Chapter 14

Earth's Oceans

14.1 Introduction to the Oceans

Lesson Objectives

- Describe how the oceans formed.
- Explain the significance of the oceans.
- Describe the composition of ocean water.
- Define the parts of the water column and oceanic divisions.

Introduction

Have you ever heard the Earth called the "Blue Planet"? This term makes sense, because over 70% of the surface of the Earth is covered with water. The vast majority of that water (97.2%) is in the oceans. Without all that water, our world would be a different place. The oceans are an important part of Earth: they help to determine the make-up of the air, they help determine the weather and temperature, and they support great amounts of life. The composition of ocean water is unique to its location and depth. Just as Earth's interior is divided into layers, the ocean separated into different layers, called the water column.

How the Oceans Formed

Scientists have developed a number of hypotheses about how the oceans formed. Though these hypotheses have changed over time, one idea now has the wide support of Earth scientists, called the volcanic outgassing theory. This means that water vapor given off by volcanoes erupting over millions or billions of years, cooled and condensed to form Earth's oceans.

Creation and Collection of Water

When the Earth was formed 4.6 billion years ago, it would never have been called the Blue Planet. There were no oceans, there was no oxygen in the atmosphere, and no life. But there were violent collisions, explosions, and eruptions. In fact, the Earth in its earliest stage was molten. This allowed elements to separate into layers within the Earth — gravity pulled denser elements toward the Earth's center, while less dense materials accumulated near the surface. This process of separation created the layers of the Earth as we know them.

As temperatures cooled, the surface solidified and an atmosphere was created. Volcanic eruptions released water vapor from the Earth's crust, while more water came from asteroids and comets that collided with the Earth (**Figure** 14.1). About 4 billion years ago, temperatures cooled enough for oceans to begin forming.

Figure 14.1: Volcanic activity was common in Earth's early stages, when the oceans had not yet begun to form. (11)

Present Ocean Formation

As you know, the continents were not always in the same shape or position as they are today. Because of tectonic plate movements, land masses have moved about the Earth since they were created. About 250 million years ago, all of the continents were arranged in one huge mass of land called Pangea (**Figure** 14.2). This meant that most of Earth's water was collected in a huge ocean called Panthalassa. By about 180 million years ago, Pangea had begun to break apart because of continental drift. This then separated the Panthalassa Ocean into separate but connected oceans that are the ocean basins we see today on Earth.

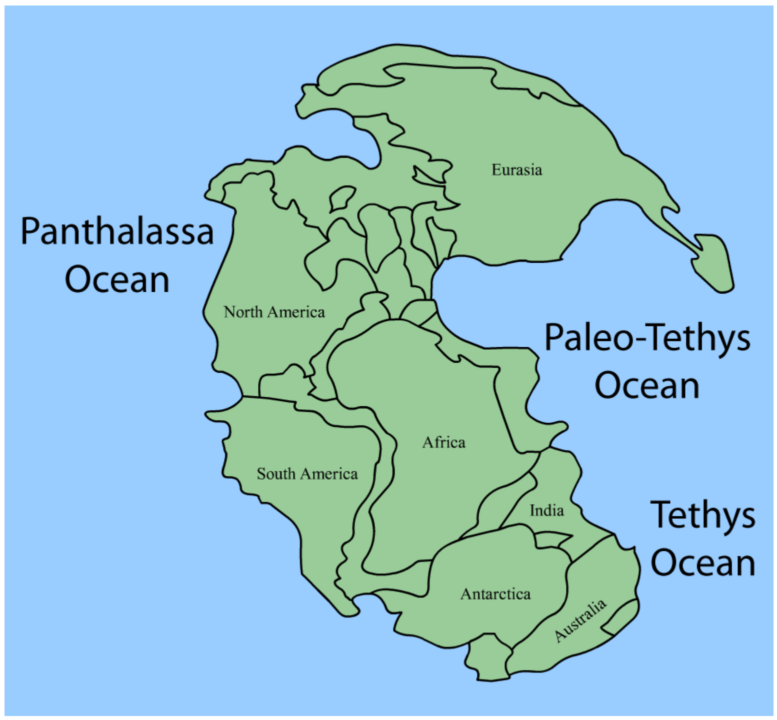

Figure 14.2: Pangea was the sole landform 250 million years ago, leaving a huge ocean called Panthalassa, along with a few smaller seas. (24)

Significance of the Oceans

The Earth's oceans play an important role in maintaining the world as we know it. Indeed, the ocean is largely responsible for keeping the temperatures on Earth fairly steady. It may get pretty cold where you live in the wintertime. Some places on Earth get as cold as -70ºC. Some places get as hot as 55ºC. This is a range of 125ºC. But compare that to the surface temperature on Mercury: it ranges from -180ºC to 430ºC, a range of 610ºC. Mercury has neither an atmosphere nor an ocean to buffer temperature changes so it gets both extremely hot and very cold.

On Earth, the oceans absorb heat energy from the Sun. Then the ocean currents move the energy from areas of hot water to areas of cold water, and vice versa. Not only does ocean circulation keep the water temperature moderate, but it also affects the temperature of the air. If you examine land temperatures on the Earth, you will notice that the more extreme temperatures occur in the middle of continents, whereas temperatures near the water tend to be more moderate. This is because water retains heat longer than land. Summer temperatures will therefore not be as hot, and winter temperatures won't be as cold, because the water takes a long time to heat up or cool down. If we didn't have the oceans, the temperature range would be much greater, and humans could not live in those harsh conditions.

The ocean is home to an enormous amount of life. This includes many kinds of microscopic life, plants and algae, invertebrates like sea stars and jellyfish, fish, reptiles, and marine mammals. The many different creatures of the ocean form a vast and complicated food web, that actually makes up the majority of all biomass on Earth. (**Biomass** is the total weight of living organisms in a particular area.) We depend on the ocean as a source of food and even the oxygen created by marine plants. Scientists are still discovering new creatures and features of the oceans, as well as learning more about marine ecosystems (**Figure** 14.3).

Finally, the ocean provides the starting point for the Earth's water cycle. Most of the water that evaporates into the atmosphere initially comes from the ocean. This water, in turn, falls on land in the form of precipitation. It creates snow and ice, streams and ponds, without which people would have little fresh water. A world without oceans would be a world without you and me.

Composition of Ocean Water

Water has oftentimes been referred to as the "universal solvent", because many things can dissolve in water (**Figure** 14.4). Many things like salts, sugars, acids, bases, and other organic molecules can be dissolved in water. Pollution of ocean water is a major problem in some areas because many toxic substances easily mix with water.

Perhaps the most important substance dissolved in the ocean is salt. Everyone knows that ocean water tastes salty. That salt comes from mineral deposits that find their way to the

Figure 14.3: Coral reefs are amongst the most densely inhabited and diverse areas on the globe. (2)

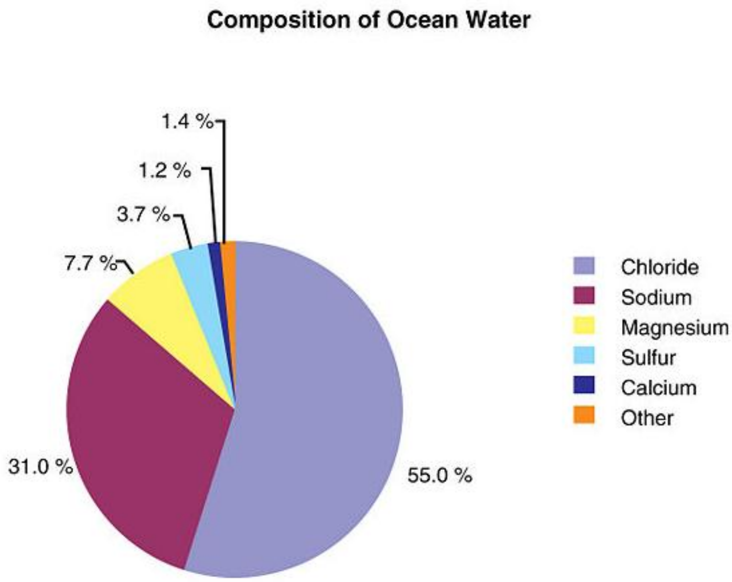

Figure 14.4: Ocean water is composed of many substances. The salts include sodium chloride, magnesium chloride and calcium chloride. (22)

ocean through the water cycle. Salts comprise about 3.5% of the mass of ocean water. Depending on specific location, the salt content or **salinity** can vary. Where ocean water mixes with fresh water, like at the mouth of a river, the salinity will be lower. But where there is is lots of evaporation and little circulation of water, salinity can be much higher. The Dead Sea, for example, has 30% salinity—nearly nine times the average salinity of ocean water. It is called the Dead Sea because so few organisms can live in its super salty water.

The density (mass per volume) of seawater is greater than that of fresh water because it has so many dissolved substances in it. When water is more dense, it sinks down to the bottom. Surface waters are usually lower in density and less saline. Temperature affects density too. Warm water is less dense and colder waters are more dense. These differences in density create movement of water or deep ocean currents that transport water from the surface to greater depths.

The Water Column

In 1960, one of the deepest parts of the ocean (10,910 meters) was reached by two men in a specially designed submarine called the *Trieste* (**Figure** 14.5). This part of the ocean has been named the Challenger Deep. In contrast, the average depth of the ocean is 3,790 meters — still an incredible depth for sea creatures to live at and for humans to travel. What makes it so hard to live at the bottom of the ocean? There are three major factors—the absence of light, low temperature, and extremely high pressure. In order to better understand regions of the ocean, the scientists define different regions by depth (**Figure** 14.6).

