the fingers are the direction of the field, and the palm is the direction of the acting force.



In dealing with the relationships that exist between magnetic fields and electric charges, there are both left hand and right hand rules that we use to indicate various directions - directions of fields, directions of currents, directions of motion. To avoid errors, it is absolutely vital to know and express whether the system we are observing is using conventional current or electron current. This allows us to use the appropriate rule.

Example 1

An electron traveling at $3.0 \times 10^6\ m/s$ passes through a $0.0400\ N/amp \cdot m$ uniform magnetic field. The electron is moving at right angles to the magnetic field. What force acts on the electron?

$F = Bqv = (0.0400\ N/amp \cdot m)(1.6 \times 10^{-19}\ C)(3.0 \times 10^6\ m/s)$

$= 1.9 \times 10^{-14}\ N$

When the current is traveling through a magnetic field while inside a wire, the magnetic force is still exerted but now it is calculated as the force on the wire rather than on the individual charges in the current.

The equation for the force on the wire is given as $F = BIL$, where B is the strength of the magnetic field, I is the current in amps and L is the length of the wire in and perpendicular to the field.

Example 2

A wire 0.10 m long carries a current of 5.0 A. The wire is at right angles to a uniform magnetic field. The force the field exerts on the wire is 0.20 N. What is the magnitude of the magnetic field?

$B = \frac{F}{IL} = \frac{0.20\ N}{(5.0\ A)(0.10\ m)} = 0.40\ \frac{N}{A \cdot m}$

Summary

- A moving charged particle creates a magnetic field around it.
- Charge through a wire creates a magnetic field around it, the properties of which can be determined using a right hand rule.
- When a moving charged particle moves through another magnetic field, that field will exert a force on the moving charged particle that can be expressed using $F = Bqv$.
- The relationships between the moving charged particle, magnetic field, and the force exerted can be determined using the right hand rule if the particle is positive, or the left hand rule if it is negative.
- When the current is traveling through a magnetic field while inside a wire, the magnetic force is still exerted but now it is calculated as the force on the wire rather than on the individual charges in the current, calculated using $F = BIL$.

Review

1. Find the force on a 115 m long wire at right angles to a $5.0 \times 10^{-5}\ N/A \cdot m$ magnetic field, if the current through the wire is 400. A.
2. Find the force on an electron passing through a 0.50 T magnetic field if the velocity of the electron is $4.0 \times 10^6\ m/s$.
3. A stream of doubly ionized particles (charge $= 2+$) moves at a velocity of $3.0 \times 10^4\ m/s$ perpendicularly to a magnetic field of 0.0900 T. What is the magnitude of the force on the particles?
4. A wire 0.50 m long carrying a current of 8.0 A is at right angles to a 1.0 T magnetic field. What force acts on the wire?
5. Suppose a magnetic field exists with the north pole at the top of the computer monitor and the south pole at the bottom of the monitor screen. If a positively charged particle entered the field moving from your face to the other side of the monitor screen, which way would the path of the particle bend?
    1. left
    2. right
    3. up
    4. down
    5. none of these
6. Suppose the surface of your dining room table is a magnetic field with the north pole at the north edge and the south pole at the south edge. If an electron passes through this field from ceiling to floor, which way will the path of the electron bend?
    1. west
    2. east
    3. north

4. south
5. toward the ceiling

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/63580

1. What happens to the wire when the current begins to flow?
2. What difference would it make if the magnetic field were stronger?
3. What difference would it make if the battery were 3.0 V instead of 1.5 V?

Vocabulary

- **left hand rule:** A rule in electricity for finding the direction of the force of a magnetic field on a negatively charged particle moving through the magnetic field at right angles. Point the fingers in the direction of the field and the thumb in the direction of the moving charge and the palm will indicate the direction of the force on the charge.
- **right hand rule:** A rule in electricity for finding the direction of the force of a magnetic field on a positively charged particle moving through the magnetic field at right angles. Point the fingers in the direction of the field and the thumb in the direction of the moving charge and the palm will indicate the direction of the force on the charge.
- **tesla:** The tesla (symbol T) is the SI derived unit of magnetic flux density, commonly denoted as B, (which is also known as "magnetic field"). One tesla is equal to one $\frac{\text{Newton}}{\text{amp}\cdot\text{meter}}$.

15.3 Electromagnets

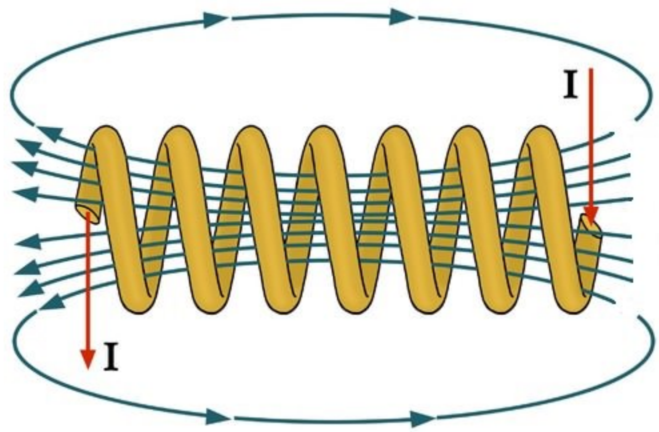
Learning Objectives

- Define and describe a solenoid.
- Define and describe an electromagnet.
- Determine the direction of the magnetic field inside a solenoid given the direction of current flow in the coil wire.
- Understand why an electromagnet has a stronger magnetic field than a solenoid.

One of the most famous electric car companies is Tesla, named after Nikola Tesla. These electric cars, and all others, require an electromagnet to run the engine.

Electromagnets

A long coil of wire consisting of many loops of wire and making a complete circuit is called a **solenoid**. The magnetic field within a solenoid can be quite large since it is the sum of the fields due to the current in each individual loop.



The magnetic field around the wire is determined by a hand rule. Since this description doesn't mention electron flow, we must assume that the current indicated by I is conventional current (positive). Therefore, we would use a right hand rule. We grasp a section of wire with our right hand pointing the thumb in the direction of the current flow and our fingers will curl around the wire in the direction of the magnetic field. Therefore, the field points down the cavity in these loops from right to left as shown in the sketch.

If a piece of iron is placed inside the coil of wire, the magnetic field is greatly increased because the domains of the iron are aligned by the magnetic field of the current. The resulting magnetic field is hundreds of time stronger than the field from the current alone. This arrangement is called an **electromagnet**. The picture below shows an electromagnet with an iron bar inside a coil.

Our knowledge of electromagnets developed from a series of observations. In 1820, Hans Oersted discovered that a current-carrying wire produced a magnetic field. Later in the same year, André-Marie Ampere discovered that a coil of wire acted like a permanent magnet and François Arago found that an iron bar could be magnetized by putting it inside of a coil of current-carrying wire. Finally, William Sturgeon found that leaving the iron bar inside the coil greatly increased the magnetic field.

Two major advantages of electromagnets are that they are extremely strong magnetic fields, and that the magnetic field can be turned on and off. When the current flows through the coil, it is a powerful magnet, but when the current is turned off, the magnetic field essentially disappears.

Electromagnets find use in many practical applications. Electromagnets are used to lift large masses of magnetic materials such as scrap iron, rolls of steel, and auto parts.

The overhead portion of this machine (painted yellow) is a lifting electromagnet. It is lowered to the deck where steel pipe is stored and it picks up a length of pipe and moves it to another machine where it is set upright and lowered into an oil well drill hole.

Electromagnets are essential to the design of the electric generator and electric motor and are also employed in doorbells, circuit breakers, television receivers, loudspeakers, electric dead bolts, car starters, clothes washers, atomic particle accelerators, and electromagnetic brakes and clutches. Electromagnets are commonly used as switches in electrical machines. A recent use for industrial electromagnets is to create **magnetic levitation** systems for bullet trains.

Summary

- A solenoid is a long coil of wire consisting of many loops of wire that makes a complete circuit.
- An electromagnet is a piece of iron inside a solenoid.
- While the magnetic field of a solenoid may be quite large, an electromagnet has a significantly larger magnetic field.
- Electromagnets' magnetic fields can be easily turned off by just halting the current.

Review

1. Magnetism is always present when electric charges ___________.
2. What happens to the strength of an electromagnet if the number of loops of wire is increased?
3. What happens to the strength of an electromagnet if the current in the wire is increased?
4. Which direction does the magnetic field point in the solenoid sketched here?

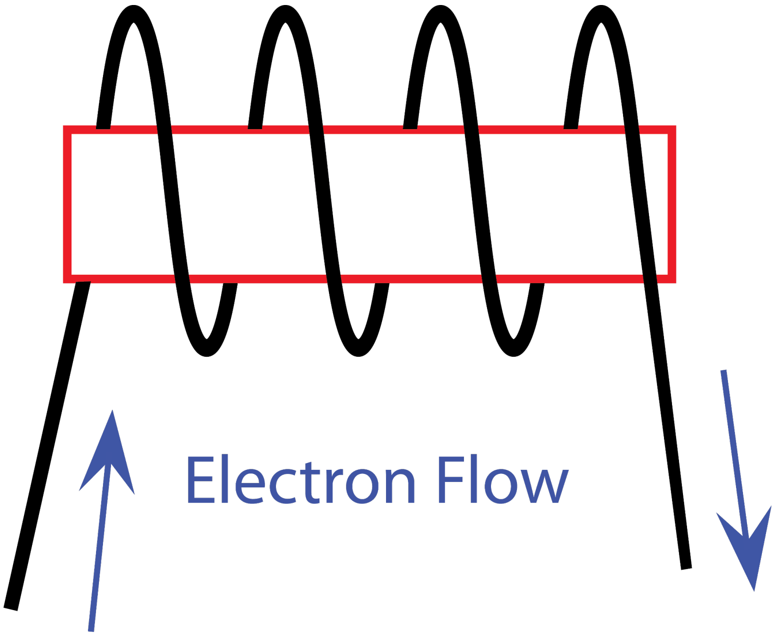


FIGURE 15.3
Practice problem for determining the direction of the magnetic field of a solenoid

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/65197

1. What components are needed to make a homemade electromagnet?
2. What objects were attracted by the electromagnet in the video?

Vocabulary

- **solenoid:** A current-carrying coil of wire that acts like a magnet when a current passes through it.
- **electromagnet:** A temporary magnet consisting of an iron or steel core wound with a coil of wire, through which a current is passed.
- **magnetic levitation:** The suspension of an object above a second object by means of magnetic repulsion.

15.4 Electromagnetic Devices

Learning Objectives

- Define electromagnet and identify electromagnetic devices.
- Explain how a doorbell works.
- Outline how an electric motor changes electrical energy to kinetic energy.

The little boy on the left is pressing the doorbell on his playhouse. The doorbell is connected to a battery, so it actually rings when he pushes the button. The little girl on the right is using a hand-held fan to cool off on a hot day. The fan is also battery-operated, and the blades of the fan turn in a blur of motion. What do the doorbell and fan have in common? Both of them work because they contain electromagnets.

Devices with Electromagnets

Many common electric devices contain electromagnets. An **electromagnet** is a coil of wire wrapped around a bar of iron or other ferromagnetic material. When electric current flows through the wire, it causes the coil and iron bar to become magnetized. An electromagnet has north and south magnetic poles and a magnetic field. Turning off the current turns off the electromagnet. To understand how electromagnets are used in electric devices, we'll focus on two common devices: doorbells and electric motors like the one that turns the blades of a fan.

Q: Besides doorbells and fans, what are some other devices that contain electromagnets?

A: Any device that has an electric motor contains electromagnets. Some other examples include hairdryers, CD players, power drills, electric saws, and electric mixers.

How a Doorbell Works

The **Figure** 15.4 represents a simple doorbell. Like most doorbells, it has a button located by the front door. Pressing the button causes two electric contacts to come together and complete an electric circuit. In other words, the button is a switch. The circuit is also connected to a source of current, an electromagnet, and a clapper that strikes a bell.

What happens when current flows through the doorbell circuit?

- The electromagnet turns on, and its magnetic field attracts the clapper. This causes the clapper to hit the bell, making it ring.

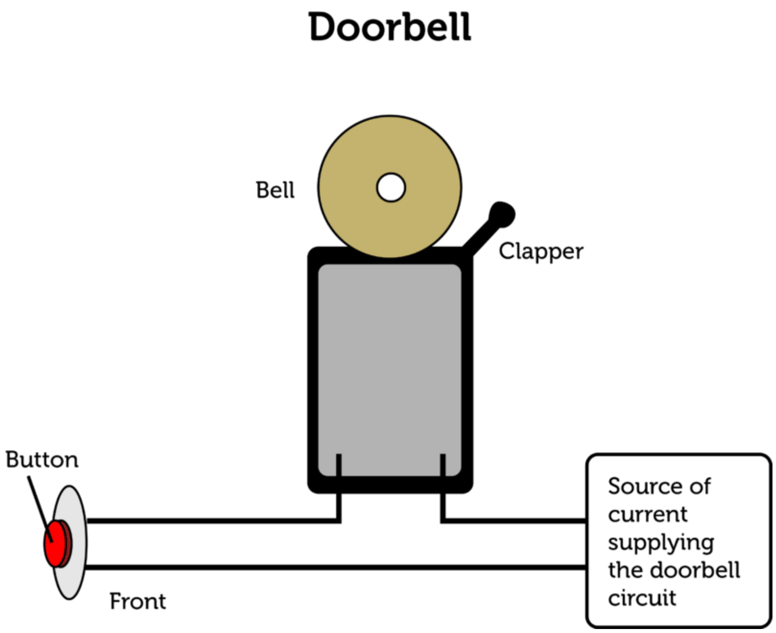


FIGURE 15.4

- Because the clapper is part of the circuit, when it moves to strike the bell, it breaks the circuit. Without current flowing through the circuit, the electromagnet turns off, and the clapper returns to its original position.
- When the clapper moves back to its original position, this closes the circuit again and turns the electromagnet back on. The electromagnet again attracts the clapper, which hits the bell once more.
- This sequence of events keeps repeating.

Q: How can you stop the sequence of events so the doorbell will stop ringing?

A: Stop pressing the button! This interrupts the circuit so no current can flow through it.

Electric Motor

An **electric motor** is a device that uses an electromagnet to change electrical energy to kinetic energy. You can see a simple diagram of an electric motor in the **Figure** 15.5. The motor contains an electromagnet that is connected to a shaft. When current flows through the motor, the electromagnet rotates, causing the shaft to rotate as well. The rotating shaft moves other parts of the device. For example, in an electric fan, the rotating shaft turns the blades of the fan.

Why does the motor's electromagnet rotate?

- The electromagnet is located between the north and south poles of two permanent magnets. When current flows through the electromagnet, it becomes magnetized, and its poles are repelled by the like poles of the permanent magnets. This causes the electromagnet to rotate toward the unlike poles of the permanent magnets.
- A device called a commutator then changes the direction of the current so the poles of the electromagnet are reversed. The reversed poles are again repelled by the poles of the permanent magnets, which have not reversed. This causes the electromagnet to continue to rotate.
- These events keep repeating, so the electromagnet rotates continuously.

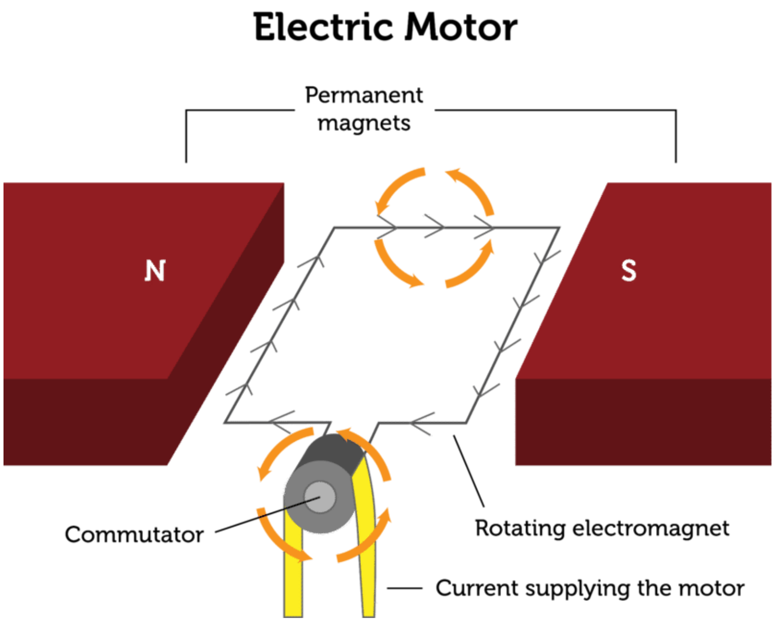


FIGURE 15.5

Summary

- Electromagnetic devices are devices that contain electromagnets. Examples of electromagnetic devices include doorbells and any devices that have electric motors, such as electric fans.
- The electromagnet in a doorbell attracts the clapper, which hits the bell and makes it ring.
- An electric motor is a device that uses an electromagnet to change electrical energy to kinetic energy. When current flows through the motor, the electromagnet rotates, causing a shaft to rotate as well. The rotating shaft moves other parts of the device.

Review

1. Describe an electromagnet.
2. What are some common devices that contain electromagnets?
3. Describe the role of the electromagnet in a doorbell.
4. What is an electric motor?
5. Explain how an electric motor turns the blades of an electric fan.

Resources

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/177816

15.5 References

1. Image copyright dvande, 2013. http://www.shutterstock.com .
2. Samantha Bacic and Laura Guerin. CK-12 Foundation .
3. Richard Parsons. CK-12 Foundation .
4. Laura Guerin. CK-12 Foundation .
5. Laura Guerin. CK-12 Foundation .
6. NRMA Motoring and Services. http://www.flickr.com/photos/nrmadriversseat/5423866558/ .
7. Laura Guerin. Diagram of the magnetic field of a solenoid .
8. Image copyright Zigzag Mountain Art, 2014. http://www.shutterstock.com .
9. Image copyright Ingvar Tjostheim, 2014. http://www.shutterstock.com .
10. Christopher Auyeung. Schematic illustrating how a doorbell works . CC BY-NC 3.0
11. Christopher Auyeung. Schematic of an electromagnetic motor . CC BY-NC 3.0

CHAPTER 16 PS 2-6

Chapter Outline

16.1 Amorphous Solid

Learning Objectives

- Define amorphous solid.
- List properties of amorphous solids.

When a tire goes flat, its shape changes. The tire might be flat because of a slow leak in the tire valve. It could be flat because it ran over a nail or screw and ended up with a small hole where the air can leak out over a period of time. Or it could go flat when it hits a large rock or other object while traveling at high speeds (this one is for those readers who enjoy detective movies or TV shows). What if a crystalline solid like LiBr were ever made into a tire (now there's a weird idea)? When it encountered a blow, the crystal would break into small pieces. Since rubber is an amorphous solid, it has a very different set of physical properties.

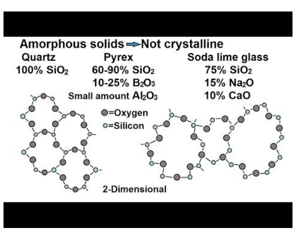
Amorphous Solids

Unlike a crystalline solid, an **amorphous** solid is a solid that lacks an ordered internal structure. Some examples of amorphous solids include rubber, plastic, and gels. Glass is a very important amorphous solid that is made by cooling a mixture of materials in such a way that it does not crystallize. Glass is sometimes referred to as a **supercooled** liquid rather than a solid. If you have ever watched a glassblower in action, you have noticed that he takes advantage of the fact that amorphous solids do not have a distinct melting point like crystalline solids do. Instead, as glass is heated, it slowly softens and can be shaped into all sorts of interesting forms. When a glass object shatters, it does so in a very irregular way, unlike crystalline solids, which always break into fragments that have the same shape as dictated by its crystal system.

Properties of amorphous solids are different in many ways from those of crystalline solids. The intermolecular force forces in amorphous solids are weaker than those in crystalline solids. Amorphous solids do not have a regular external structure and they do not have sharp melting points. Unlike crystalline solids that have regular planes of cleavage, the physical properties of amorphous solids are the same in all directions.

Plastics are used for many purposes because they are inexpensive to produce and do not shatters like glass or ceramic materials. Since they are easily disposed of, the accumulation of plastic garbage has become a serious problem in many parts of the world. Recycling programs that help reuse the plastics are growing in popularity.

FIGURE 16.1
Plastic cup.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185097

Watch a short video on the production of glass sheets:

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/62914

Summary

- An amorphous solid is a solid that lacks an ordered internal structure.
- Examples of amorphous solids include glass, rubber, and plastics.
- The physical properties of amorphous solids differ from those of crystalline solids.

Review

1. What is an amorphous solid?
2. List three common examples of amorphous solids.
3. Do amorphous solids have sharp melting points?
4. What word is sometimes used to refer to glass?

Vocabulary

- **amorphous:** A solid that lacks an ordered internal structure.
- **supercooled:** A liquid at a temperature lower than its freezing point that has not solidified.

16.2 Metallic Bonding

Learning Objectives

- Define metallic bond.
- Describe properties of metals.

Why do metals behave the way they do?

The image above is of a copper plate that was made in 1893. The utensil has a great deal of elaborate decoration and the item is very useful. What would have happened if we decided that copper (I) chloride was just as good a material (well, it does have copper in it). The CuCl would end up as a powder when we pounded on it to shape it. Metals behave in unique ways. The bonding that occurs in a metal is responsible for its distinctive properties: luster, malleability, ductility, and excellent conductivity.

The Metallic Bond

Pure metals are crystalline solids, but unlike ionic compounds, every point in the crystal lattice is occupied by an identical atom. The electrons in the outer energy levels of a metal are mobile and capable of drifting from one metal atom to another. This means that the metal is more properly viewed as an array of positive ions surrounded by a sea of mobile valence electrons. Electrons which are capable of moving freely throughout the empty orbitals of the metallic crystal are called **delocalized electrons** (see **Figure** 16.2). A **metallic bond** is the attraction of the stationary metal cations to the surrounding mobile electrons.

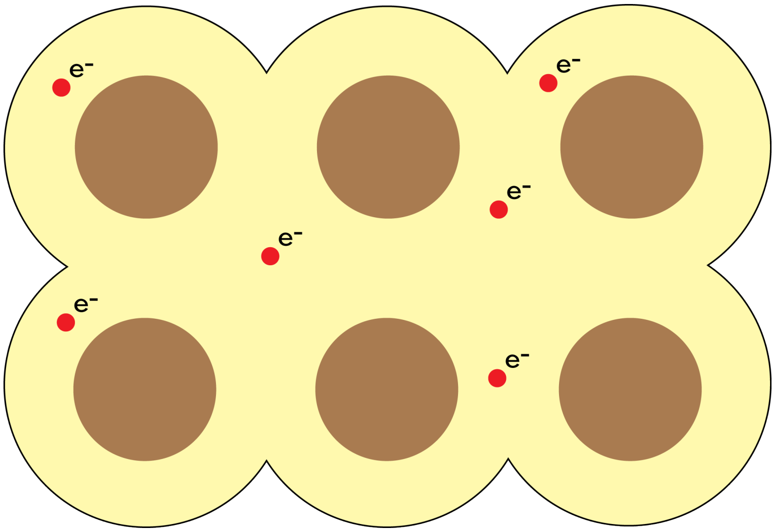
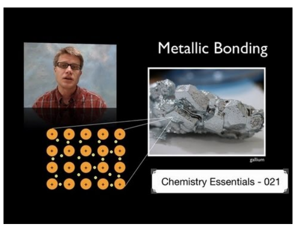


FIGURE 16.2
In a metal, the stationary metal cations are surrounded by a sea of mobile valence electrons that are not associated with any one cation.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/184749

Properties of Metals

The metallic bonding model explains the physical properties of metals. Metals conduct electricity and heat very well because of their free-flowing electrons. As electrons enter one end of a piece of metal, an equal number of electrons flow outward from the other end. When light is shone on to the surface of a metal, its electrons absorb small amounts of energy and become excited into one of its many empty orbitals. The electrons immediately fall back down to lower energy levels and emit light. This process is responsible for the high **luster** of metals.

FIGURE 16.3
The American Platinum Eagle is the official platinum bullion coin of the United States and was first minted in 1997. The luster of a metal is due to its metallic bonds.

Recall that ionic compounds are very brittle. Application of a force results in like-charged ions in the crystal coming too close to one another, causing the crystal to shatter. When a force is applied to a metal, the free-flowing electrons can slip in between the stationary cations and prevent them from coming in contact. Imagine ball bearings that have been coated with oil sliding past one another. As a result, metals are very **malleable** and **ductile**. They can be hammered into shapes, rolled into thin sheets, or pulled into thin wires.

Summary

- The metallic bond is responsible for the properties of metals.
- Metals conduct electricity and heat well.
- Metals are ductile and malleable.
- Metals have luster.

Review

1. What is a delocalized electron?
2. Why do metals conduct electricity and heat well?
3. Why do metals have luster?

Vocabulary

- **delocalized electrons:** Electrons which are capable of moving freely throughout the empty orbitals of the metallic crystal.
- **ductile:** Able to be drawn out into a thin wire.
- **luster:** A gentle sheen or soft glow, especially that of a partly reflective surface.
- **malleable:** Able to be hammered or pressed permanently out of shape without breaking or cracking.
- **metallic bond:** The attraction of the stationary metal cations to the surrounding mobile electrons.

16.3 Alloys

Learning Objectives

- Define alloy.
- Describe compositions and uses for common alloys.

What are the best guitar strings to use?

Many guitar players are very meticulous when it comes to their strings. There is a variety to select from, depending on the type of guitar and the style of music. Electric guitars need steel strings so the magnetic pick-up will detect the string vibrations. Acoustic guitar players have several choices. Bronze strings (mixed with different amounts of cooper and zinc) have perhaps the brightest tone. There are several combinations of bronze alloys to choose from. For those with lots of money, titanium strings are available (but very expensive). Gold coating also helps string life and makes its unique contribution to tone. Alloy chemistry has contributed greatly to the strength, durability, and tonal quality of guitar strings.

Alloys

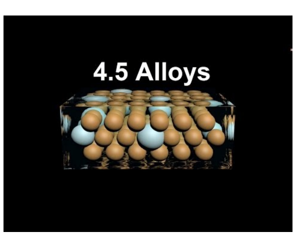
An **alloy** is a mixture composed of two or more elements, at least one of which is a metal. You are probably familiar with some alloys such as brass and bronze. **Brass** is an alloy of copper and zinc. **Bronze** is an alloy of copper and tin. Alloys are commonly used in manufactured items because the properties of these metal mixtures are often superior to a pure metal. Bronze is harder than copper and more easily cast. Brass is very malleable and its acoustic properties make it useful for musical instruments.

FIGURE 16.4
Bronze, an alloy of copper and tin, has been in use since ancient times. The Bronze Age saw the increased use of metals rather than stone for weapons, tools, and decorative objects. Brass, an alloy of copper and zinc, is widely used in musical instruments like the trumpet and trombone.

Steels are a very important class of alloys. The many types of steels are primarily composed of iron, with various amounts of the elements carbon, chromium, manganese, nickel, molybdenum, and boron. Steels are widely used in building construction because of their strength, hardness, and resistance to corrosion. Most large modern structures like skyscrapers and stadiums are supported by a steel skeleton (see **Figure** 16.5).

FIGURE 16.5
The Willis Tower (formerly called the Sears Tower) in Chicago was once the tallest building in the world and is still the tallest in the Western Hemisphere. The use of steel columns makes it possible to build taller, stronger, and lighter buildings.

Alloys can be one of two general types. In one type, called a **substitutional alloy,** the various atoms simply replace each other in the crystal structure. In another type, called an **interstitial alloy,** the smaller atoms such as carbon fit in between the larger atoms in the crystal packing arrangement.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/184755

Summary

- Alloys are mixtures of materials, at least one of which is a metal.
- Bronze alloys were widely used in weapons.
- Brass alloys have long been employed in musical instruments.
- Steel alloys are strong and durable.

Review

1. What is brass made of?
2. What is bronze made of?
3. Why is steel widely used in construction?
4. What is a substitutional alloy?

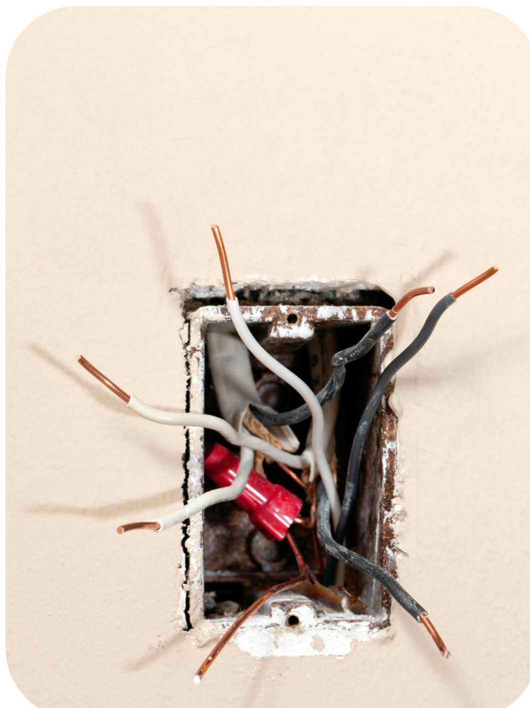
Vocabulary

- **alloy:** A mixture composed of two or more elements, at least one of which is a metal.
- **brass:** An alloy of copper and zinc.
- **bronze:** An alloy of copper and tin.
- **interstitial alloy:** The smaller atoms such as carbon fit in between the larger atoms in the crystal packing arrangement.
- **substitutional alloy:** The various atoms simply replace each other in the crystal structure.