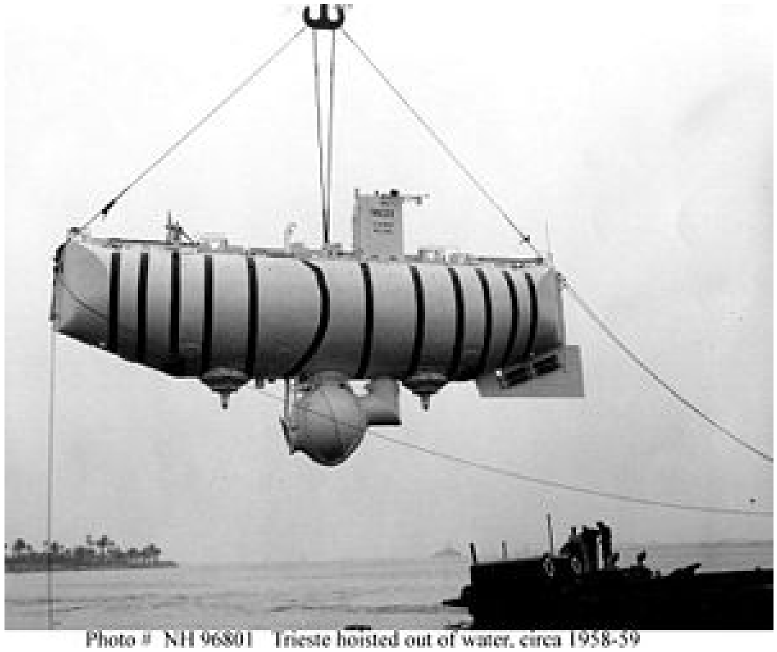

Figure 14.5: The Trieste made a record dive to the Challenger Deep in 1960. No craft exists today that can reach that depth. (7)

Sunlight only penetrates water to a depth of about 200 meters, a region called the **photic zone** (photic means light). Since organisms that photosynthesize depend on sunlight, they can only live in the top 200 meters of water. Such photosynthetic organisms supply almost all the energy and nutrients to the rest of the marine food web. Animals that live deeper than 200 meters mostly feed on whatever drops down from the photic zone.

Beneath the photic zone is the **aphotic zone,** where there is not enough light for photosynthesis. The aphotic zone makes up the majority of the ocean but a minority of its life forms. Descending to the ocean floor, the water temperature decreases while pressure increases tremendously. Each region is progressively deeper and colder, with the very deepest areas in ocean trenches.

The ocean can also be divided by horizontal distance from the shore. Nearest to the shore lies the **intertidal zone**. In this region, you might find waves, changes in tide, and constant motion in the water that exposes the water to large amounts of air. Organisms that live in this zone are adapted to withstand waves and exposure to air in low tides, by having strong attachments and hard shells. The **neritic zone** includes the intertidal zone and the part of the ocean floor that very gradually slopes downward, the continental shelf. Lots of oceanic plants live in this zone, since some sunlight still penetrates to the bottom of the ocean floor in the neritic zone. Beyond the neritic zone is the **oceanic zone**, where the sloping sea floor takes a much even steeper dive and sunlight does not reach. Animals such as sharks, fish, and whales can be found in this zone. They feed on materials that sink from upper levels, or consume one another. At hydrothermal vents, areas of extremely hot water with lots of dissolved materials allow rare and unusual producers to thrive.

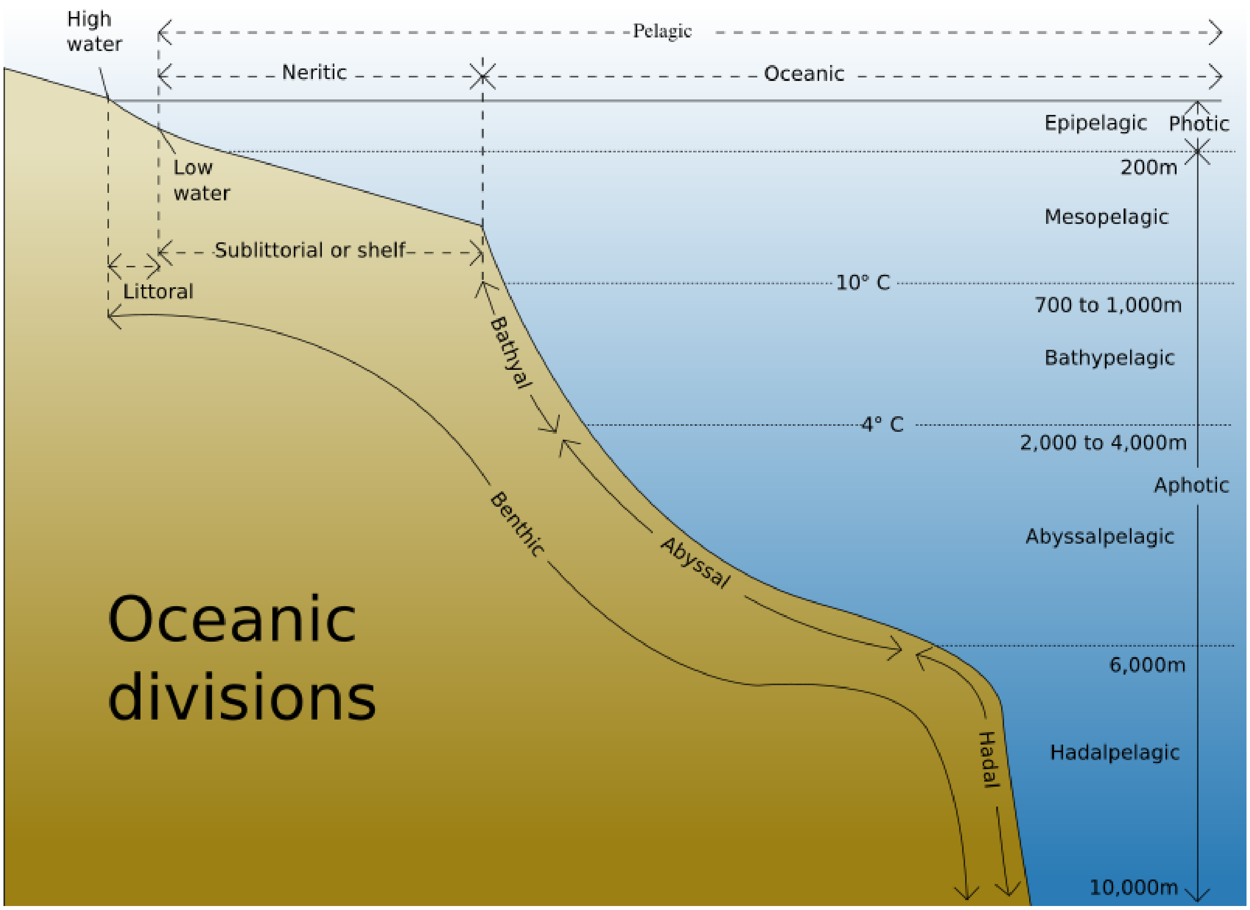

Figure 14.6: The ocean environment is divided into many regions based on factors like availability of light and nutrients.Organisms adapt to the conditions and resources in the regions in which they live. (18)

Lesson Summary

- Our oceans originally formed as a water vapor released by volcanic outgassing cooled and condensed.
- The oceans serve the very important role of helping to moderate Earth's temperatures.
- The oceans are home to a tremendous diversity of life, and algae which are all photosynthetic organisms.
- The main elements dissolved in seawater are chlorine, sodium, magnesium, sulfate and calcium.

- Usual salinity for the oceans is about 3.5% or 35 parts per thousand.
- Some regions in areas of high evaporation, like the Dead Sea, have exceptionally high salinities.
- The photic zone is the surface layer of the oceans, down to about 200m, where there is enough available light for photosynthesis.
- Below the photic zone, the vast majority of the oceans lies within the aphotic zone, where there is not enough light for photosynthesis.
- On average, the ocean floor is about 3,790m but there are ocean trenches as deep as 10,910m.
- The ocean has many biological zones determined by availability of different abiotic factors.
- Neritic zones are nearshore areas, including the intertidal zone. Oceanic zones are offshore regions of the ocean.

Review Questions

1. What was the name of the single continent that separated to form today's continents?
2. From what three sources did water originate on Earth?
3. What percent of the Earth's surface is covered by water?
4. How do the oceans help to moderate Earth's temperatures?
5. Over time, the Earth's oceans have become more and more salty. Why?
6. What is the most common substance that is dissolved in ocean water?
7. What is density?
8. Compare and contrast the photic and aphotic zones.
9. Describe the types of organisms found in the intertidal, neritic, and oceanic zones. Give examples of a life form you think might be found in each.

Vocabulary

aphotic zone

The zone in the water column deeper than 200 m. Sunlight does not reach this region of the ocean.

biomass The total mass of living organisms in a certain region.

current The movement of water in a stream, lake, or ocean.

density Mass per volume. The units for density are usually g/cm^3 or g/mL.

intertidal zone The part of the ocean closest to the shore, between low and high tide.

neritic zone The part of the ocean where the continental shelf gradually slopes outward from the edge of the continent. Some sunlight can penetrate this region of the ocean.

oceanic zone The open ocean, where the seafloor is deep. No sunlight reaches the floor of the ocean here.

Pangea The supercontinent that tectonically broke apart about 200 million years ago, forming the continents and oceans that we see today on Earth.

photic zone The topmost region of the water column, extending from the surface down to about 200 m in depth. Sunlight easily penetrates this region of the water column.

salinity A measure of the amount of dissolved salt in water.

water column A vertical column of ocean water, which is divided into different zones according to their depth.

Points to Consider

- What creates the movement of water like tides and waves?
- Is it possible to have a river in the middle of the ocean?
- What other factors affect the movement of ocean water? How do these factors affect to the world's climate and the ocean's ecosystem?

14.2 Ocean Movements

Lesson Objectives

- Define waves and explain their formation.
- Describe what causes tides.
- Describe how surface currents form and how they affect the world's climate.
- Describe the causes of deep currents.
- Relate upwelling areas to their impact on the food chain.

Introduction

Ocean water is constantly in motion (**Figure** 14.7). From north to south, east to west, and up and down the shore, ocean water moves all over the place. These movements can be explained as the result of many separate forces, including local conditions of wind, water, the position of the moon and Sun, the rotation of the Earth, and the position of land formations.

Figure 14.7: Ocean waves transfer energy through the water over great distances. (34)

Waves

A *wave* is a disturbance that transfers energy through matter or empty space. Sound waves move through the air, earthquakes send powerful waves through solid earth, spacecraft radio waves travel across millions of miles through the vacuum of empty space, and ocean waves move through water. All of these types of waves are able to transfer energy over great distances. The size of a wave and the distance it travels depends on the amount of energy that the wave carries.

The most familiar waves occur on the ocean's surface. It is upon these waves that surfers play and boogie boarders ride. These waves are mostly created by the wind. There are three factors wind that determine the size of the wave: 1) the speed of the wind, 2) the distance over which the wind has blown, and 3) the length of time that the wind has blown. The greater each of these factors, the bigger the wave.

Waves can be measured by their amplitude, a distance measured vertically from the **crest** (the top of the wave) to the **trough** (the bottom of the wave). They can also be measured by their **wavelength**, which is the horizontal distance between crests (**Figure** 14.8). When wind blows across the water surface, energy is transferred to the water. The transfer of that energy may create tiny ripples that disappear when the wind dies down, or it may create larger waves that continue until they reach the shore. Most waves reach the shore.

Scientists sometimes describe waves by measuring the speed of a wave. A wave's speed is determined by measuring the time it takes for one wavelength to pass by. Interestingly, particles in the ocean are not significantly moved by waves; although they are bobbled around by the waves, the particles tend to stay where they are.

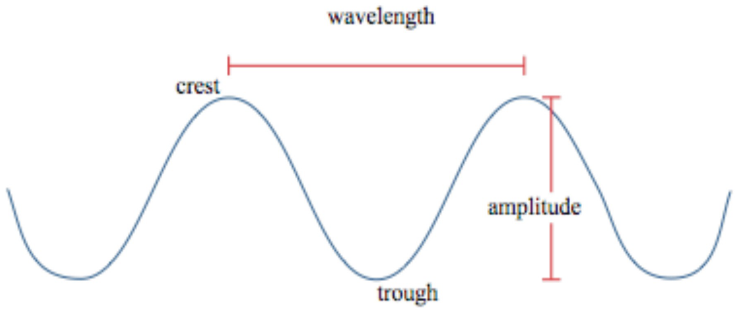

Figure 14.8: Waves are measured by their amplitude and by their wavelength. (14)

Waves can also form when a rapid shift in ocean water is caused by underwater earthquakes, landslides, or meteors that hit the ocean. These waves, called **tsunami** (**Figure** 14.9), can travel at speeds of 800 kilometers per hour (500 miles per hour). Tsunami have small, often unnoticeable wave heights in the deep ocean. However as a tsunami approaches the continental shelf, wave height increases. The wave speed is also slowed by friction with the shallower ocean floor, which causes the wavelength to decrease, creating a much taller wave. Many people caught in a tsunami have no warning of its approach. Tsunami warning systems are important for protecting for coastal areas and low-lying countries.

Waves break when they get close to the shore. That is due to the wave's interaction with the sea floor. When the wave hits the shore, the energy at the bottom of the wave is transferred to the ocean floor, which slows down the bottom of the wave. The energy at the top of the wave, in the crest, continues at the same speed, however. Since the top of this wave is going faster than the bottom, the crest falls over and crashes down.

Tides

Wind is the primary force that causes ocean surface waves, but it does not cause the tides. Tides are the daily changes in the level of the ocean water at any given place. The main factors that causes tides are the gravitational pull of the Moon and the Sun (**Figure** 14.10).

How does the Moon affect the oceans? Since the Moon is a relatively large object in space that is very close to the Earth, its gravity actually pulls Earth's water towards it. Wherever the moon is, as it orbits the Earth, there is a high tide 'bulge' that stays lined up with the Moon. The side of the Earth that is furthest from the Moon also has a high tide 'bulge'. This is because the Earth is closer to the moon the water on its far side. The Moon's gravity pulls more on the planet than the water on the opposite side. These two water bulges on opposite sides of the Earth aligned with the Moon are the **high tides**. Since ocean water is

Figure 14.9: An undersea earthquake caused the Boxing Day Tsunami in 2004 which devastated Indonesia, Sri Lanka, India, Thailand, and Myanmar. In this photo, the tsunami hits the Maldives in the Indian Ocean. (17)

Figure 14.10: High tide (left) and low tide (right) at Bay of Fundy on the Gulf of Maine in North America. The Bay of Fundy has one of the greatest tidal ranges on Earth. (31)

pulled higher in the areas of the two high tides, there is less water in between the two high tides. These areas are the **low tides** (**Figure** 14.11).

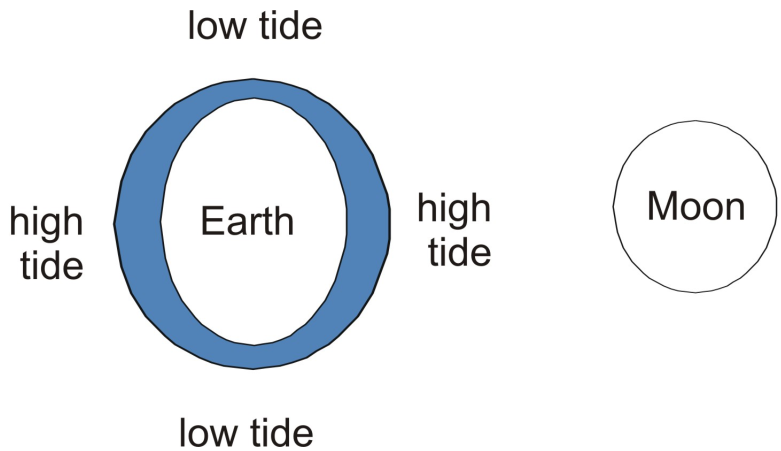

Figure 14.11: High tide is created by the gravitational pull of the moon which pulls water toward it. Water on the opposite side of the Earth is pulled least by the moon so the water bulges away from the moon. High tide occurs where the water is bulging. Low tide occurs where it is not. (35)

The **tidal range** is the difference between the ocean level at high tide and the ocean at low tide (**Figure** 14.12). Some places have a greater tidal range than others. High tides occur about twice a day, about every 12 hours and 24 minutes.

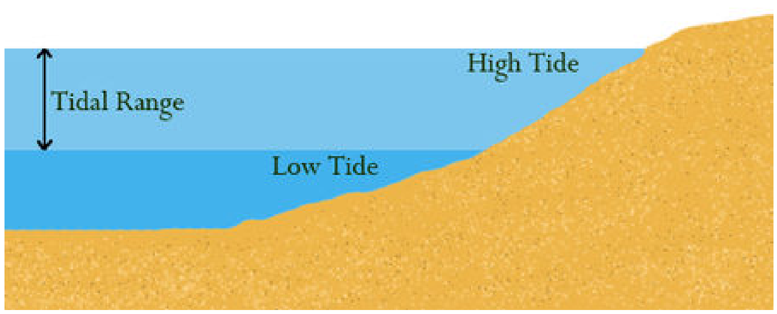

Figure 14.12: The tidal range is the difference between the ocean level at high tide and low tide. (26)

The Moon's gravity is mostly responsible for our tides, but the Sun also plays a role (**Figure** 14.13). The Sun is much larger than our Moon. It has a mass about 27,500,000 times greater than the Moon. A very large object like the Sun would produce tremendous tides if it were as near to Earth as the Moon. However it is so far from the Earth that its effect on the tides is only about half as strong as the Moon's. When both the Sun and Moon are aligned, the effect of each is added together, producing higher than normal tides called **spring tides**.

Spring tide are tides with the greatest tidal range. Despite their name, spring tides don't just occur in the spring; they occur throughout the year whenever the Moon is in a new-moon or full-moon phase, or about every 14 days.

Here is a link to see these tides in motion: http://oceanservice.noaa.gov/education/kits/tides/media/tide06a_450.gif *License:* GNU-FDL)

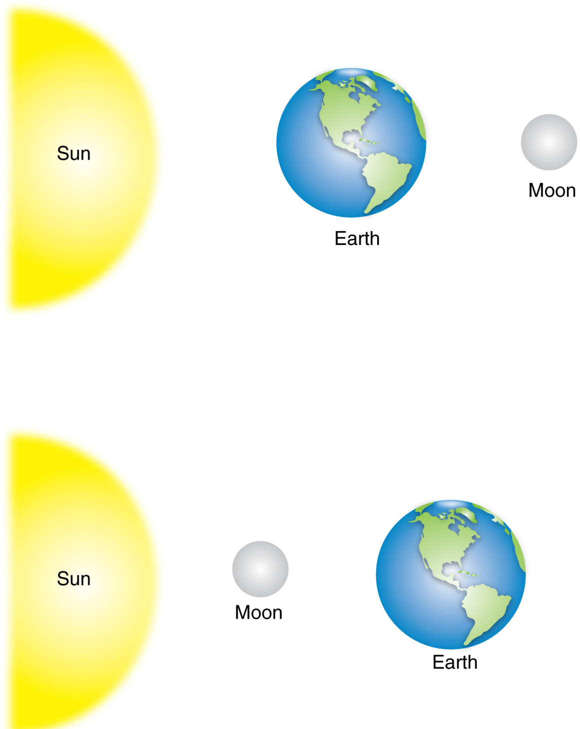

Figure 14.13: Spring tides occur when the Earth, the Sun, and the Moon are aligned, increasing the gravitational pull on the oceans. Sometimes, the Sun and Moon are on opposite sides of the Earth while at other times, they are on the same side. (29)

Neap tides are tides that have the smallest tidal range, and occur when the Earth, the Moon, and the Sun form a 90° angle (**Figure** 14.14). They occur exactly halfway between the spring tides, when the Moon is at first or last quarter. This happens because the Moon's high tide occurs in the same place as the Sun's low tide and the Moon's low tide is added to by the Sun's high tide.