16.4 Classes of Crystalline Solids

Learning Objectives

- List the four types of crystalline solids.
- Describe the properties of each type.



We often take a lot of things for granted. We just assume that we will get electric power when we connect a plug to an electrical outlet. The wire that comprises that outlet is almost always copper, a material that conducts electricity well. The unique properties of the solid copper allow electrons to flow freely through the wire and into whatever device we connect it to. Then we can enjoy music, television, work on the computer, or whatever other activity we want to undertake.

Classes of Crystalline Solids

Crystalline substances can be described by the types of particles in them and the types of chemical bonding that takes place between the particles. There are four types of crystals: (1) **ionic**, (2) **metallic**, (3) **covalent** network, and (4) **molecular**. Properties and several examples of each type are listed in the following table and are described in **Table** 16.1.

TABLE 16.1: Crystalline Solids - Melting and Boiling Points

TABLE 16.1: (continued)

Type of Crystalline Solid	**Examples (formulas)**	**Melting Point (°C)**	**Normal Boiling Point (°C)**
Ionic	NaCl CaF_2	801 1418	1413 2533
Metallic	Hg Na Au W	-39 371 1064 3410	630 883 2856 5660
Covalent network	B C (diamond) SiO_2	2076 3500 1600	3927 3930 2230
Molecular	H_2 I_2 NH_3 H_2O	-259 114 -78 0	-253 184 -33 100

1. Ionic crystals – The ionic crystal structure consists of alternating positively-charged cations and negatively-charged anions (see **Figure** 16.6). The ions may either be monatomic or polyatomic. Generally, ionic crystals form from a combination of Group 1 or 2 metals and Group 16 or 17 nonmetals or nonmetallic polyatomic ions. Ionic crystals are hard and brittle and have high melting points. Ionic compounds do not conduct electricity as solids, but do conduct when molten or in aqueous solution.

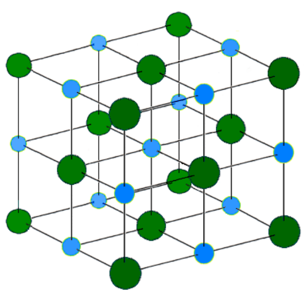


FIGURE 16.6
NaCl crystal.

2. Metallic crystals – Metallic crystals consist of metal cations surrounded by a "sea" of mobile valence electrons (see **Figure** 16.7). These electrons, also referred to as delocalized electrons, do not belong to any one atom, but are capable of moving through the entire crystal. As a result, metals are good conductors of electricity. As seen in **Table** 16.1, the melting points of metallic crystals display a wide range.

3. Covalent network crystals – A covalent network crystal consists of atoms at the lattice points of the crystal, with each atom being covalently bonded to its nearest neighbor atoms (see **Figure** 16.8). The covalently bonded network is three-dimensional and contains a very large number of atoms. Network solids include diamond, quartz, many metalloids, and oxides of transition metals and metalloids. Network solids are hard and brittle, with extremely high melting and boiling points. Being composed of atoms rather than ions, they do not conduct electricity in any state.

4. Molecular crystals – Molecular crystals typically consist of molecules at the lattice points of the crystal, held together by relatively weak intermolecular forces (see **Figure** 16.9). The intermolecular forces may be dispersion forces in the case of nonpolar crystals, or dipole-dipole forces in the case of polar crystals. Some molecular crystals, such as ice, have molecules held together by hydrogen bonds. When one of the noble gases is cooled and solidified, the lattice points are individual atoms rather than molecules. In all cases, the intermolecular forces holding the

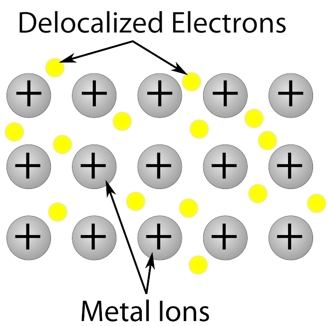


FIGURE 16.7
Metallic crystal lattice with free electrons able to move among positive metal atoms.

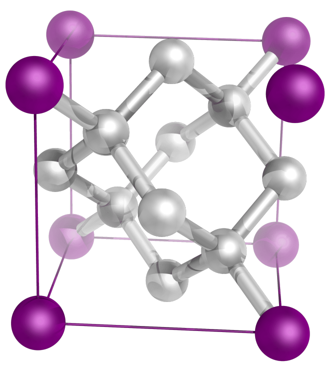


FIGURE 16.8
Diamond is a network solid and consists of carbon atoms covalently bonded to one another in a repeating three-dimensional pattern. Each carbon atom makes four single covalent bonds in a tetrahedral geometry.

particles together are far weaker than either ionic or covalent bonds. As a result, the melting and boiling points of molecular crystals are much lower. Lacking ions or free electrons, molecular crystals are poor electrical conductors.

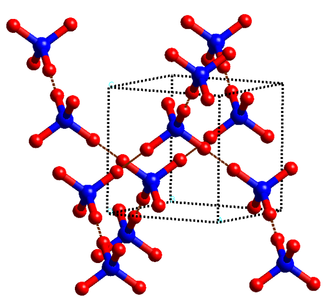
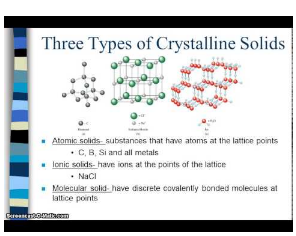


FIGURE 16.9
Ice crystal structure.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185091

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/185093

Summary

- Ionic crystals are composed of alternating positive and negative ions.
- Metallic crystals consist of metal cations surrounded by a "sea" of mobile valence electrons.
- Covalent crystals are composed of atoms which are covalently bonded to one another.
- Molecular crystals are held together by weak intermolecular forces.

Review

1. What is an ionic crystal?
2. What type of crystal is a diamond?
3. What forces hold molecular crystals together?
4. Which type of crystal is a good conductor of electricity?

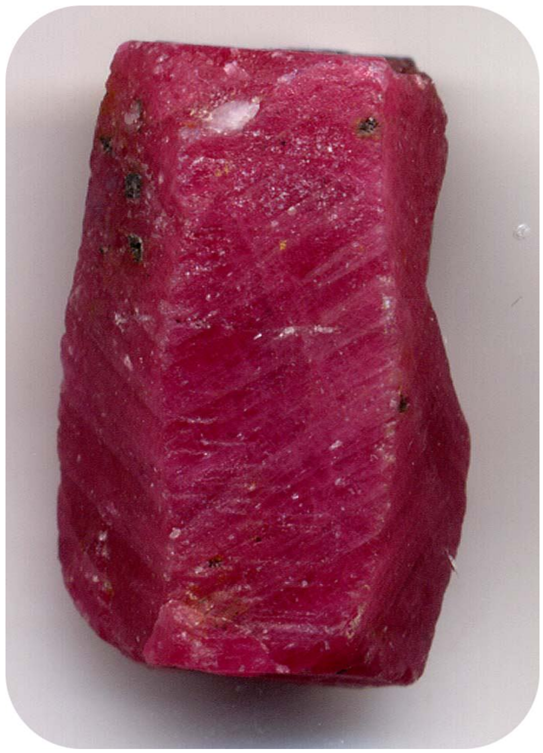
Vocabulary

- **covalent:** Are composed of atoms which are covalently bonded to one another.
- **ionic:** Composed of alternating positive and negative ions.
- **metallic:** Consist of metal cations surrounded by a "sea" of mobile valence electrons.
- **molecular:** Held together by weak intermolecular forces.

16.5 Ionic Crystal Structure

Learning Objectives

- Describe the lattice structure of ionic compounds.



Crystals are found everywhere chemical deposits are located. The ruby crystal shown above is extremely valuable, both because of its beauty and its utility in equipment such as lasers. For some people, crystals are said to have magical qualities. For others, the "magic" is in the regular structure of the crystal as the cations and anions line up in a regular order.

Ionic Crystal Structure

Electron dot diagrams show the nature of the electron transfer that takes place between metal and nonmetal atoms. However, ionic compounds do not exist as discrete molecules, as the dot diagrams may suggest. In order to minimize the potential energy of the system, ionic compounds take on the form of an extended three-dimensional array of alternating cations and anions. This maximizes the attractive forces between the oppositely charges ions. The figure below shows two different ways of representing the ionic crystal lattice. A ball and stick model makes it easier to see how individual ions are oriented with respect to one another. A space filling diagram is a more accurate representation of how the ions pack together in the **crystal**.

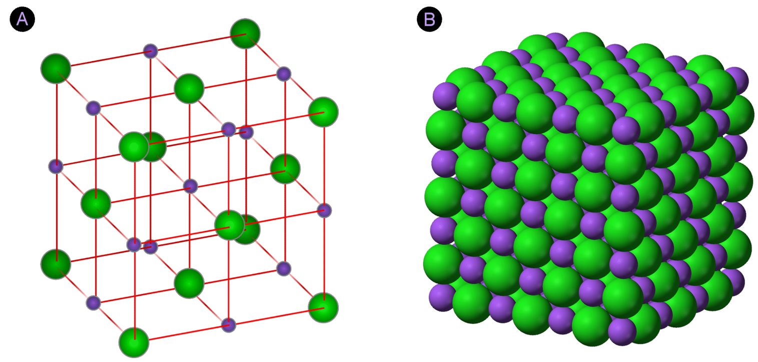
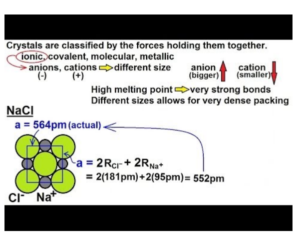


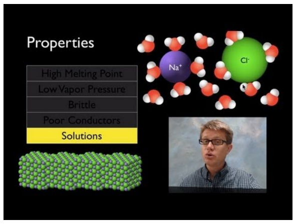
FIGURE 16.10
Two models of a sodium chloride crystal are shown. The purple spheres represent the Na^{+} ions, while the green spheres represent the Cl^{-} ions. (A) In an expanded view, the distances between ions are exaggerated, more easily showing the coordination numbers of each ion. (B) In a space filling model, the electron clouds of the ions are in contact with each other.

Naturally occurring sodium chloride **(halite)** does not look at first glance like the neat diagrams shown above. It is only when we use modern techniques to analyze the crystal structure at the atomic level that we can see the true regularity of the organized ions.

FIGURE 16.11
Halite crystals.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/184715



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/184717

Summary

- Ionic compounds take on the form of extended three-dimensional arrays of cations and anions.
- The arrangement maximizes the attractive force between oppositely-charged ions.

Review

1. Do ionic compounds exist as discrete molecules?
2. What does this three-dimensional array do?
3. What gives the most accurate rendition of how the ions arrange themselves?

Vocabulary

- **crystal:** A solid material whose constituent atoms, molecules, or ions are arranged in an ordered pattern extending in three-dimensional space.
- **halite:** Naturally occurring form of sodium chloride.

16.6 Physical Properties of Ionic Compounds

Learning Objectives

- List and describe the physical properties of ionic compounds.

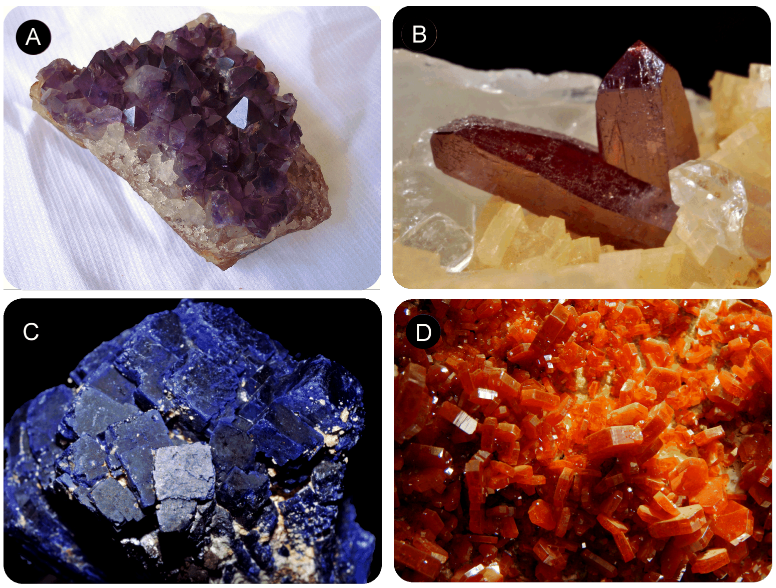


FIGURE 16.12
In nature, the ordered arrangement of ionic solids gives rise to beautiful crystals. (A) Amethyst - a form of quartz, SiO_2, whose purple color comes from iron ions. (B) Cinnabar - the primary ore of mercury is mercury(II) sulfide, HgS. (C) Azurite - a copper mineral, $Cu_3(CO_3)_2(OH)_2$. D) Vanadinite - the primary ore of vanadium, $Pb_5(VO_4)_3Cl$.

What produces colored crystals?

The figure above shows just a few examples of the color and brilliance of naturally occurring ionic crystals. The regular and orderly arrangement of ions in the crystal lattice is responsible for the various shapes of these crystals, while transition metal ions give rise to the colors.

Physical Properties of Ionic Compounds

Melting Points

Because of the many simultaneous attractions between cations and anions that occur, ionic crystal lattices are very strong. The process of melting an ionic compound requires the addition of large amounts of energy in order to break all of the ionic bonds in the crystal. For example, sodium chloride has a melting temperature of about 800°C.

Shattering

Ionic compounds are generally hard, but **brittle.** Why? It takes a large amount of mechanical force, such as striking a crystal with a hammer, to force one layer of ions to shift relative to its neighbor. However, when that happens, it brings ions of the same charge next to each other (see **Figure** 16.13). The repulsive forces between like-charged ions cause the crystal to shatter. When an ionic crystal breaks, it tends to do so along smooth planes because of the regular arrangement of the ions.