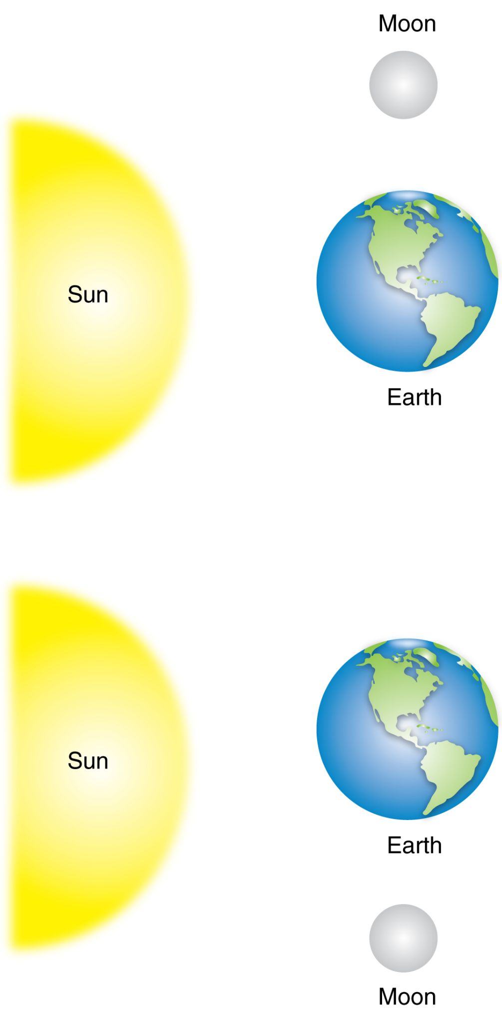

Figure 14.14: Neap tides occur when the Earth, the Sun, and the Moon form a right angle, at first and last quarters for the Moon. The two possible angles are shown below. (28)

Surface Currents

Wind that blows over the ocean water creates waves. It also creates **surface currents,** which are horizontal streams of water that can flow for thousands of kilometers and can reach depths of hundreds of meters. Surface currents are an important factor in the ocean because they are a major factor in determining climate around the globe.

Causes of Surface Currents

Currents on the surface are determined by three major factors:the major overall global wind patterns, the rotation of the Earth, and the shape of ocean basins.

When you blow across a cup of hot chocolate, you create tiny ripples on its surface that continue to move after you've stopped blowing. The ripples in the cup are tiny waves, just like the waves that wind forms on the ocean surface. The movement of hot chocolate throughout the cup forms a stream or current, just as oceanic water moves when wind blows across it.

But what makes the wind start to blow? When sunshine heats up air, the air expands, which means the density of the air decreases and it becomes lighter. Like a balloon, the light warm air floats upward, leaving a slight vacuum below, which pulls in cooler, denser air from the sides. The cooler air coming into the space left by the warm air is wind.

Because the Earth's equator is warmed by the most direct rays of the Sun, air at the equator is hotter than air further north or south. This hotter air rises up at the equator and as colder air moves in to take its place, winds begin to blow and push the ocean into waves and currents.

Wind is not the only factor that affects ocean currents. The 'Coriolis Effect' describes how Earth's rotation steers winds and surface currents (**Figure** 14.15). The Earth is a sphere that spins on its axis in a counterclockwise direction when seen from the North Pole. The further towards one of the poles you move from the equator, the shorter the distance around the Earth. This means that objects on the equator move faster than objects further from the equator. While wind or an ocean current moves, the Earth is spinning underneath it. As a result, an object moving north or south along the Earth will appear to move in a curve, instead of in a straight line. Wind or water that travels toward the poles from the equator is deflected to the east, while wind or water that travels toward the equator from the poles gets bent to the west. The Coriolis Effect bends the direction of surface currents.

The third major factor that determines the direction of surface currents is the shape of ocean basins (**Figure** 14.16). When a surface current collides with land, it changes the direction of the currents. Imagine pushing the water in a bathtub towards the end of the tub. When the water reaches the edge, it has to change direction.

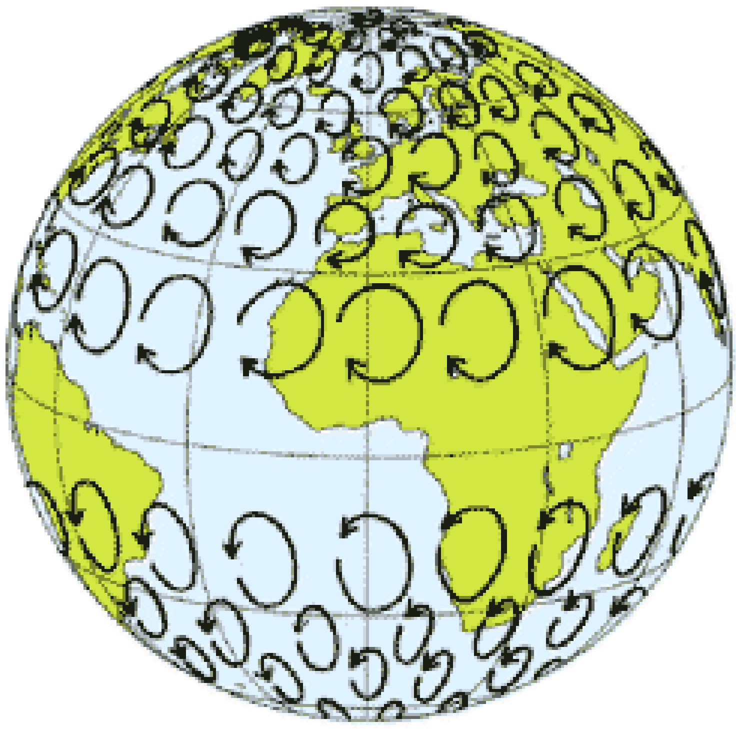

Figure 14.15: The Coriolis Effect causes winds and currents to form circular patterns. The direction that they spin depend on the hemisphere that they are in. (19)

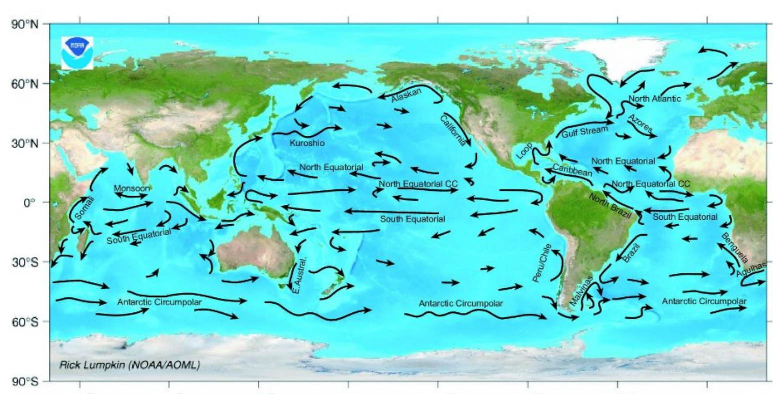

Figure 14.16: This map shows the major surface currents at sea. Currents are created by wind, and their directions are determined by the Coriolis effect and the shape of ocean basins. (6)

Effect on Global Climate

Surface currents play a large role in determining climate. These currents bring warm water from the equator to cooler parts of the ocean; they transfer heat energy. Let's take the Gulf Stream as an example; you can find the Gulf Stream in the North Atlantic Ocean in **Figure** 14.15. The Gulf Stream is an ocean current that transports warm water from the equator past the east coast of North America and across the Atlantic to Europe. The volume of water it transports is more than 25 times that of all of the rivers in the world combined, and the energy it transfers is more than 100 times the world's energy demand. It is about 160 kilometers wide and about a kilometer deep. The Gulf Stream's warm waters give Europe a much warmer climate than other places at the same latitude. If the Gulf Stream were severely disrupted, temperatures would plunge in Europe.

Deep Currents

Surface currents occur close to the surface of the ocean and mostly affect the photic zone. Deep within the ocean, equally important currents exist that are called **deep currents**. These currents are not created by wind, but instead by differences in density of masses of water. Density is the amount of mass in a given volume. For example, if you take two full one liter bottles of liquid, one might weigh more, that is it would have greater mass than the other. Because the bottles are both of equal volume, the liquid in the heavier bottle is denser. If you put the two liquids together, the one with greater density would sink and the one with lower density would rise.

Two major factors determine the density of ocean water: salinity (the amount of salt dissolved in the water) and temperature (**Figure** 14.17). The more salt that is dissolved in the water, the greater its density will be. Temperature also affects density: the colder the temperature, the greater the density. This is because temperature affects volume but not mass. Colder water takes up less space than warmer water (except when it freezes). So, cold water has greater density than warm water.

More dense water masses will sink towards the ocean floor. Just like convection in air, when denser water sinks, its space is filled by less dense water moving in. This creates convection currents that move enormous amounts of water in the depths of the ocean. Why is the water temperature cooler in some places? Water cools as it moves from the equator to the poles via surface currents. Cooler water is more dense so it begins to sink. As a result, the surface currents and the deep currents are linked. Wind causes surface currents to transport water around the oceans, while density differences cause deep currents to return that water back around the globe (**Figure** 14.18).

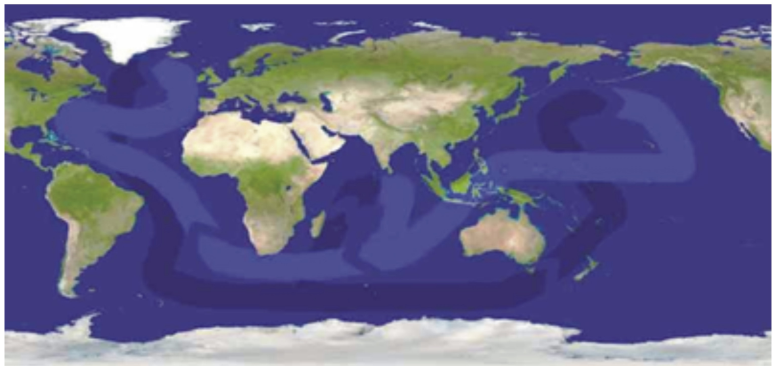

Figure 14.17: Thermohaline currents are created by differences in density due to temperature (thermo) and salinity (haline). The dark arrows are deep currents and the light ones are surface currents. (20)

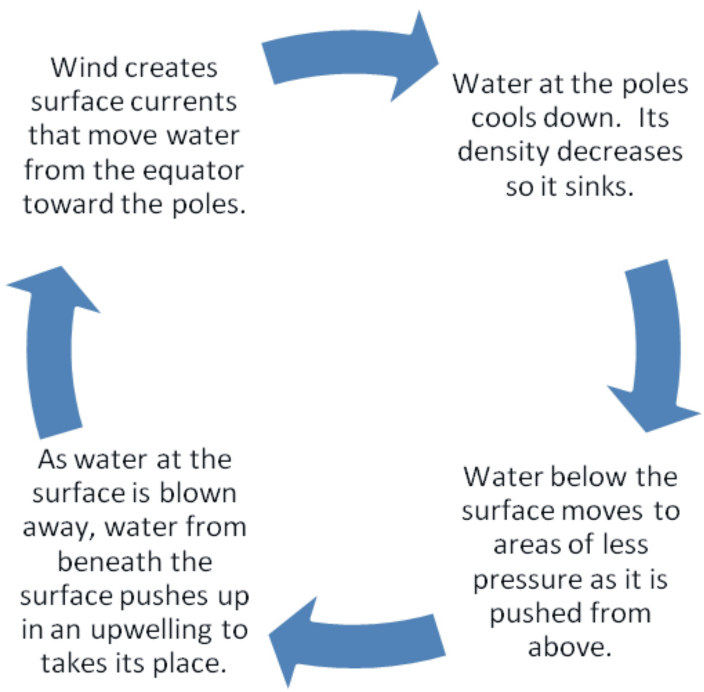

Figure 14.18: Surface and deep currents together form convection currents that circulate water from one place to another and back again. A water particle in the convection cycle can take 1600 years to complete the cycle. (10)

Upwelling

As you have seen, water that has greater density usually sinks to the bottom. However, in the right conditions, this process can be reversed. Denser water from the deep ocean can come up to the surface in an **upwelling** (**Figure** 14.19). Generally, an upwelling occurs along the coast when wind blows water strongly away from the shore. As the surface water is blown away from the shore, colder water from below comes up to take its place. This is an important process in places like California, South America, South Africa, and the Arabian Sea because the nutrients brought up from the deep ocean water support the growth of plankton which, in turn, supports other members in the ecosystem. Upwelling also takes place along the equator between the North and South Equatorial Currents.

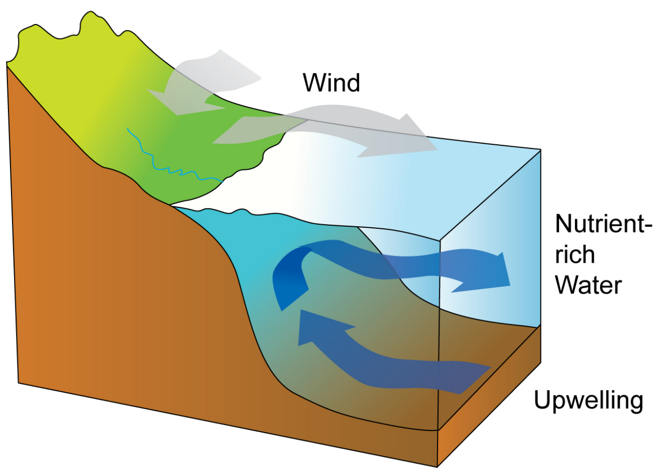

Figure 14.19: An upwelling forces denser water from below to take the place of less dense water at the surface that is pushed away by the wind. (9)

Lesson Summary

- Ocean waves are energy traveling through the water.
- The highest portion of a wave is the crest and the lowest is the trough.
- The horizontal distance between two wave crests is the wave's length.
- Most waves in the ocean are wind generated waves. Tsunami are exceptionally long wavelength waves often caused by earthquakes.
- Tides are produced by the gravitational pull of the Moon and Sun on Earth's oceans.
- Spring tides happen at full and new moons, when the Earth, Moon, and Sun are all aligned.

- Neap tides are tides of lower than normal tidal range that occur at first and last quarter moons, when the Moon is at right angles to the Sun.
- Ocean surface currents are produced by major overall patterns of atmospheric circulation, the Coriolis Effect and the shape of each ocean basin.
- Each half of each ocean basin has a major circular pattern of surface water circulation called a gyre.
- Ocean surface circulation brings warm equatorial waters towards the poles and cooler polar water towards the equator.
- Deep ocean circulation is density driven circulation produced by differences in salinity and temperature of water masses.
- Upwelling areas are biologically important areas that form as ocean surface waters are blown away from a shore, causing cold, nutrient rich waters to rise to the surface.

Review Questions

1. What factors of wind determine the size of a wave?
2. Define the *crest* and *trough* of a wave.
3. Why does a hurricane create big waves?
4. Tsunami are sometimes incorrectly called "tidal waves." Explain why this is not an accurate term for tsunami.
5. What is the principle cause of the tides?
6. What is a tidal range?
7. Why do you think that some places have a greater tidal range than other places?
8. Which has a greater tidal range, spring tides or neap tides? Explain.
9. What is the most significant cause of the surface currents in the ocean?
10. How do ocean surface currents affect climate?
11. What is the Coriolis Effect?
12. Some scientists have hypothesized that if enough ice in Greenland melts, the Gulf Stream might be shut down. Without the Gulf Stream to bring warm water northward, Europe would become much colder. Explain why melting ice in Greenland might affect the Gulf Stream.
13. What process can make denser water rise to the top?
14. Why are upwelling areas important to marine life?

Further Reading / Supplemental Links

- Learn About Ocean Currents, 5 min Life Videopedia http://www.5min.com/Video/Learn-about-Ocean-Currents-117529352

Vocabulary

amplitude The vertical height of a wave, measured from trough to crest.

Coriolis effect the apparent deflection of a moving object like water or air caused by Earth's rotation.

crest The highest point in a wave.

deep current A current deep within the ocean, which moves because of density differences (caused by differences in water temperature and salinity).

high tide The maximum height reached by a tide in the course of a day.

low tide The minimum height reached by a tide in the course of a day.

neap tide A tide that occurs when the Moon, Sun, and Earth are at 90° angles to one another. Tides have the smallest tidal range during a neap tide.

rip current A strong surface current of water that is returning to the ocean from the shore.

spring tide A tide that occurs when the Moon, Sun, and Earth area all in a line. Tides will have the greatest tidal range during a spring tide.

surface current A horizontal movement of ocean water, caused by surface winds.

tidal range The difference between the high and low tide.

tide The daily rise and fall in the level of the ocean water.

trough The lowest point in a wave.

tsunami A seismic sea wave generated by vertical movement of the ocean floor underwater earthquake, underwater volcanic eruption or landslide or meteorite impact.

upwelling Cold, nutrient-rich water that rises from oceanic depths usually near the continents, when wind blows the overlying surface away or along the equator.

wave A change in the shape of water caused by energy moving through the water.

wavelength The horizontal distance between two troughs, or two crests in a wave.

Points to Consider

- What is the bottom of the ocean like?
- How is the seafloor studied?
- How does the ocean floor contribute to the ocean's ecosystem?

Going Further - Applying Math

Tide Generating Force

In this chapter, you have learned some of the fundamental forces that influence tides. You can also learn some more about tides by using an equation to calculate the tide generating force. Like the force of gravity, the pull of the tide generating force is directly related to the masses of the astronomical objects involved and inversely related to the square of the distance between them. Tides are caused by both the gravitational pull of the Moon and the gravitational pull of the Sun on the layer of water that covers the Earth. Unlike the gravitational force, the tide generating force varies with the distance between the Moon (or the Sun) and the Earth cubed. So the equation for the tide generating force is as follows: $T = G\ (m_1 \cdot m_2 / d^3)$ where T is the tide generating force, G is the universal gravitational constant, m_1 and m_2 are the mass of the Earth and the mass of the Moon (or the mass of the Earth and the mass of the Sun), and d is the distance between them.

If we plug in values for the gravitational constant, the mass of the Earth and the mass of the Moon, we can calculate the tide generating force when the Moon is at apogee (farthest from the Earth in its orbit). Use $G = 6.673 \times 10^{-11}\ m^3 / kg \cdot s^2$; $m_1 = 7.35 \times 10^{22}$ kg for the mass of the Moon, $m_2 = 5.974 \times 10^{24}$ kg for the mass of the Earth; and d = 405,500 km for the distance from the Earth to the Moon at apogee.

You could use all the same values but substitute in d = 363,300 km for the distance from the Earth to the Moon when the Moon is at perigee (point when the Moon is closest to the Earth) and compare the tide generating force each distance.

Tsunami Tag

Often students ask if they could simply outrun a tsunami as it approaches them. How fast would you have to run to do this? You can calculate how fast a tsunami travels in the ocean using the equation for the speed of a shallow water wave, which is: V = the square root of g x d, where V = wave speed (velocity), g = the acceleration of gravity: 9.8 meters / s^2, and d = the depth of the water. If you use d = 3,940m (the average depth of the Pacific Ocean), how fast does a tsunami travel? Do you think you could outrun this wave?

14.3 The Seafloor

Lesson Objectives

- Describe the obstacles to studying the seafloor and methods for doing so.
- Describe the features of the seafloor.
- List the living and non-living resources that people use from the seafloor.

Introduction

The ocean surface is vast and hides an entire world underneath it. The ocean floor is sometimes called the final frontier of the modern era. Though people have traveled on the ocean for millennia, people have explored only a tiny fraction of the ocean floor. We know very little about the vast expanse of our oceans. Today's technology has allowed us to learn more about the seafloor, including both its physical properties and its effects on living organisms.

Studying the Seafloor

Ancient myth says that Atlantis was a powerful undersea city whose warriors conquered many parts of Europe. There is little proof that such a city existed, but human fascination with the world under the oceans certainly has existed for centuries. Not much was known about the aphotic zone of the ocean until scientists developed a system modeled after the way that bats and dolphins use echolocation to navigate in the dark (**Figure** 14.20). Prompted by the need to find submarines during World War II, scientists learned to bounce sound waves through the ocean to detect underwater objects. The sound waves bounce back like an echo off of whatever object may be in the ocean. The distance of the object can be calculated based on the time that it takes for the sound waves to return. Finally, scientists were able to map the ocean floor.