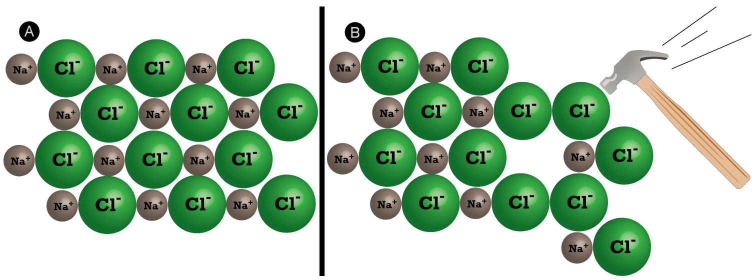


FIGURE 16.13

(A) The sodium chloride crystal is shown in two dimensions. (B) When struck by a hammer, the negatively-charged chloride ions are forced near each other and the repulsive force causes the crystal to shatter.

Conductivity

Another characteristic property of ionic compounds is their **electrical conductivity.** The figure below shows three experiments in which two electrodes that are connected to a light bulb are placed in beakers containing three different substances.

In the first beaker, distilled water does not conduct a current because water is a molecular compound. In the second beaker, solid sodium chloride also does not conduct a current. Despite being ionic and thus composed of charges particles, the solid crystal lattice does not allow the ions to move between the electrodes. Mobile charged particles are required for the circuit to be complete and the light bulb to light up. In the third beaker, the NaCl has been dissolved into the distilled water. Now the crystal lattice has been broken apart and the individual positive and negative ions can move. Cations move to one electrode, while anions move to the other, allowing electricity to flow (see **Figure** 16.15). Melting an ionic compound also frees the ions to conduct a current. Ionic compounds conduct an electric current when melted or dissolved in water.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/184723

Summary

- Ionic compounds have high melting points.
- Ionic compounds are hard and brittle.
- Solutions of ionic compounds and melted ionic compounds conduct electricity, but solid materials do not.

Review

1. Why are ionic compounds brittle?

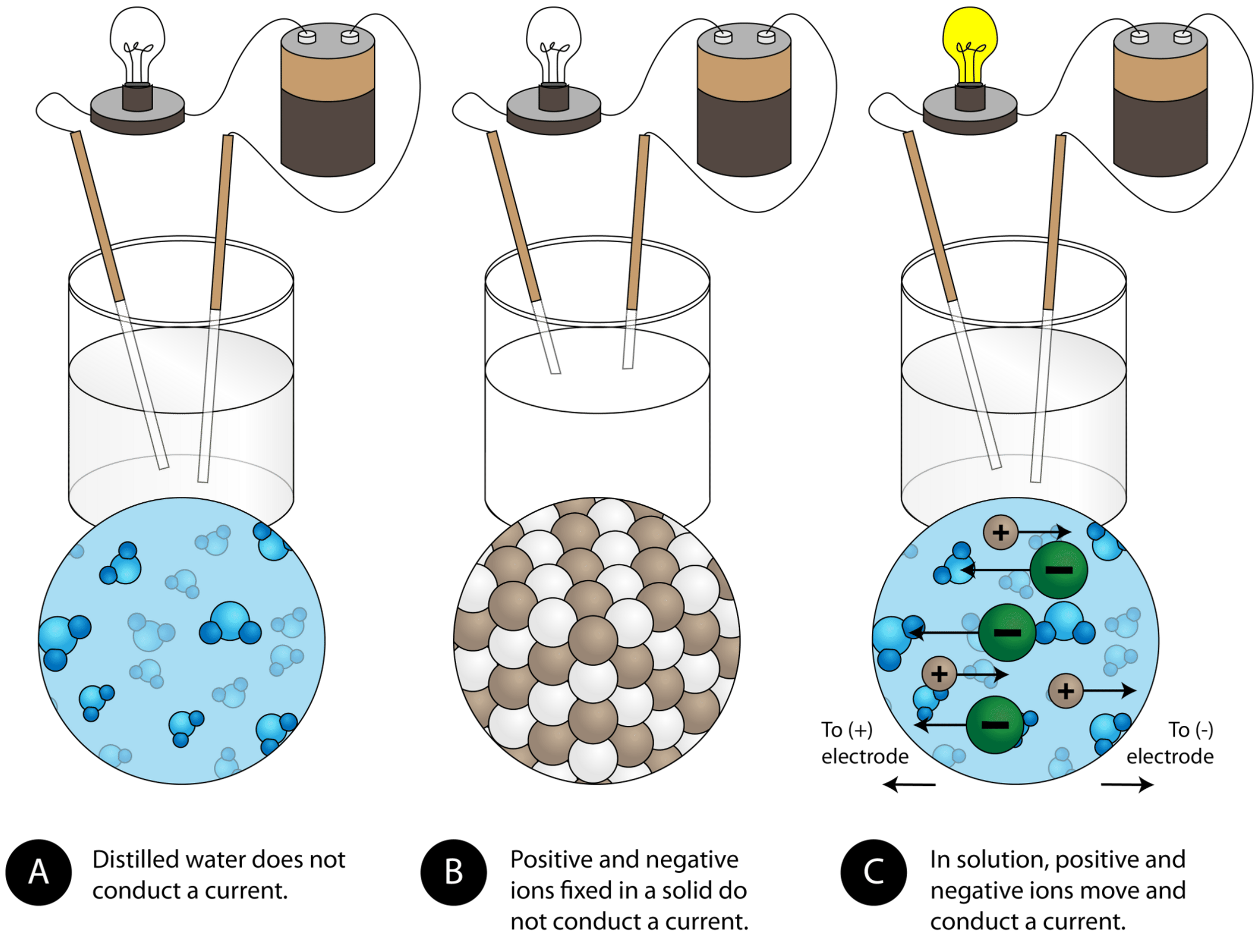


FIGURE 16.14

(A) Distilled water does not conduct electricity. (B) A solid ionic compound also does not conduct. (C) A water solution of an ionic compound conducts electricity well.

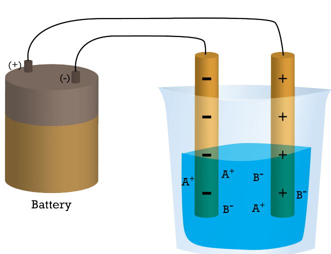


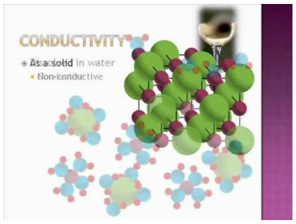
FIGURE 16.15

In an ionic solution, the A^+ ions migrate toward the negative electrode, while the B^- ions migrate toward the positive electrode.

2. Why are melting points high for ionic compounds?
3. What happens when an electric current is passed through a solution of an ionic compound?

Explore More

Watch the video below and answer the following questions:



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/62060

1. Do all ionic compounds form crystals?
2. Will melted ionic compounds conduct electricity?
3. What are the melting and boiling points of KI?

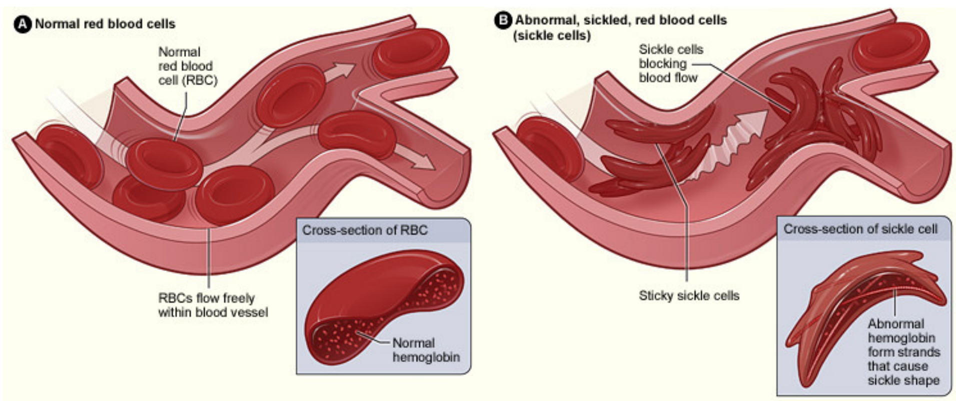
Vocabulary

- **brittle:** Easily broken, cracked, or snapped.
- **electrical conductivity:** The ability to conduct an electric current.

16.7 Proteins

Learning Objectives

- Define polypeptide.
- Define protein.
- List and describe the four levels of protein structure.



A serious shift?

Hemoglobin is a complex protein which has a quaternary structure and contains iron. There are four subunits in the hemoglobin molecule - two alpha subunits and two beta subunits. Each subunit contains one iron ion, whose oxidation state changes from +2 to +3 and back again, depending upon the environment around the iron. When the oxygen binds to the iron, the three-dimensional shape of the molecule changes. Upon release of the oxygen to the cells, the shape changes again.

With hemoglobin of normal structure, this shift in conformation does not present any problems. However, individuals with hemoglobin S do experience serious complications. This hemoglobin has one amino acid in the two beta chains that is different from the amino acid at that point in the primary structure of normal hemoglobin. The result of this one structural change is aggregation of the individual protein molecules when oxygen is released. Adjacent hemoglobin molecules come in contact with one another and clump up, causing the red cells to deform and break.

This abnormality, known as sickle cell, is genetic in nature. A person may inherit the gene from one parent and have sickle cell trait (only some of the hemoglobin is hemoglobin S), which is usually not life-threatening. Inheriting the gene from both parents will result in sickle cell disease, a very serious condition.

Proteins

A **polypeptide** is a sequence of amino acids between ten and one hundred in length. A **protein** is a peptide that is greater than one hundred amino acids in length. Proteins are very prevalent in living organisms. Hair, skin, nails, muscles, and the hemoglobin in red blood cells are some of the important parts of your body that are made of different proteins. The wide array of chemical and physiological properties of proteins is a function of their amino acid sequences. Since proteins generally consist of one hundred or more amino acids, the number of amino acid sequences that are possible is virtually limitless.

The three-dimensional structure of a protein is very critical to its function. This structure can be broken down into four levels. The **primary structure** is the amino acid sequence of the protein. The amino acid sequence of a given protein is unique and defines the function of that protein. The **secondary structure** is a highly regular sub-structure of the protein. The two most common types of protein secondary structure are the alpha helix and the beta sheet. An alpha helix consists of amino acids that adopt a spiral shape. A beta sheet is alternating rows of amino acids that line up in a side-by-side fashion. In both cases, the secondary structures are stabilized by extensive hydrogen bonding between the side chains. The interaction of the various side chains in the amino acid, specifically the hydrogen bonding, leads to the adoption of a particular secondary structure.

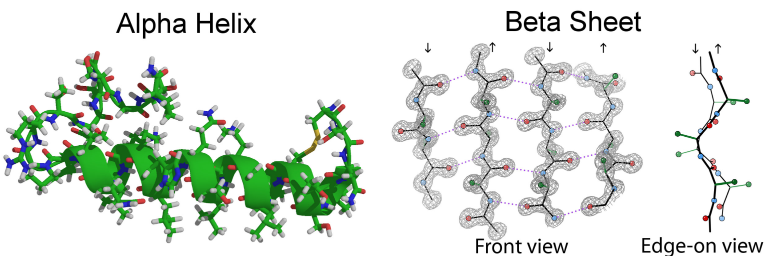


FIGURE 16.16
Secondary structure: alpha helix and beta sheet.

The **tertiary structure** is the overall three-dimensional structure of the protein. A typical protein consists of several sections of a specific secondary structure (alpha helix or beta sheet) along with other areas in which a more random structure occurs. These areas combine to produce the tertiary structure.

Some protein molecules consist of multiple protein subunits. The **quaternary structure** of a protein refers to the specific interaction and orientation of the subunits of that protein Hemoglobin is a very large protein found in red blood cells and whose function is to bind and carry oxygen throughout the bloodstream. Hemoglobin consists of four subunits - two α subunits (yellow) and two β subunits (gray) - which then come together in a specific and defined way through interactions of the side chains (see **Figure** 16.17). Hemoglobin also contains four iron atoms, located in the middle of each of the four subunits. The iron atoms are part of a structure called a porphyrin, shown in red in the figure.

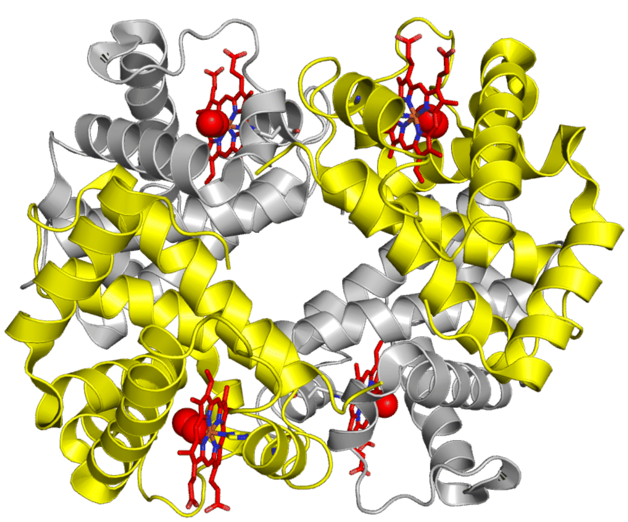


FIGURE 16.17
Hemoglobin

Some proteins consist of only one subunit and thus do not have a quaternary structure. **Figure** 16.18 diagrams the interaction of the four levels of protein structure.