Three main obstacles have kept us from studying the depths of the ocean: absence of light, very cold temperatures, and high pressure. As you know, light only penetrates the top 200 meters of the ocean; the depths of the ocean can be as much as 11,000 meters deep. Most places in the ocean are completely dark, which makes it impossible for humans to explore without bringing a source of light with them. Secondly, the ocean is very cold; colder than 0ºC (32ºF) in many places. Such cold temperatures pose significant obstacles to human exploration of the oceans. Finally, the pressure in the ocean increases tremendously as you go deeper. Scuba divers can rarely go deeper than 40 meters due to the pressure. The pressure on a diver at 40 meters would be 4 kilograms/square centimeter (60 lbs/sq in). Even though we don't think about it, the air in our atmosphere has weight. It presses down on us with a force of about 1 kilogram per square centimeter (14.7 lbs/ sq in). In the ocean,

Figure 14.20: Dolphins and whales use echolocation, a natural sonar system, to navigate the ocean. (15)

for every 10 meters of depth, the pressure increases by nearly 1 atmosphere! Imagine the pressure at 10,000 meters; that would be 1,000 kilograms per square centimeter (14,700 lbs/sq in). Today's submarines usually dive to only about 500 meters; to go deeper than this they must be specially designed for greater depth (**Figure** 14.21).

In the 19th century, explorers mapped ocean floors by painstakingly dropping a line over the side of a ship to measure ocean depths, one tiny spot at a time. SONAR, which stands for *So*und *N*avigation *A*nd *R*anging, has enabled modern researchers to map the ocean floor much more quickly and easily. Researchers send a pulse of sound down to the ocean floor and calculate the depth based on how long it takes the sound to return. Of course, some scientific research requires actually traveling to the bottom of the ocean to collect samples or directly observe the ocean floor, but this is more expensive and can be dangerous.

In the late 1950s, the bathyscaphe (deep boat) *Trieste* was the first manned vehicle to venture to the deepest parts of the ocean, a region of the Marianas Trench named the Challenger Deep. It was built to withstand 1.2 metric tons per square centimeter and plunged to a depth of 10,900 meters. No vehicle has carried humans again to that depth, though robotic submarines have returned to collect sediment samples from the Challenger Deep. *Alvin* is a submersible used by the United States for a great number of studies; it can dive up to 4,500 meters beneath the ocean surface (**Figure** 14.22).

In order to avoid the expense, dangers and limitations of human missions under the sea, remotely operated vehicles or ROV's, allow scientists to study the ocean's depths by sending vehicles carrying cameras and special measuring devices. Scientists control them electronically with sophisticated operating systems (**Figure** 14.23).

Features of the Seafloor

Before scientists invented sonar, many people believed the ocean floor was a completely flat surface. Now we know that the seafloor is far from flat. In fact, the tallest mountains and

Figure 14.21: Submarines are built to withstand great pressure under the sea, up to 680 atmospheres of pressure (10,000 pounds per square inch). They still rarely dive below 400 meters. (25)

deepest canyons are found on the ocean floor; far taller and deeper than any landforms found on the continents. The same tectonic forces that create geographical features like volcanoes and mountains on land create similar features at the bottom of the oceans.

Look at (**Figure** 14.24). If you follow the ocean floor out from the beach at the top left, the seafloor gently slopes along the **continental shelf.** The sea floor then drops off steeply along the **continental slope,** the true edge of the continent. The smooth, flat regions that make up 40% of the ocean floor are the **abyssal plain.** Running through all the world's oceans is a continuous mountain range, called the **mid-ocean ridge** ("submarine ridge" in **Figure** 14.24). The mid-ocean ridge is formed where tectonic plates are moving apart from each other, allowing magma to seep out in the space where the plates pulled apart. The mid-ocean ridge system is 80,000 kilometers in total length and mostly underwater except for a few places like Iceland. Other underwater mountains include undersea volcanoes (called **seamounts**), which may rise more than 1,000 meters above the ocean floor. Those that reach the surface become volcanic islands, such as the Hawaiian Islands. Deep oceanic **trenches** are created where a tectonic plate dives beneath (subducts) another plate.

Resources From the Seafloor

The seafloor provides important living and non-living resources, which must be managed sustainably in order to maintain these resources. It is important for us to use the resources in a renewable way and to be careful not to contaminate the ocean because pollution affects the very resources that we need.

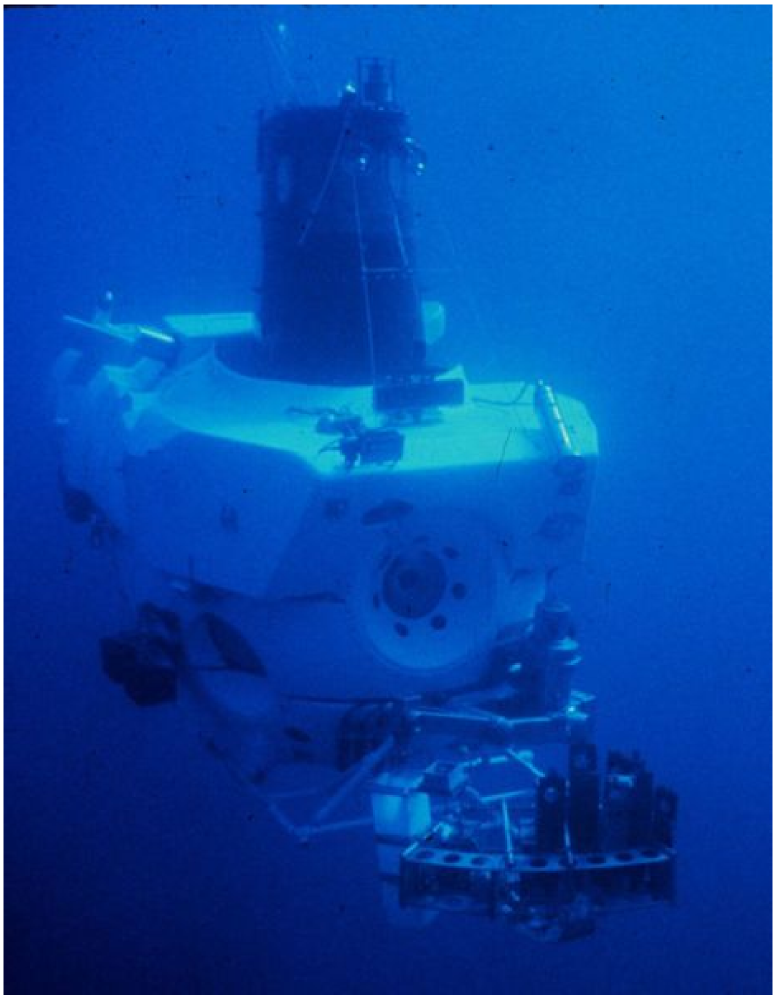

Figure 14.22: Alvin allows for a nine hour dive for up to two people and a pilot. It was commissioned in the 1960's. (8)

Figure 14.23: Remotely-operated vehicles like this one allow scientists to study the seafloor. (30)

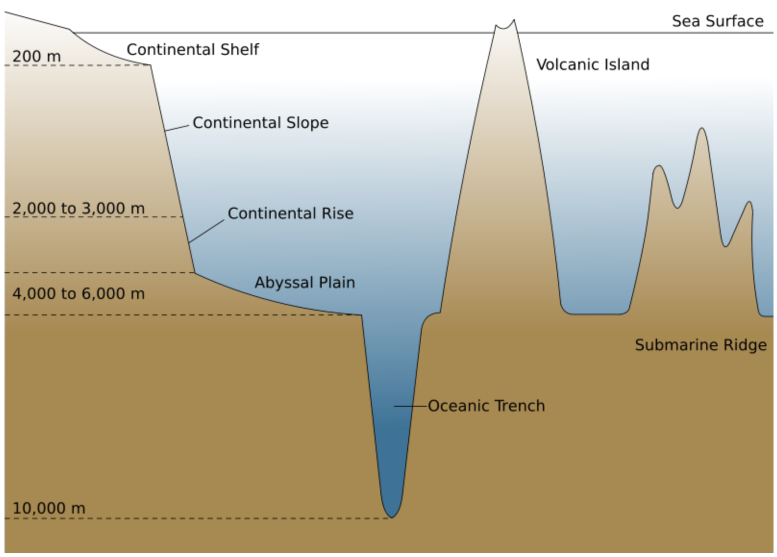

Figure 14.24: The seafloor is as varied a landscape as the continents. (4)

Living Resources

Although most fish are caught as they swim in the open waters of the ocean, **bottom trawling** is a method of fishing that involves towing a weighted net across the seafloor to harvest fish from the ocean floor. In many areas where bottom trawling is done, ecosystems are severely disturbed by the large nets and other fishing gear that people use. Many species of fish are being overharvested, which means their rate of reproduction cannot keep up with the rate at which people consume them. For this reason, a few areas in the world have laws that limit bottom trawling to waters not more than 1,000 meters deep or waters far from protected and sensitive areas. Still, recent reports on fishing resources tell us that urgent action is required to restore species of fish that have been taken in too great numbers.

The seafloor is home to many types of sea creatures, like clams, abalone, sea snails, and slugs. Some of these animals are used as food by people. Like the rich range of life in the rainforests, coral reefs in the ocean are sites of great biological diversity (**Figure** 14.25). Some of the organisms found in the ocean provide us with medications. The ocean floor also indirectly supports most life in the oceans, since upwelling currents bring important nutrients from the seafloor to plankton. These plankton in turn, provide food for most other creatures in the oceanic food web.

Figure 14.25: The seafloor in the coral reefs of Papua New Guinea is home to many important species. (33)

Non-living Resources

The most valuable non-living resources found in the ocean are oil and natural gas. Of course, these resources are below the seafloor, and require drilling to reach. Oil platforms can hosts dozens of oil wells that are drilled in places where the ocean is sometimes 2,000 meters deep (**Figure** 14.26). Working on oil platforms is dangerous for workers, who are exposed to harsh ocean conditions and gas explosions. Oil rigs also pose a threat to the ocean ecosystem, as a result of oil leaks and disruption of the natural environment.

Figure 14.26: Oil platforms like this one of the coast of the Gulf of Mexico can be fixed or they can float. They are generally used on the continental shelf but new technology allows them to be in deeper places. (5)

Many minerals are found on the ocean floor. They can form crystallized spheres called *nodules* that one day may be collected or mined from the bottom of the ocean (**Figure**

14.27). The nodules may be as small as a pea or as large as a basketball. Common mineral resources found in these nodules include manganese, iron, copper, nickel, phosphate, and cobalt. These minerals have many uses in the industrial world. It is estimated that there may be as much as 500 billion tons of nodules on the seafloor. Currently, there is not significant mineral mining on the seafloor, in part because of expense and concerns about how this mining would disrupt the seafloor.

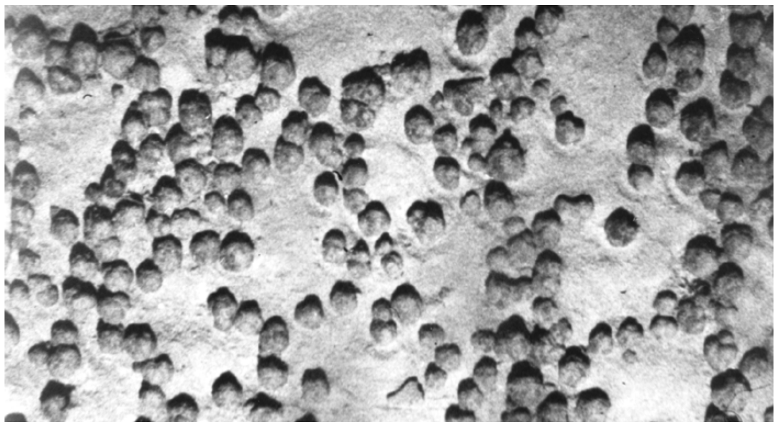

Figure 14.27: Manganese nodules from the seafloor are often rich in metals like manganese, iron, nickel, copper, and cobalt. (32)

Lesson Summary

- Until the development of sonar, we knew very little about the ocean floor.
- The deep ocean is dark, very cold and has tremendous pressure from the overlying water.
- Scuba divers can explore only to about 40 meters, while most submarines dive only to about 500 meters. Scientific research submersibles have explored the ocean's deepest trenches, but most are designed to reach only the ocean floor.
- Today much of our exploration of the oceans happens using sonar and remotely operated vehicles.
- Features of the ocean include the continental shelf, slope and rise. The ocean floor is called the abyssal plain. Below the ocean floor, there are a few small deeper areas called ocean trenches. Features rising up from the ocean floor include seamounts, volcanic islands and the mid-oceanic ridges and rises.
- The oceans provide us with both living and non-living resources.
- Living oceanic resources include fish that are harvested for food as well as the photosynthetic algae which begin the food chain in the surface waters of the ocean.
- Non-living resources include oil and natural gas found on our continental shelves and mineral resources like manganese nodules found on the deep ocean floor.

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Review Questions

1. What are three obstacles to studying the seafloor?
2. The atmospheric pressure is about 1 kilogram per centimeter squared (14.7 pounds per square inch or 1 atmosphere) at sea level. About what is the pressure if you are 100 meters deep in the ocean?
3. What invention gave people the ability to map the ocean floor?
4. Which parts of the ocean floor would you expect there to be the greatest amount of living organisms?
5. How much deeper did the Trieste submerge than Alvin?
6. Compare and contrast the continental shelf and the abyssal plain.
7. Why do you think mapping the seafloor is important to the Navy? Explain.
8. If the mid-ocean ridge is created where the tectonic plates separate, why is a mountain range formed there?
9. Why is bottom trawling damaging to the seafloor?
10. Many people rely on the ocean to live because it provides them with food or work. As the world population grows, the resources in the ocean are used more and more. What can we do to make sure that people use the resources in the ocean at a rate that can be replenished?
11. What is a mineral nodule?

Vocabulary

abyssal plain The flat bottom of the ocean floor; the deep ocean floor.

bottom trawling Fishing by dragging deep nets along the ocean floor, so that they gather up living creatures along the bottom of the ocean.

continental shelf The shallow, gradually sloping seabed around the edge of a continent. Usually less than 200 meters in depth. The continental shelf can be thought of as the submerged edge of a continent.

continental slope The sloped bottom of the ocean that extends from the continental shelf down to the deep ocean bottom.

mid ocean ridge Mountain range on the ocean floor where magma upwells and new ocean floor is formed.

seamount A mountain rising from the seafloor that does not reach above the surface of the water. Usually formed from volcanoes.

trench Deepest areas of the ocean; found where subduction takes place.

Points to Consider

- What types of organisms are found in the ocean?
- How does ocean life differ in different regions of the ocean?
- How do ocean organism interact?

14.4 Ocean Life

Lesson Objectives

- Describe the different types of ocean organisms.
- Describe the interactions among different ocean organisms.

Introduction

The ocean covers an area of about 361 million square kilometers, about 71% of the Earth. For that reason, it is a home to a large portion of all life on Earth. The life in the ocean includes many different species. Some species seem bizarre, others are enormous, some are delicious to eat, and others are dangerous. Living organisms can be found throughout the ocean, even in the most remote and harsh parts.

Types of Ocean Organisms

There is a great variety of ocean life that ranges from the smallest animals on Earth to the largest. Some of these organisms breathe air from the atmosphere, while others can extract oxygen from the water. There are those that mostly float on the surface and those found in the ocean's depths. Some animals eat other organisms, while other creatures generate food from sunlight. The abundance of life in the oceans can seem endless. However pollution, acidification of the oceans, and overfishing can greatly reduce the diversity and abundance of ocean life. By studying and understanding the creatures of the ocean, humans can better preserve these organisms. With this in mind, we'll learn about the life forms in the ocean by dividing them into seven basic groups.

Plankton

The most abundant life forms in the ocean are **plankton**; most are so small that you can't even see them (**Figure** 14.28). These include many types of algae, copepods, and jellyfish. Because exploring the oceans is much harder than studying the land, many marine organisms haven't been extensively studied by humans. Scientists believe many species of marine organisms haven't even been discovered yet. The plankton are one group of organisms that have been studied extensively. The word "plankton," which comes from the Greek for wanderer, describes how these organisms live. All plankton float freely or drift, wandering at the ocean's surface.

The first link in all marine food chains are the **phytoplankton**, or 'plant' plankton, which use sunlight to make sugars from carbon dioxide and water (photosynthesis). Because they need sunlight, they can only live in the photic zone. Through photosynthesis, phytoplankton make food for themselves and give off oxygen, which is a waste product for them but essential for all animals on Earth. Phytoplankton produce all the food at the bottom of the ocean food chain, so they are called primary producers. Most of the photosynthesis on Earth happens in the oceans and phytoplankton produce a large share of the oxygen in the air we breathe. **Zooplankton**, or animal plankton eat phytoplankton as their source of food. They can be found in all parts of the ocean.

Figure 14.28: Plankton are perhaps the most important part of the food chain because they supply food for most aquatic life. (23)

Plants and Algae

There are only a few true plants in the oceans; these include salt marsh grasses and mangrove trees. But large algae, or seaweed, also use photosynthesis to make food, just as plants do on land. These organisms have to live in the photic zone, because they require sunlight for photosynthesis. For that reason, most plants, seaweeds and algae in the ocean are found near the ocean surface or close to the shore. The large algae *kelp* grows in the neritic zone (**Figure** 14.29). Kelp tends to grow in forests, and can reach over 50 meters long. Kelp forests sustain an abundance of life, like the otter that lives in their swaying stems. It is thought that land plants adapted from ocean organisms some 500 million years ago.

Figure 14.29: Kelp is common off the shores of California. Kelp is a crucial organism in many food webs near the coast. (12)

Marine Invertebrates

The ocean includes a great variety of animals. One major group of animals is the **invertebrates**. Invertebrates are animals with no spinal column. Marine invertebrates include sea slugs, sea anemones, starfish, octopi, clams, sponges, sea worms, crabs and lobsters. Most of these animals are found close to the shore, but they can be found throughout the ocean. In fact, scientists were amazed to discover invertebrates that thrived in the deep ocean near hydrothermal(hot water) vents, including giant tube worms, crabs, and shrimps (**Figure** 14.30).

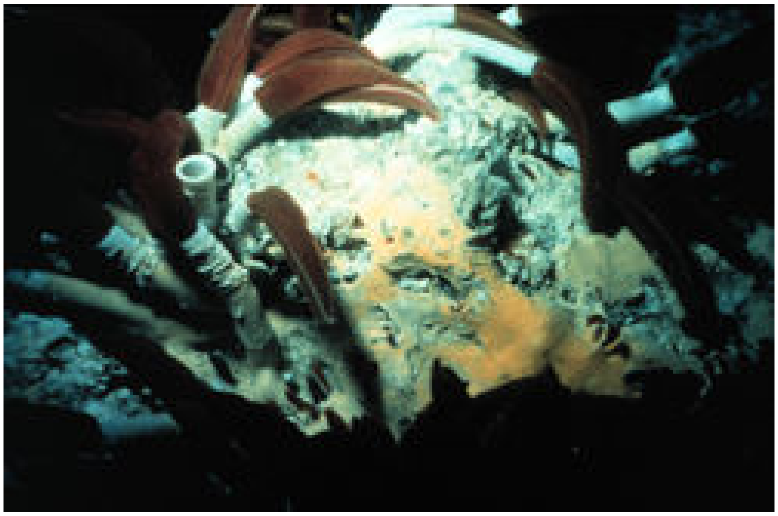

Figure 14.30: Giant tube worms have been found a mile deep in the ocean. They can grow up to 8 feet long and can withstand the very high water temperatures heated by hydrothermal vents. (3)

Fish

Like us, fish are **vertebrates** that have a spinal column and a hard skull. They are animals that have adapted to life in the water. Most fish are "cold-blooded" animals that have fins with which to move and steer, scales that protect them, gills with which to extract oxygen from the water, and a swim bladder that lets them float at particular depths within the ocean. Included among the fish are sardines, salmon, and eels, as well as the sharks and rays (which lack swim bladders)(**Figure** 14.31).