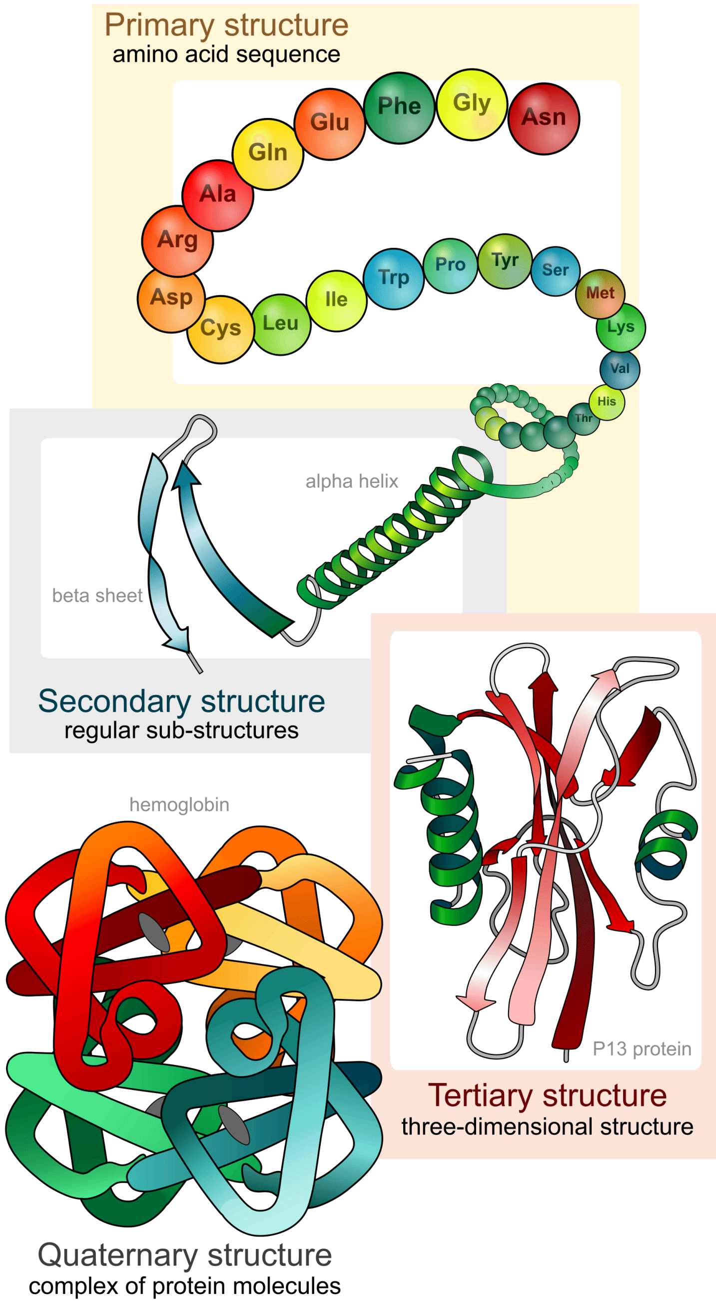
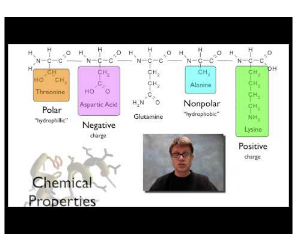


FIGURE 16.18

The four levels of protein structure.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/181175

Science Friday: The Medical Wonders of Worm Spit

How useful is worm spit? It turns out that worm spit, also known as silk, is a very useful material in medicine. In this video by Science Friday, Dr. David Kaplan describes how silk is used in a variety of medical applications.

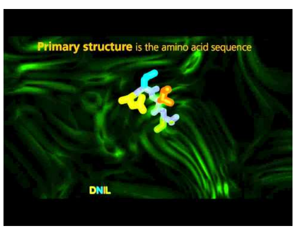
MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/191874

Review

1. A protein has the following sequence: ser-his-thr-tyr. What component of protein structure is this?
2. What do we call the overall three-dimensional shape of a protein?
3. A protein has one subunit. Would it have a quaternary structure?

Explore More

Use the resource below to answer the questions that follow.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/66403

1. What is part of what determines how a protein folds?
2. What holds secondary structure together?
3. What holds the tertiary structure together?

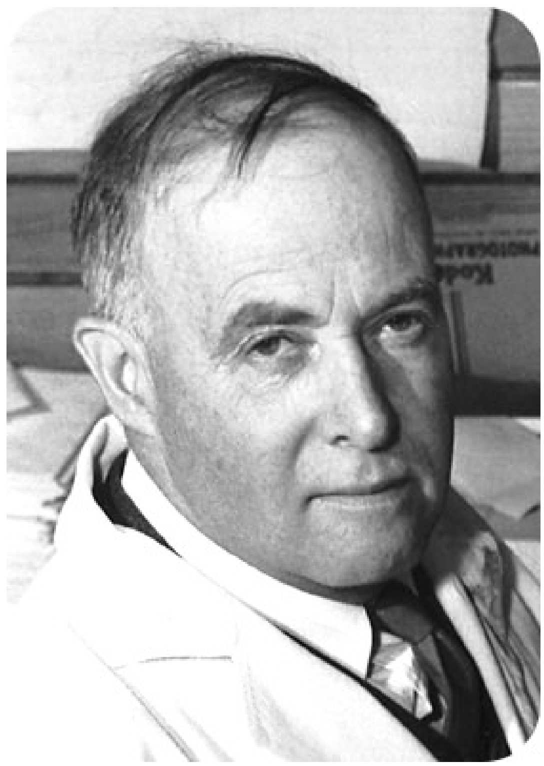
Vocabulary

- **polypeptide:** A sequence of amino acids between ten and one hundred in length.
- **primary structure:** The amino acid sequence of the protein.
- **protein:** A peptide that is greater than one hundred amino acids in length.
- **quaternary structure:** The specific interaction and orientation of the subunits of that protein.
- **secondary structure:** A highly regular sub-structure of the protein.
- **tertiary structure:** The overall three-dimensional structure of the protein.

16.8 Enzymes

Learning Objectives

- Define enzyme.
- Define active site.
- Describe the process of an enzyme reaction.
- Describe the process by which a competitive inhibitor alters the rate of an enzyme reaction.
- Describe the process by which a non-competitive inhibitor alters the rate of an enzyme reaction.
- Explain the role of cofactors in enzyme reactions.



What did he discover?

The first enzyme to be isolated was discovered in 1926 by American chemist James Sumner, who crystallized the protein. The enzyme was urease, which catalyzes the hydrolytic decomposition of urea, a component of urine, into ammonia and carbon dioxide.

$$H_2NCONH_2(aq) + H_2O(l) \xrightarrow{\text{urease}} 2NH_3(g) + CO_2(g)$$

His discovery was ridiculed at first because nobody believed that enzymes would behave the same way that other chemicals did. Sumner was eventually proven right and won the Nobel Prize in Chemistry in 1946.

Enzymes

An **enzyme** is a protein that acts as a biological catalyst. Recall that a catalyst is a substance that increases the rate of a chemical reaction without itself being consumed in the reaction. Cellular processes consist of many chemical reactions that must occur quickly in order for the cell to function properly. Enzymes catalyze most of the chemical reactions that occur in a cell. A **substrate** is the molecule or molecules on which the enzyme acts. In the urease catalyzed reaction above, urea is the substrate. **Figure** 16.19 diagrams a typical enzymatic reaction.

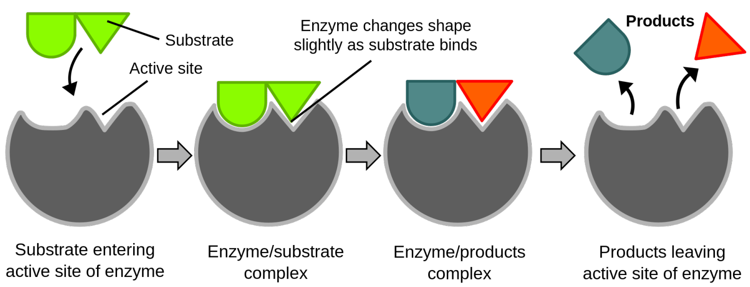


FIGURE 16.19
The sequence of steps for a substrate binding to an enzyme in its active site, reacting, then being released as products.

The first step in the reaction is that the substrate binds to a specific part of the enzyme molecule. The binding of the substrate is dictated by the shape of each molecule. Side chains on the enzyme interact with the substrate in a specific way, resulting in the making and breaking of bonds. The **active site** is the place on an enzyme where the substrate binds. An enzyme folds in such a way that it typically has one active site, usually a pocket or crevice formed by the folding pattern of the protein. Because the active site of an enzyme has such a unique shape, only one particular substrate is capable of binding to that enzyme. In other words, each enzyme catalyzes only one chemical reaction with only one substrate. Once the enzyme/substrate complex is formed, the reaction occurs and the substrate is transformed into products. Finally, the product molecule or molecules are released from the active site. Note that the enzyme is left unaffected by the reaction and is now capable of catalyzing the reaction of another substrate molecule.

Inhibitors

An **inhibitor** is a molecule which interferes with the function of an enzyme, either by slowing or stopping the chemical reaction. Inhibitors can work in a variety of ways, but one of the most common is illustrated in **Figure** 16.20.

The inhibitor binds competitively at the active site and blocks the substrate from binding. Since no reaction occurs with the inhibitor, the enzyme is prevented from catalyzing the reaction. Cyanide is a potent poison which acts as a competitive inhibitor. It binds to the active site of the enzyme *cytochrome c oxidase* and interrupts cellular respiration. The binding of the cyanide to the enzyme is irreversible and the affected organism dies quickly.

Non-competitive Inhibition

A non-competitive inhibitor does not bind at the active site. It attaches at some other site on the enzyme and changes the shape of the protein. This shift in three-dimensional structure alters the shape of the active site so that the substrate will no longer fit in the site properly (see **Figure** 16.21).

Co-factors

Some enzymes require the presence of a non-protein molecule called a cofactor in order to function properly. Cofactors can be inorganic metal ions or small organic molecules. Many vitamins, such as B vitamins, act as

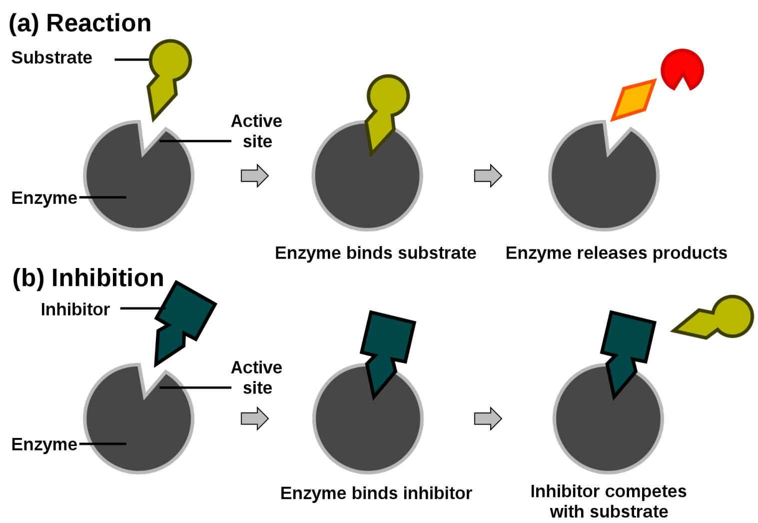


FIGURE 16.20
A competitive inhibitor is a molecule that binds to the active site of an enzyme without reacting, thus preventing the substrate from binding.

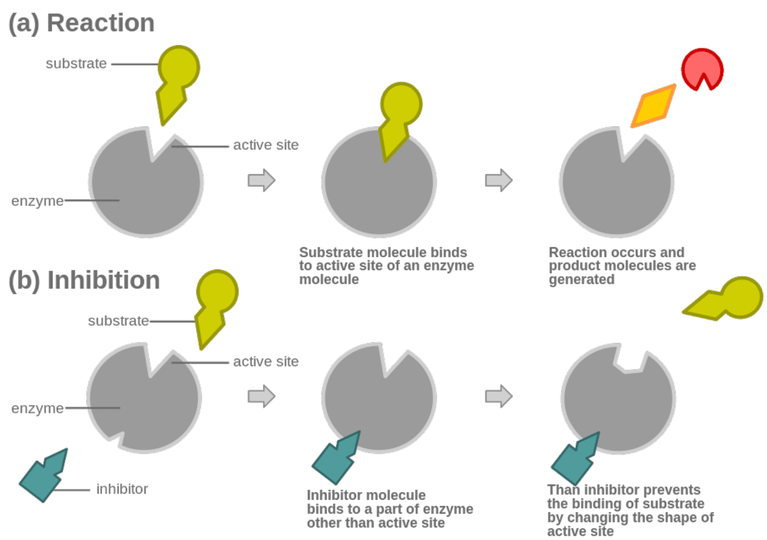
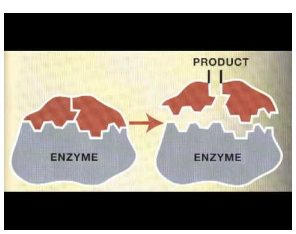


FIGURE 16.21
Non-competitive inhibition

cofactors. Some metal ions which function as cofactors for various enzymes include zinc, magnesium, potassium, and iron.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185867

Science Friday: Stained Glass Conservation

Stained glass from the Middle Ages is often hundreds of years old. Unfortunately, many of these relics are in need of cleaning and maintenance. In this video by Science Friday, conservator Mary Higgins discusses the methods used to protect the stained glass.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/191875

Review

1. What is the substrate?
2. How does a competitive inhibitor work?
3. How does a non-competitive inhibitor work?

Vocabulary

- **active site:** The place on an enzyme where the substrate binds.
- **enzyme:** A protein that acts as a biological catalyst.
- **inhibitor:** A molecule which interferes with the function of an enzyme, either slowing or stopping the chemical reaction.
- **substrate:** The molecule or molecules on which the enzyme acts.

16.9 References

1. Gerlach. http://commons.wikimedia.org/wiki/File:Flat_Tire.JPG .
2. User:Kirschblut/De.Wikipedia. http://commons.wikimedia.org/wiki/File:Plastikbecher.JPG .
3. John Pearson. http://commons.wikimedia.org/wiki/File:John_Pearson01.png .
4. CK-12 Foundation - Christopher Auyeung. .
5. Courtesy of the US Mint. Front: http://commons.wikimedia.org/wiki/File:2005_AEPlat_Proof_Obv.png; Back: http://commons.wikimedia.org/wiki/File:American_Platinum_Eagle_2008_Proof_Rev.jpg .
6. Sharat Ganapati (Flickr: frozenchipmunk). http://www.flickr.com/photos/frozenchipmunk/47133328/ .
7. (A) Davide Ferro; (B) Guillaume Piolle. (A) http://commons.wikimedia.org/wiki/File:Ancient_bronze_greek_helmet_-South_Italy.jpg; (B) http://commons.wikimedia.org/wiki/File:Trompette_piccolo_-_pavillon.jpg .
8. User:Soakologist/Wikipedia. http://commons.wikimedia.org/wiki/File:Sears_Tower_ss.jpg .
9. User:H Padleckas/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Sodium_chloride_crystal.png .
10. CK-12 Foundation - Joy Sheng. .
11. User:YassineMrabet/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Carbon_lattice_diamond.png .
12. User:Yadevol/Wikipedia. http://commons.wikimedia.org/wiki/File:Iceviistructure-ru.gif .
13. Adrian Pingstone (Wikimeda: Arpingstone). http://commons.wikimedia.org/wiki/File:Ruby_cristal.jpg .
14. (A) Eloy; (B) Ben Mills (Wikimedia: Benjah-bmm27). (A) http://commons.wikimedia.org/wiki/File:NaCl-estructura_cristalina.svg; (B) http://commons.wikimedia.org/wiki/File:Sodium-chloride-3D-ionic.png .
15. Ingo Wölbern (Wikimedia: Iwoelbern). http://commons.wikimedia.org/wiki/File:Halit_crystal,_Pedra_Lume,_Cape_Verde.jpg .
16. (A) Mauro Cateb; (B) Parent Géry; (C) Parent Géry; (D) User:vassil/Wikimedia Commons. (A) http://www.flickr.com/photos/mauroescritor/6544460363/; (B) http://commons.wikimedia.org/wiki/File:Cinabre_macl%C3%A9_%28Chine%29_.jpg; (C) http://commons.wikimedia.org/wiki/File:Azurite_cristallis%C3%A9e_%28Chine%29_2_.jpg; (D) http://commons.wikimedia.org/wiki/File:Vanadinite_21207.jpg .
17. CK-12 Foundation - Christopher Auyeung. .
18. CK-12 Foundation - Christopher Auyeung. .
19. CK-12 Foundation - Christopher Auyeung. .
20. The National Heart, Lung, and Blood Institute (NHLBI) . http://commons.wikimedia.org/wiki/File:Sickle_cell_01.jpg .
21. Alpha: User:Ayacop/Wikimedia Commons; Beta: User:Dcrjsr/Wikimedia Commons. Alpha: https://commons.wikimedia.org/wiki/File:CALC1_2GLH.png; Beta: http://commons.wikimedia.org/wiki/File:1gwe_antipar_betaSheet_both.png .
22. Courtesy of Todd L. Mollan, CBER, US Food and Drug Administration. http://blogs.fda.gov/fdavoice/index.php/tag/blood-substitutes/ .
23. Mariana Ruiz Villarreal (Wikimedia: LadyofHats). http://commons.wikimedia.org/wiki/File:Main_protein_structure_levels_en.svg .
24. Nobel Foundation. http://commons.wikimedia.org/wiki/File:James_Batcheller_Sumner.jpg .
25. User:TimVickers/Wikimedia Commons and User:Fvasconcellos/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Induced_fit_diagram.svg .
26. Jerry Crimson Mann (Wikimedia: Mcy jerry), User:TimVickers/Wikimedia Commons, and User:Fvasconcellos/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Competitive_inhibition.svg .
27. Jerry Crimson Mann (Wikimedia: Mcy jerry). http://commons.wikimedia.org/wiki/File:Allosteric_competitive_inhibition_3.svg .

CHAPTER 17 PS3-1, PS3-2, and PS3-4

Chapter Outline

17.1 Conservation of Energy

Learning Objectives

- Apply energy conservation in a closed system.

Energy is conserved in a closed system. That is, if you add up all the energy of an object(s) at one time it will equal all the energy of said object(s) at a later time. A closed system is a system where no energy is transferred in or out. The total energy of the universe is a constant (i.e. it does not change). The problems below do not consider the situation of energy transfer (called work). So friction and other sources where energy leaves the system are not present. Thus, one simply adds up all the potential energy and kinetic energy *before* and sets it equal to the addition of the total potential energy and kinetic energy *after*.

Key Equations

$\sum E_{\text{initial}} = \sum E_{\text{final}}$ The total energy does not change in closed systems

Example

Billy is standing at the bottom of a ramp inclined at 30 degrees. Billy slides a 2 kg puck up the ramp with an initial velocity of 4 m/s. How far up the ramp does the ball travel before it begins to roll back down? Ignore the effects of friction.

The potential energy of the puck when it stops at the top of it's path will be equal to the kinetic energy that it was initially rolled with. We can use this to determine the how high above the ground the puck will be above the ground when it stops, and then use trigonometry to find out how far up the ramp the puck will be when it stops.

$$PE_i + KE_i = PE_f + KE_f \quad \text{start with conservation of energy}$$

$$0 + \frac{1}{2}mv^2 = mgh + 0 \quad \text{take out the energy terms we know will be zero and substitute the equations for potential and kinetic energy}$$

$$\frac{1}{2}v^2 = gh \quad \text{simplify the equation}$$

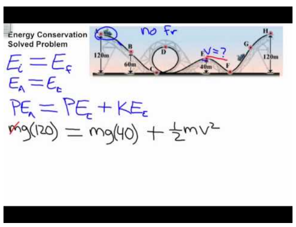
$$h = \frac{v^2}{2g} \quad \text{solve for } h$$

$$h = \frac{(4\text{ m/s})^2}{2 * 9.8\text{ m/s}^2} \quad \text{substitute in the known values}$$

$$h = 0.82\text{ m}$$

Now we can find the distance up the ramp the ball traveled since we know the angle of the ramp and the height of the ball above the ground.

$$\sin(30) = \frac{h}{x}$$
$$x = \frac{h}{\sin(30)}$$
$$x = \frac{0.82 \text{ m}}{\sin(30)}$$
$$x = 1.6 \text{ m}$$

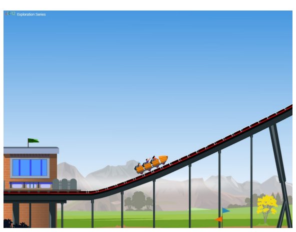


MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/403

Interactive Simulation



SIMULATION

Learn about the conservation of energy in the context of a roller coaster.

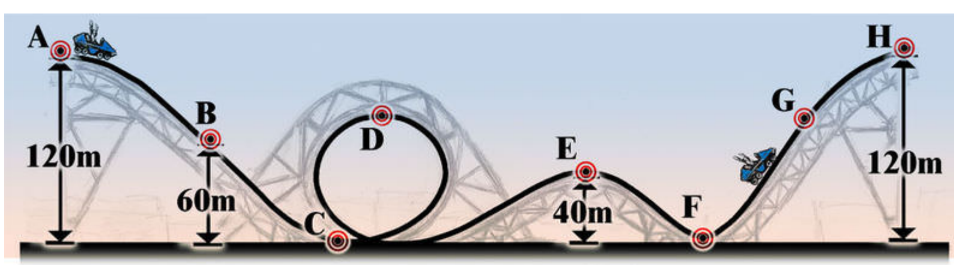
URL: http://www.ck12.org/physics/Energy/simulationint/Roller-Coaster

Review

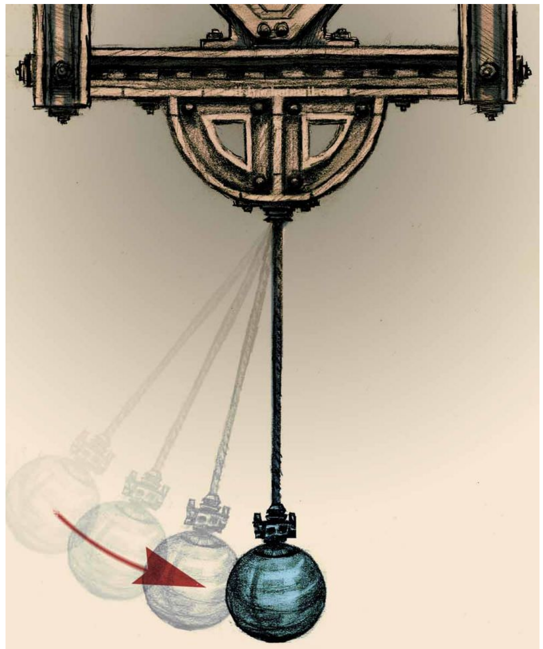
1. At 8:00 AM, a bomb exploded in mid-air. Which of the following is true of the pieces of the bomb after explosion? (Select all that apply.)
   a. The vector sum of the momenta of all the pieces is zero.
   b. The total kinetic energy of all the pieces is zero.
   c. The chemical potential energy of the bomb has been converted entirely to the kinetic energy of the pieces.
   d. Energy is lost from the system to sound, heat, and a pressure wave.
2. You are at rest on your bicycle at the top of a hill that is 20 m tall. You start rolling down the hill. At the bottom of the hill you have a speed of 22 m/s. Your mass is 80 kg. Assuming no energy is gained by or lost to any other source, which of the following must be true?
   a. The wind must be doing work on you.
   b. You must be doing work on the wind.

c. No work has been done on either you or the wind.
d. Not enough information to choose from the first three.

3. A stationary bomb explodes into hundreds of pieces. Which of the following statements best describes the situation?
   a. The kinetic energy of the bomb was converted into heat.
   b. The chemical potential energy stored in the bomb was converted into heat and gravitational potential energy.
   c. The chemical potential energy stored in the bomb was converted into heat and kinetic energy.
   d. The chemical potential energy stored in the bomb was converted into heat, sound, kinetic energy, and gravitational potential energy.
   e. The kinetic and chemical potential energy stored in the bomb was converted into heat, sound, kinetic energy, and gravitational potential energy.
4. You hike up to the top of Granite Peak in the Trinity Alps to think about physics.
   a. Do you have more potential or kinetic energy at the top of the mountain than you did at the bottom? Explain.
   b. Do you have more, less, or the same amount of energy at the top of the mountain than when you started? (Let's assume you did not eat anything on the way up.) Explain.
   c. How has the total energy of the Solar System changed due to your hike up the mountain? Explain.
   d. If you push a rock off the top, will it end up with more, less, or the same amount of energy at the bottom? Explain.
   e. For each of the following types of energy, describe whether you *gained* it, you *lost*it, or it stayed the same during your hike:
      i. Gravitational potential energy
      ii. Energy stored in the atomic nuclei in your body
      iii. Heat energy
      iv. Chemical potential energy stored in the fat cells in your body
      v. Sound energy from your footsteps
      vi. Energy given to you by a wind blowing at your back
5. A 1200 kg>car traveling with a speed of 29 m/s drives horizontally off of a 90 m cliff.
   a. Sketch the situation.
   b. Calculate the potential energy, the kinetic energy, and the total energy of the car as it leaves the cliff.
   c. Make a graph displaying the kinetic, gravitational potential, and total energy of the car at each 10 m increment of height as it drops
6. A roller coaster begins at rest 120 m above the ground, as shown. Assume no friction from the wheels and air, and that no energy is lost to heat, sound, and so on. The radius of the loop is 40 m.



   a. Find the speed of the roller coaster at points B, C, D, E, F, and H.
   b. Assume that 25% of the initial potential energy of the coaster is lost due to heat, sound, and air resistance along its route. How far short of point H will the coaster stop?
7. A pendulum has a string with length 1.2 m. You hold it at an angle of 22 degrees to the vertical and release it. The pendulum bob has a mass of 2.0 kg.



a. What is the potential energy of the bob before it is released? (*Hint: use geometry to determine the height when released.*)
b. What is its speed when it passes through the midpoint of its swing?
c. Now the pendulum is transported to Mars, where the acceleration of gravity g is 2.3 m/s^2. Answer parts (a) and (b) again, but this time using the acceleration on Mars.

Review (Answers)

1. d
2. a
3. d
4. a. more PE b. same c. same d. same e. i. gained ii. same iii. gained iv. lost v. lost vi. gained
5. b. $KE = 504,600$ J; $U_g = 1,058,400$ J; $E_{total} = 1,563,000$ J
6. a. 34 m/s at B; 49 m/s at C and F; 28 m/s at D, 40 m/s at E, 0 m/s at H b. it will make it up to only 90m, so 30m short of point H
7. a. 1.7 J b. 1.3 m/s c. 0.4 J, 0.63 m/s

17.2 Heat, Temperature, and Thermal Energy Transfer

Learning Objectives

- Define heat.
- Define temperature.
- Describe thermal energy transfer.
- Define Celsius and Kelvin temperature scales.
- Convert Celsius temperatures to Kelvin and vice versa.

The temperature of basalt lava at Kilauea (Hawaii) reaches 1,160 degrees Celsius (2,120 degrees Fahrenheit). A crude estimation of temperature can be determined by looking at the color of the rock: orange-to-yellow colors are emitted when rocks (or metals) are hotter than about 900 degrees Celsius; dark-to-bright cherry red is characteristic as material cools to 630 degrees Celsius; faint red glow persists down to about 480 degrees Celsius. For comparison, a pizza oven is commonly operated at temperatures ranging from 260 to 315 degrees Celsius.

Heat, Temperature, and Thermal Energy Transfer

The first theory about how a hot object differs from a cold object was formed in the 18th century. The suggested explanation was that when an object was heated, an invisible fluid called "caloric" was added to the object. Hot objects contained more caloric than cold objects. The caloric theory could explain some observations about heated objects (such as that the fact that objects expanded as they were heated) but could not explain others (such as why your hands got warm when you rub them together).

In the mid-19th century, scientists devised a new theory to explain heat. The new theory was based on the assumption that matter is made up of tiny particles that are always in motion. In a hot object, the particles move faster and therefore have greater kinetic energy. The theory is called the kinetic-molecular theory and is the accepted theory of heat. Just as a baseball has a certain amount of kinetic energy due to its mass and velocity, each molecule has a certain amount of kinetic energy due to its mass and velocity. Adding up the kinetic energy of all the molecules in an object yields the **thermal energy** of the object.

When a hot object and a cold object touch each other, the molecules of the objects collide along the surface where they touch. When higher kinetic energy molecules collide with lower kinetic energy molecules, kinetic energy is passed from the molecules with more kinetic energy to those with less kinetic energy. In this way, heat always flows from hot to cold and heat will continue to flow until the two objects have the same temperature. The movement of heat from one object to another by molecular collision is called **conduction**.

Heat is the energy that flows as a result of a difference in temperature. We use the symbol Q for heat. Heat, like all forms of energy, is measured in joules.

The **temperature** of an object is a measurement of the average kinetic energy of all the molecules of the object. You should note the difference between heat and temperature. Heat is the *sum* of all the kinetic energies of all the molecules of an object, while temperature is the *average* kinetic energy of the molecules of an object. If an object was composed of exactly three molecules and the kinetic energies of the three molecules are 50 J, 70 J, and 90 J, the heat would be 210 J and the temperature would be 70 J.

The terms *hot* and *cold* refer to temperature. A hot object has greater average kinetic energy but may not have greater total kinetic energy. Suppose you were to compare a milliliter of water near the boiling point with a bathtub full of water at room temperature. The bathtub contains a billion times as many water molecules, and therefore has a higher total kinetic energy and more heat. Nonetheless, we would consider the bathtub colder because its average kinetic energy, or temperature, is lower.

Temperature Scales: Celsius and Kelvin

A **thermometer** is a device used to measure temperature. It is placed in contact with an object and allowed to reach thermal equilibrium with the object (they will have the same temperature). The operation of a thermometer is based on some property, such as volume, that varies with temperature. The most common thermometers contain liquid mercury, or some other liquid, inside a sealed glass tube. The liquid expands and contracts faster than the glass tube. Therefore, when the temperature of the thermometer increases, the liquid volume expands faster than the glass volume, allowing the liquid to rise in the tube. The positions of the liquid in the tube can then be calibrated for accurate temperature readings. Other properties that change with temperature can also be used to make thermometers; liquid crystal colors and electrical conductivity change with temperature, and are also relatively common thermometers.

The most commonly used temperature scale in the United States is the Fahrenheit scale. However, this scale is rarely used throughout the world; the metric temperature scale is Celsius. This scale, based on the properties of water, was devised by the Swedish physicist, Anders Celsius (1704 - 1744). The freezing point of water is 0°C and the boiling point of water was assigned to be 100°C. The kinetic energies between these two points was divided evenly into 100 “degrees Celsius”.

The Kelvin or “Absolute” temperature scale is the scale often used by chemists and physicists. It is based on the temperature at which all molecular motion ceases; this temperature is called absolute zero and is 0 K. This temperature corresponds to -273.15°C. Since absolute zero is the coldest possible temperature, there are no negative values on the Kelvin temperature scale. Conveniently, the Kelvin and Celsius scales have the same definition of a degree, which makes it very easy to convert from one scale to the other. The relationship between Celsius and Kelvin temperature scales is given by:

$$K = {}^\circ C + 273.15$$

On the Kelvin scale, water freezes at 273 K and boils at 373 K.

Example

Convert 25°C to Kelvin.

K = °C + 273 = 25°C + 273 = 298 K

Summary

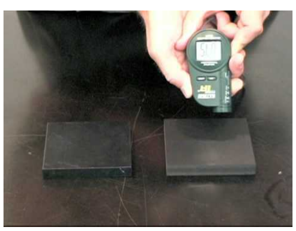
- The thermal energy, or heat, of an object is obtained by adding up the kinetic energy of all the molecules within it.
- Temperature is the average kinetic energy of the molecules.
- Absolute zero is the temperature where molecular motion stops and is the lowest possible temperature.
- Zero on the Celsius scale is the freezing point of water and 100°C is the boiling point of water.
- The relationship between Celsius and Kelvin temperature scales is given by K = °C + 273.15.

Review

1. Convert 4.22 K to °C.
2. Convert 37°C to K.
3. If you had beeswax attached to one end of a metal skewer and you placed the other end of the skewer in a flame, what would happen after a few minutes?
4. Which contains more heat, a coffee cup of boiling water or a bathtub of room temperature water?

Explore More

Use this resource to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/82540

1. Which material was a better conductor of heat?
2. Explain why metals feel cold even when thay are at room temperature.

Resources

By clicking this link, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

This MIT video examines the phenomenon of Joule heating through the perspective of a blender, reproducing the experiment of the English physicist James Prescott Joule. See the video at http://techtv.mit.edu/videos/14887-blender-the-next-stove-the-joule-experiment .

Vocabulary

- **thermal energy:** The total energy of a substance particles due to their translational movement or vibrations.
- **heat:** energy transferred from one body to another by thermal interactions.
- **temperature:** A measurement of the average kinetic energy of the molecules in an object or system and can be measured with a thermometer or a calorimeter.
- **conduction:** The transfer of thermal energy by the movement of particles that are in contact with each other.
- **absolute zero:** The lowest possible temperature, at which point the atoms of a substance transmit no thermal energy - they are completely at rest. It is 0 degrees on the Kelvin scale, which translates to -273.15 degrees Celsius (or -459.67 degrees Fahrenheit).

17.3 Heat

Learning Objectives

- Define heat.
- Define thermochemistry.

Blacksmiths, like the one mentioned in Longfellow's poem, heat solid iron in order to shape it into a variety of different objects. Iron is a rigid, solid metal. At room temperature, it is extremely difficult to bend iron. However, when heated to a high enough temperature, iron can be easily worked. The heat energy in the forge is transferred to the metal, making the iron atoms vibrate more and move around more readily.

Heat

Heat is energy that is transferred from one object or substance to another because of a difference in temperature between them. Heat always flows from an object at a higher temperature to an object a lower temperature (see **Figure** 17.1). The flow of heat will continue until the two objects are at the same temperature.

Thermochemistry is the study of energy changes that occur during chemical reactions and during changes of state. When chemical reactions occur, some chemical bonds are broken, while new chemical bonds form. As a result of the rearrangement of atoms, the total chemical potential energy of the system either increases or decreases.

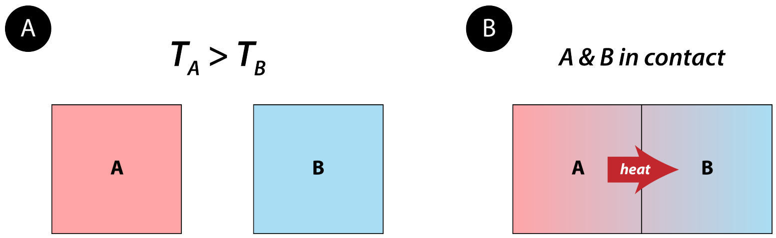
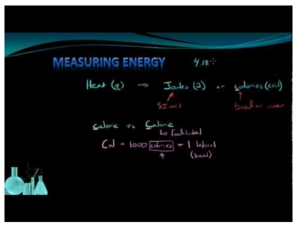


FIGURE 17.1
Object A starts with a higher temperature than object B. No heat flows when the objects are isolated from each other. When brought into contact, heat flows from A to B until the temperatures of the two objects are the same.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185305

Summary

- Heat is transferred energy from a site of higher energy to a site of lower energy.

Review

1. What is heat?
2. In which direction does heat flow?
3. What does thermochemistry involve?

Vocabulary

- **heat:** Energy that is transferred from one object or substance to another because of a difference in temperature between them.
- **thermochemistry:** The study of energy changes that occur during chemical reactions and during changes of state.

17.4 Specific Heat

Learning Objectives

- Define specific heat.
- Calculate heat transfer.

This image is of the Beehive Geyser in Yellowstone National Park. Underground water is heated by the earth's molten core and, when sufficient pressure is built up, the water shoots out of the ground in an amazing display.

Specific Heat

When heat flows into an object, its thermal energy increases and so does its temperature. The amount of temperature increase depends on three things: 1) how much heat was added, 2) the size of the object, and 3) the material of which the object is made. When you add the same amount of heat to the same mass of different substances, the amount of temperature increase is different. Each substance has a **specific heat,** which is the amount of heat necessary to raise one mass unit of that substance by one temperature unit.

In the SI system, specific heat is measured in J/kg•K. (Occasionally, you may also see specific heat expressed sometimes in J/g•K). The specific heat of aluminum is 903 J/kg•K. Therefore, it requires 903 J to raise 1.00 kg of aluminum by 1.00 K.

TABLE 17.1: Specific Heat of Some Common Substances

Material	Specific Heat (J/kg•K)
Aluminum	903
Brass	376
Carbon	710

TABLE 17.1: (continued)

Copper	385
Glass	664
Ice	2060
Lead	130
Methanol	2450
Water Vapor	2020
Water (liquid)	4180
Zinc	388

The amount of heat gained or lost by an object when its temperature changes can be calculated by the formula

$Q = mc\Delta t$,

where Q is the heat gained or lost, m is the mass of the object, c is its specific heat, and Δt is the change in temperature. You should note that the size of a Celsius degree and a Kelvin degree are exactly the same, and therefore Δt is the same whether measured in Celsius or Kelvin.

Examples

Example 1

A 0.500 kg block of zinc is heated from 295 K to 350. K. How much heat was absorbed by the zinc?

$Q = mc\Delta t = (0.500\ kg)(388\ J/kg \cdot K)(350.\ K - 295\ K) = 10,600\ J$

Example 2

845 J of heat are added to a 0.200 kg block of aluminum at a temperature of 312.00 K. How high will the temperature of the aluminum rise?

$(t_2 - t_1) = \frac{Q}{mc} = \frac{845\ J}{(0.200\ kg)(903\ J/kg \cdot K)} = 4.68\ K$

$t_2 = t_1 + 4.68\ K = 312.00\ K + 4.68\ K = 316.68\ K$

Summary

- When heat flows into an object, its thermal energy increases and so does its temperature.
- The amount of temperature increase depends on three things: 1) how much heat was added, 2) the size of the object, and 3) the material of which the object is made.
- Each substance has a specific heat, which is the amount of heat necessary to raise one mass unit of that substance by one temperature unit.
- The amount of heat gained or lost by an object when its temperature changes can be calculated by the formula $Q = mc\Delta t$.

Review

1. How much heat is absorbed by 60.0 g of copper when it is heated from 20.0°C to 80.0°C?
2. A 40.0 kg block of lead is heated from -25°C to 200.°C. How much heat is absorbed by the lead block?
3. The cooling system of an automobile motor contains 20.0 kg of water. What is the Δt of the water if the engine operates until 836,000 J of heat have been added to the water?

Explore More

By clicking these links, you will leave the CK-12 site and open external sites in new tabs. This page will remain open in the original tab.

Interactive step by step demonstration of how to calculate the specific heat of a material.

http://www.chem.uiuc.edu/webfunchem/specificheat/newSample.htm

Practice problems in specific heat.

http://www.kwanga.net/chemnotes/specific-heat-practice.pdf $Q = mc\Delta t = (0.500\,kg)(388\,J/kg \cdot K)(350.\,K - 295\,K) = 10,600\,J$

Interactive step by step demonstration of how to calculate the specific heat of a material.

http://www.chem.uiuc.edu/webfunchem/specificheat/newSample.htm

Practice problems in specific heat.

http://www.kwanga.net/chemnotes/specific-heat-practice.pdf

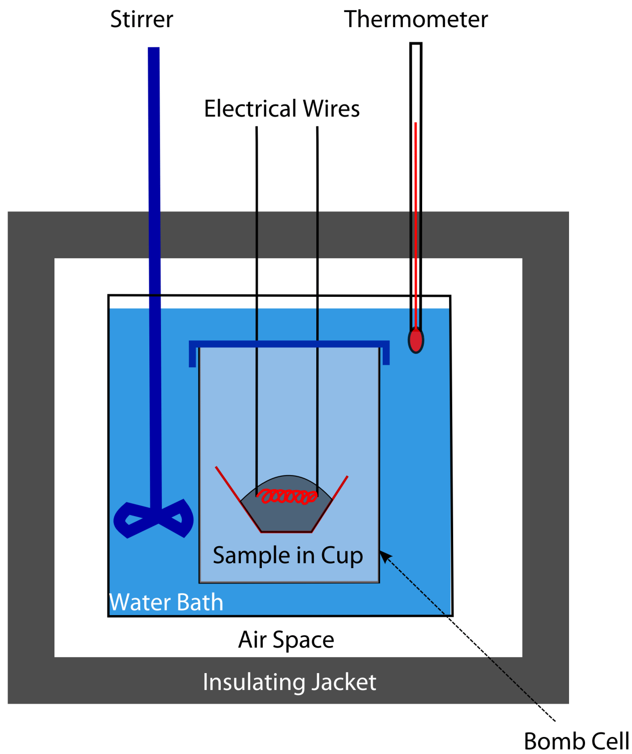
Vocabulary

- **specific heat:** The heat required to raise a unit mass of a substance by one unit temperature interval under specified conditions, such as constant pressure: usually measured in joules per kelvin per kilogram.

17.5 Calorimetry

Learning Objectives

- Define calorimetry.
- Perform calculations involving calorimetry relationships.



How many calories are in your food?

At one time, calories in foods were measured with a bomb calorimeter (see figure above). A weighed amount of the food would be placed in the calorimeter and the system was then sealed and filled with oxygen. An electric spark ignited the food-oxygen mixture. The amount of heat released when the food burned would give an idea of the food calories present. Today calories are calculated from the protein, carbohydrate, and fat content of the food (all determined by chemical analysis). No more bombs needed.

Calorimetry

Calorimetry is the measurement of the transfer of heat into or out of a system during a chemical reaction or physical process. A **calorimeter** is an insulated container that is used to measure heat changes. The majority of reactions that can be analyzed in a calorimetry experiment are either liquids or aqueous solutions. A frequently used and inexpensive calorimeter is a set of nested foam cups fitted with a lid to limit the heat exchange between the liquid in the cup and the air in the surroundings (see **Figure** 17.2). In a typical calorimetry experiment, specific volumes of the reactants are dispensed into separate containers and the temperature of each is measured. They are then mixed into the calorimeter, which starts the reaction. The reactant mixture is stirred until the reaction is complete, while the temperature of the reaction is continuously monitored.

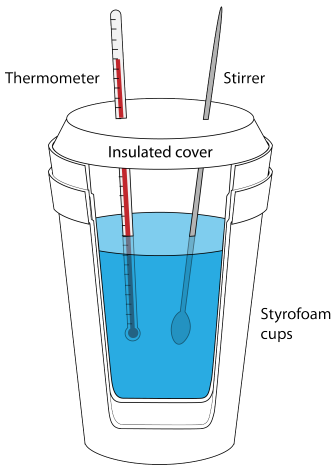


FIGURE 17.2
A simple constant-pressure calorimeter.

The key to all calorimetry experiments is the assumption that there is no heat exchange between the insulated calorimeter and the room. Consider the case of a reaction taking place between aqueous reactants. The water in which the solids have been dissolved is the surroundings, while the dissolved substances are the system. The temperature change that is measured is the temperature change that is occurring in the surroundings. If the temperature of the water increases as the reaction occurs, the reaction is exothermic. Heat was released by the system into the surrounding water. An endothermic reaction absorbs heat from the surroundings, so the temperature of the water decreases as heat leaves the surroundings to enter the system.

The temperature change of the water is measured in the experiment and the specific heat of water can be used to calculate the heat absorbed by the surroundings (q_{surr}).

$$q_{\text{surr}} = m \times c_p \times \Delta T$$

In the equation, m is the mass of the water, c_p is the specific heat of the water, and ΔT is $T_f - T_i$. The heat absorbed by the surroundings is equal, but opposite in sign, to the heat released by the system. Because the heat change is determined at constant pressure, the heat released by the system (q_{sys}) is equal to the enthalpy change (ΔH).

$$q_{\text{sys}} = \Delta H = -q_{\text{surr}} = -(m \times c_p \times \Delta T)$$

The sign of ΔH is positive for an endothermic reaction and negative for an exothermic reaction.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185322

Sample Problem: Calorimetry and Enthalpy Changes

In an experiment, 25.0 mL of 1.00 M HCl at 25.0°C is added to 25.0 mL of 1.00 M NaOH at 25.0°C in a foam cup calorimeter. A reaction occurs and the temperature rises to 32.0°C. Calculate the enthalpy change (ΔH) in kJ for this reaction. Assume the densities of the solutions are 1.00 g/mL and that their specific heat is the same as that of water.

Step 1: List the known quantities and plan the problem.

Known

- $c_p = 4.18$ J/g°C
- $V_{\text{final}} = 25.0\text{ mL} + 25.0\text{ mL} = 50.0\text{ mL}$
- $\Delta T = 32.0°\text{C} - 25.0°\text{C} = 7.0°\text{C}$
- Density = 1.00 g/mL

Unknown

- $\Delta H = ?$ kJ

The volume and density can be used to find the mass of the solution after mixing. Then calculate the change in enthalpy by using $\Delta H = q_{\text{sys}} = -q_{\text{surr}} = -(m \times cp \times \Delta T)$.

Step 2: Solve.

$$m = 50.0\text{ ml} \times \frac{1.00\text{ g}}{\text{mL}} = 50.0\text{ g}$$
$$\Delta H = -(m \times c_p \times \Delta T) = -(50.0\text{ g} \times 4.18\text{ J/g°C} \times 7.0°\text{C}) = -1463\text{ J} = -1.5\text{ kJ}$$

Step 3: Think about the result.

The enthalpy change is negative because the reaction releases heat to the surroundings, resulting in an increase in temperature of the water.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/185326

Summary

- The process of calorimetry is described.
- Calculations involving enthalpy changes are illustrated.

Review

1. What kinds of reactions are usually analyzed in a calorimeter?
2. What is a constant-pressure calorimeter?
3. Why are foam cups used in a calorimeter?

Vocabulary

- **calorimeter:** An insulated container that is used to measure heat changes.
- **calorimetry:** The measurement of the transfer of heat into or out of a system during a chemical reaction or physical process.

17.6 Potential Energy

Learning Objectives

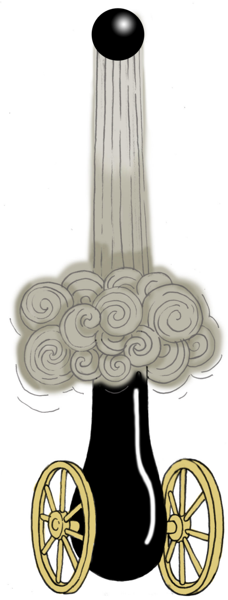
- Define potential energy.
- Solve problems involving gravitational potential energy.
- Solve problems involving the conversion of potential energy to kinetic energy and vice versa.

Shooting an arrow from a bow requires work done on the bow by the shooter's arm to bend the bow and thus produce potential energy. The release of the bow converts the potential energy of the bent bow into the kinetic energy of the flying arrow.

Potential Energy

When an object is held above the earth, it has the ability to make matter move because all you have to do is let go of the object and it will fall of its own accord. Since energy is defined as the ability to make matter move, this object has energy. This type of energy is stored energy and is called **potential energy.** An object held in a stretched rubber band also contains this stored energy. Specifically, a rubber band (and the bow pictured above) has *elastic* potential energy. If the stretched rubber band is released, the object will move. If you hold two positive charges near each other, their *electromagnetic* potential energy pushes them apart when you let go. Potential energy is stored in chemical bonds (*chemical*). When these bonds are broken, the excess energy is seen as molecular motion and heat.

If a cannon ball is fired straight up into the air, it begins with a high kinetic energy. As the cannon ball rises, it slows down due to the force of gravity pulling it toward the earth. As the ball rises, its gravitational potential energy is increasing and its kinetic energy is decreasing. When the cannon ball reaches the top of its arc, its kinetic energy is zero and its potential energy is at the maximum. As gravity continues to pull the cannon ball toward the earth, the ball will fall downwards, causing its height to decrease and its speed to increase. The ball's potential energy decreases and its kinetic energy increases. When the ball returns to its original height, its kinetic energy will be the same as when it started upward.



When work is done on an object, the work may be converted into either kinetic or potential energy. Work resulting in motion is caused when the work is converted into kinetic energy, while work resulting in a change of position is caused by a conversion into potential energy. Work is also spent overcoming friction and that work would be converted into heat, but we will consider primarily frictionless systems.

If we consider the potential energy of a bent stick or a stretched rubber band, the potential energy can be calculated by multiplying the force exerted by the stick or rubber band by the distance over which the force will be exerted. The formula for calculating this potential energy looks exactly like the formula for calculating work done: $W = Fd$. The only difference is that work is calculated when the object actually moves and potential energy is calculated when the system is still at rest, before any motion actually occurs.

In the case of gravitational potential energy, the force exerted by the object is its weight and the distance it can travel is its height above the earth. Since the weight of an object is calculated by $W = mg$, then gravitational potential energy can be calculated by $PE = mgh$, where m is the mass of the object, g is the acceleration due to gravity, and h is the height the object will fall.

Examples

Example 1

A 3.00 kg object is lifted from the floor and placed on a shelf that is 2.50 m above the floor.

(a) What was the work done in lifting the object?

(b) What is the gravitational potential energy of the object sitting on the shelf?

(c) If the object falls off the shelf and falls to the floor in the absence of air resistance, what will its velocity be when it hits the floor?

weight of the object $= mg = (3.00\ kg)(9.80\ m/s^2) = 29.4\ N$

(a) $W = Fd = (29.4\ N)(2.50\ m) = 73.5\ J$

(b) $PE = mgh = (3.00\ kg)(9.80\ m/s^2)(2.50\ m) = 73.5\ J$

(c) $KE = PE$ so $\frac{1}{2}\ mv^2 = 73.5\ J$

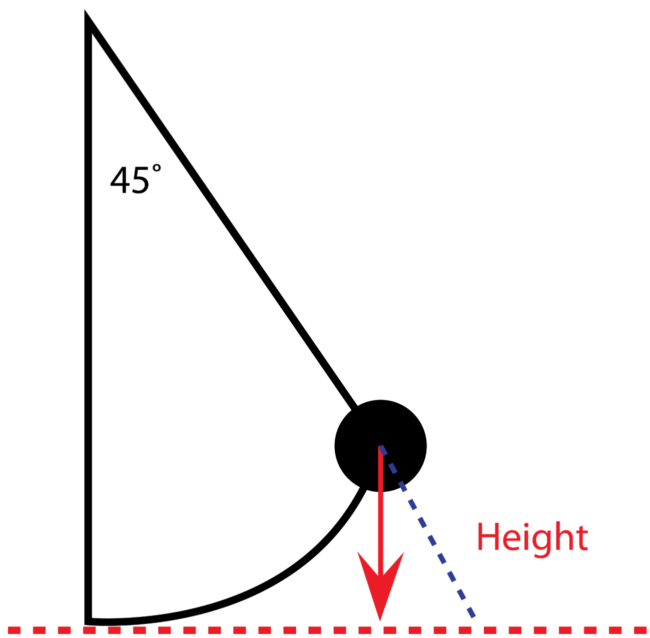
$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(73.5\ J)}{3.00\ kg}} = 7.00\ m/s$$

Example 2

A pendulum is constructed from a 7.58 kg bowling ball hanging on a 3.00 m long rope. The ball is pulled back until the rope makes an angle of 45° with the vertical.

(a) What is the potential energy of the ball?

(b) If the ball is released, how fast will it be traveling at the bottom of its arc?



You can use trigonometry to find the vertical height of the ball in the pulled back position. This vertical height is found to be 0.877 m.

$PE = mgh = (7.58\ kg)(9.80\ m/s^2)(0.877\ m) = 65.1\ J$

When the ball is released, the PE will be converted into KE as the ball swings through the arc.

$KE = \frac{1}{2}\ mv^2 = 65.1\ J$

$$v = \sqrt{\frac{(2)(65.1\ kg \cdot m^2/s^2)}{7.58\ kg}} = 4.14\ m/s$$

Summary

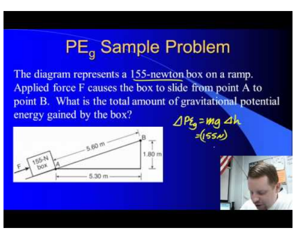
- Stored energy is called potential energy.
- Energy may be stored by holding an object elevated in a gravitational field or by holding it while a force is attempting to move it.
- Potential energy may be converted to kinetic energy.
- The formula for gravitational potential energy is $PE = mgh$.
- In the absence of friction or bending, work done on an object must become either potential energy or kinetic energy or both.

Review

1. A 90.0 kg man climbs hand over hand up a rope to a height of 9.47 m. How much potential energy does he have at the top?
2. A 50.0 kg shell was fired from a cannon at earth's surface to a maximum height of 400. m.
   1. What is the potential energy at maximum height?
   2. It then fell to a height of 100. m. What was the loss of PE as it fell?
3. A person weighing 645 N climbs up a ladder to a height of 4.55 m.
   1. What work does the person do?
   2. What is the increase in gravitational potential energy?
   3. Where does the energy come from to cause this increase in PE?

Explore More

Use this resource to answer the questions that follow.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/63876

1. What is the definition of energy?
2. Name two types of potential energy.
3. How is energy transferred from one object to another?

Vocabulary

- **potential energy:** Otherwise known as stored energy, is the ability of a system to do work due to its position or internal structure. For example, gravitational potential energy is a stored energy determined by an object's position in a gravitational field while elastic potential energy is the energy stored in a spring.

17.7 Kinetic Energy

Learning Objectives

- Define energy.
- Define kinetic energy.
- Given the mass and speed of an object, calculate its kinetic energy.
- Solve problems involving kinetic energy.

This military jet, like all jets, requires a large amount of work to get into the air; unlike most jets, this one is taking off from the deck of aircraft carrier. This requires careful coordination of the plane's engines and the ship's catapults and harnesses to accelerate the jet to about 270 km per hour in just two seconds. This incredible feat requires huge energy conversions.

Kinetic Energy

Energy is the capacity of an object to do work, and like work, energy's unit is the joule (J). Energy exists in many different forms, but the one we think of most often when we think of energy is **kinetic energy**. Kinetic energy is often thought of as the energy of motion because it is used to describe objects that are moving. Remember, though, that energy is the ability of an object to do work. Any moving object has the capacity to cause another object to move if they collide. This ability is what we mean when we refer to an object's kinetic energy: the ability to change another object's motion or position simply by colliding with it. The equation of an object's kinetic energy depends on its mass and velocity:

$KE = \frac{1}{2}\, mv^2$,

The kinetic energy of a moving object is directly proportional to its mass and directly proportional to the square of its velocity. This means that an object with twice the mass and equal speed will have twice the kinetic energy while an object with equal mass and twice the speed will have quadruple the kinetic energy.

The kinetic energy of an object can be changed by doing work on the object. The work done on an object equals the kinetic energy gain or loss by the object. This relationship is expressed in the work-energy theorem $W_{\text{NET}} = \Delta KE$.

Examples

Example 1

A farmer heaves a 7.56 kg bale of hay with a final velocity of 4.75 m/s.

(a) What is the kinetic energy of the bale?

(b) The bale was originally at rest. How much work was done on the bale to give it this kinetic energy?

(a) $KE = \frac{1}{2}mv^2 = \left(\frac{1}{2}\right)(7.56 \text{ kg})(4.75)^2 = 85.3 \text{ Joules}$

(b) Work done $= \Delta KE = 85.3$ Joules

Example 2

What is the kinetic energy of a 750. kg car moving at 50.0 km/h?

$$\left(\frac{50.0 \textbf{ km}}{\textbf{h}}\right)\left(\frac{1000 \textbf{ m}}{\textbf{km}}\right)\left(\frac{1 \textbf{ h}}{3600 \textbf{ s}}\right) = 13.9 \textbf{ m/s}$$

$$KE = \frac{1}{2}mv^2 = \left(\frac{1}{2}\right)(750. \text{ kg})(13.9 \text{ m/s})^2 = 72,300 \text{ Joules}$$

Example 3

How much work must be done on a 750. kg car to slow it from 100. km/h to 50.0 km/h?

From the previous example problem, we know that the KE of this car when it is moving at 50.0 km/h is 72,300 Joules. If the same car is going twice as fast, its KE will be four times as great because KE is proportional to the square of the velocity. Therefore, when this same car is moving at 100. km/h, its KE is 289,200 Joules. Therefore, the work done to slow the car from 100. km/h to 50.0 km/h is $(289,200 \text{ Joules}) - (72,300 \text{ Joules}) = 217,000 \text{ Joules}$.

Summary

- Energy is the ability to change an object's motion or position.
- The energy of motion is called kinetic energy.
- The formula for kinetic energy is $KE = \frac{1}{2}mv^2$.
- The work done on an object equals the kinetic energy gain or loss by the object, $W_{\text{NET}} = \Delta KE$.

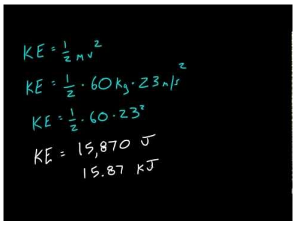
Review

1. A comet with a mass of 7.85×10^{11} kg is moving with a velocity of 25,000 m/s. Calculate its kinetic energy.
2. A rifle can shoot a 4.00 g bullet at a speed of 998 m/s.
    1. Find the kinetic energy of the bullet.
    2. What work is done on the bullet if it starts from rest?
    3. If the work is done over a distance of 0.75 m, what is the average force on the bullet?

4. If the bullet comes to rest after penetrating 1.50 cm into a piece of metal, what is the magnitude of the force bringing it to rest?

Explore More

Use this resource to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/63874

1. Potential energy is present in objects that are _______________.
2. Kinetic energy is present in objects that are _______________.
3. What formula is given for kinetic energy?

Vocabulary

- **energy:** An indirectly observed quantity that is often understood as the ability of a physical system to do work.
- **kinetic energy:** The energy an object has due to its motion.

17.8 References

1. Courtesy of the National Parks Service. http://commons.wikimedia.org/wiki/File:Volcano_q.jpg .
2. Gemma Stiles. http://www.flickr.com/photos/gemmastiles/6927436488/ .
3. CK-12 Foundation - Christopher Auyeung. .
4. Courtesy of the National Park Service. http://commons.wikimedia.org/wiki/File:Beehive_geyser_2.jpg .
5. User:Lanzi/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Drawing-kalorimeter.svg .
6. CK-12 Foundation - Christopher Auyeung. .
7. Image copyright Skynavin, 2014. http://www.shutterstock.com .
8. Laura Guerin. CK-12 Foundation .
9. Samantha Bacic. CK-12 Foundation .
10. Courtesy of Mass Communication Specialist 3rd Class Torrey W. Lee, U.S. Navy. Jet Takeoff .

Concept 18

PS3-4