Reptiles

Reptiles are air-breathing, "cold-blooded" vertebrates. A few groups of reptiles have adapted to life at sea. These include sea turtles, sea snakes, a few saltwater crocodiles, and the marine

Figure 14.31: The Great White Shark is a fish that preys on other fish and marine mammals. (13)

iguana, which is found only at the Galapagos Islands (**Figure** 14.32). Most sea snakes bear live young in the ocean and do not need to come on land to breed. But turtles, crocodiles, and marine iguanas all lay their eggs on land, which makes both eggs and adults vulnerable to predation. For example, people use sea turtles or their eggs for food, for their shells, and for the medicinal purposes that some cultures believe they possess. Sea turtles are endangered species, so they are protected in many countries around the world.

Seabirds

Everybody loves penguins, a type of bird adapted to the sea (**Figure** 14.33). They do not fly; rather they are adapted to swimming and may spend half of their time at sea looking for food. There are many other kinds of seabirds, though, like gulls, gannets, pelicans, and petrels. Seabirds are adapted to catching fish by diving or by grabbing them at the surface with their claws.

Marine Mammals

Mammals are warm-blooded vertebrates that feed their young with milk. Most mammals have hair, ears, a jaw bone with teeth, and give birth to developed young. There are five types of marine mammals. The first type is termed Cetaceans which include whales, dolphins, and porpoises. The second type is called Sirenians which include the manatee and the dugong. Seals, sea lions, and walruses comprise the Pinniped group. Sea otters are the ocean members of the fourth group, the Mustelids, which also includes skunks, badgers and

Figure 14.32: Sea turtles are found all over the oceans, but their numbers are diminishing. (27)

weasels (**Figure** 14.34). The final type of ocean marine mammal is the polar bear, which depends heavily on the ocean for survival and is adapted to a life around the sea.

Interactions Among Ocean Organisms

To best understand how ocean organisms interact, it is necessary to consider the particular environments in which they live. There are four main ocean habitats: the intertidal zone and shore, reefs, the open ocean, and the deep sea including trenches. Most organisms have some adaptations specific to their preferred habitat.

A great abundance of life can be found in the intertidal zone. Many intertidal animals can live in or out of the water; some spend one part of their lives in the water and another out of the water. They must be adapted to frequent shifting of water levels and wave impacts. In response, many have hard shells and strong attachments that keep them safe. Some animals, like marine mussels, cling steadily to a rock for their entire lives (**Figure** 14.35). Many young organisms get their start in estuaries, which are special ecosystems affected by the tides, where freshwater and salt water come together.

Reefs are built up by corals and other animals that deposit the mineral calcium carbonate to make rock formations near the shore. They support a complex ecosystem of ocean organisms that live within the coral reef. These diverse organisms have complex interactions with one another; some species help each other to survive. When reefs are destroyed or polluted, certain species can be affected more than others. Harm to one species may have a *domino*

Figure 14.33: Many penguins live in and around Antarctica, but some penguins live farther north on islands such as the Galapagos Islands (near the Equator). The Southern Rockhopper Penguin lives in the Falkland Islands off the coast of Argentina, a long way from the ice. (21)

Figure 14.34: The sea otter is an marine mammal that depends on the ocean for survival. (16)

Figure 14.35: Marine mussels live in the intertidal zone. How are they adapted for life in the intertidal zone? (1)

effect on other species. This may cause the entire ecosystem to collapse. Coral reefs are particularly sensitive to certain threats like temperature change and oil spills.

The open ocean refers to the large open expanses of ocean water. This vast area is the primary habitat for relatively few animals. Most of the food in the ocean is found nearer to shore, so most of these animals are just passing through. Some larger animals like whales and giant groupers may live their entire lives in the open water.

As you know, scientists were surprised to find life in ocean trenches, the deepest parts of the ocean. How can animals survive at that depth? They have adapted to the resources available there, and some bacteria can even use inorganic compounds as energy sources instead of relying on the sun as a source of energy. This is called **chemosynthesis**. Shrimp, clams, fish, and giant tube worms have been found in these extreme places.

Still other animals can live on floating rafts of algae or in frozen places, like the North and South Poles. No matter where you might look in the grand ocean, some creature has found a way to live there. Almost all of these creatures depend on each other. Certainly all creatures depend on producers that convert sunlight into biomass. Our oceans are currently threatened by global warming, overuse and pollution. These imbalances in the ecosystems may someday devastate the delicate web of life on which humans depend.

Lesson Summaries

- Our oceans are home to a tremendous diversity of life including the very smallest bacteria to the very largest baleen whale.
- Some marine organisms float at the surface using the sun's energy, some exist at great ocean depths transforming chemicals in the water into food.
- Plankton are freely floating organisms that include the photosynthetic phytoplankton as well as the animals that eat them, the zooplankton.
- Virtually every phyla on Earth is represented in the ocean including invertebrate and vertebrate organisms, fish, reptiles, seabirds and even air breathing mammals.
- Many creatures in the ocean live in cooperation with other organisms, like coral animals that live symbiotically with dinoflagellates in their tissues.

Review Questions

1. What are seven categories of life in the ocean?
2. What does "invertebrate" mean?
3. What is the group of organisms are the primary producers in the ocean, on which all other life depends?
4. If fish require oxygen to live, why can't they survive on land?
5. Some people argue that polar bears are not really marine mammals because they don't live in the ocean itself. They would say polar bears are land animals like all other

bears. What is your opinion? Explain.
6. What are four major habitats of ocean organisms?
7. Describe adaptations that an organism that lives in a reef might have. How might these adaptations be different from an organism that lives in the open ocean?
8. Describe the importance of maintaining the ecosystem in the ocean.

Vocabulary

chemosynthesis Using inorganic compounds to produce food.

invertebrates Animals with no spinal column.

phytoplankton Plankton that can photosynthesize and therefore create oxygen and sugars.

plankton A diverse group of tiny animals and plants that freely drift in the water.

reef A large underwater structure created from the calcium carbonate skeletons of coral.

vertebrates Animals with a spinal column.

zooplankton Plankton that are tiny animals; they usually consume phytoplankton or other zooplankton as food.

Points to Consider

- How does the ocean interact with the atmosphere?
- How is energy transferred around the planet and how does this affect life on Earth?
- What does global warming mean for the oceans and how might this affect the entire globe?

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Chapter 15

Earth's Atmosphere

15.1 The Atmosphere

Lesson Objectives

- Describe the importance of the atmosphere to our planet and its life.
- Outline the role of the atmosphere in the water cycle.
- List the major components of the atmosphere and know their functions.
- Describe how atmospheric pressure changes with altitude.

Introduction

Earth's atmosphere is a thin blanket of gases and tiny particles—together called air. Without air, the Earth would just be another lifeless rock orbiting the Sun. Although we are rarely aware of it, air surrounds us. We are most aware of air when it moves, creating wind. Like all gases, air takes up space. These gases that make up our air are packed closer together near the Earth's surface than at higher elevations.

All living things need some of the gases in air for life support. In particular, all organisms rely on oxygen for respiration — even plants require oxygen to stay alive at night or when the Sun is obscured. Plants also require carbon dioxide in the air for photosynthesis. All weather happens in the atmosphere. The atmosphere has many other important roles as well. These include moderating Earth's temperatures and protecting living things from the Sun's most harmful rays.

Significance of the Atmosphere

Without the atmosphere, planet Earth would be much more like the Moon than like the planet we live on today. The Earth's atmosphere, along with the abundant liquid water on the Earth's surface, are keys to our planet's unique place in the solar system. Much of what makes Earth exceptional depends on the atmosphere. Let's consider some of the many reasons we are lucky to have an atmosphere.

Atmospheric Gases Are Indispensable for Life on Earth

Without the atmosphere, Earth would be lifeless. Carbon dioxide (CO_2) and oxygen (O_2) are the most important gases for living organisms. CO_2 is vital for use by plants in **photosynthesis**, in which plants use CO_2 and water to convert the Sun's energy into food energy. This food energy is in the form of the sugar glucose ($C_6H_{12}O_6$). Plants also produce O_2. Photosynthesis is responsible for nearly all of the oxygen currently found in the atmosphere.

The chemical reaction for photosynthesis is:

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

By creating oxygen and food, plants have made an environment that is favorable for animals. In **respiration**, animals use oxygen to convert sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

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

Notice that respiration looks like photosynthesis in reverse. In photosynthesis, CO_2 is converted to O_2 and in respiration, O_2 is converted to CO_2.

The Atmosphere is a Crucial Part of the Water Cycle

Water moves from the atmosphere onto the land, into soil, through organisms, to the oceans and back into the atmosphere in any order. This movement of water is called the water cycle or **hydrologic cycle** (**Figure** 15.1).

Water changes from a liquid to a gas by **evaporation**. **Water vapor** is the name for water when it is a gas. When the Sun's energy evaporates water from the ocean surface or from lakes, streams, or puddles on land, it becomes water vapor. The water vapor remains in the atmosphere until it **condenses** to become tiny droplets of liquid. The tiny droplets may come together to create **precipitation**, like rain and snow. Snow may become part of the ice in a glacier, where it may remain for hundreds or thousands of years. Eventually, the snow or ice will melt to form liquid water. A water droplet that falls as rain, could become part of a stream or a lake, or it could sink into the ground and become part of **groundwater**.

At the surface, the water will eventually undergo evaporation and reenter the atmosphere. If the water is taken up by a plant and then evaporates from the plant, the process is called **evapotranspiration**.

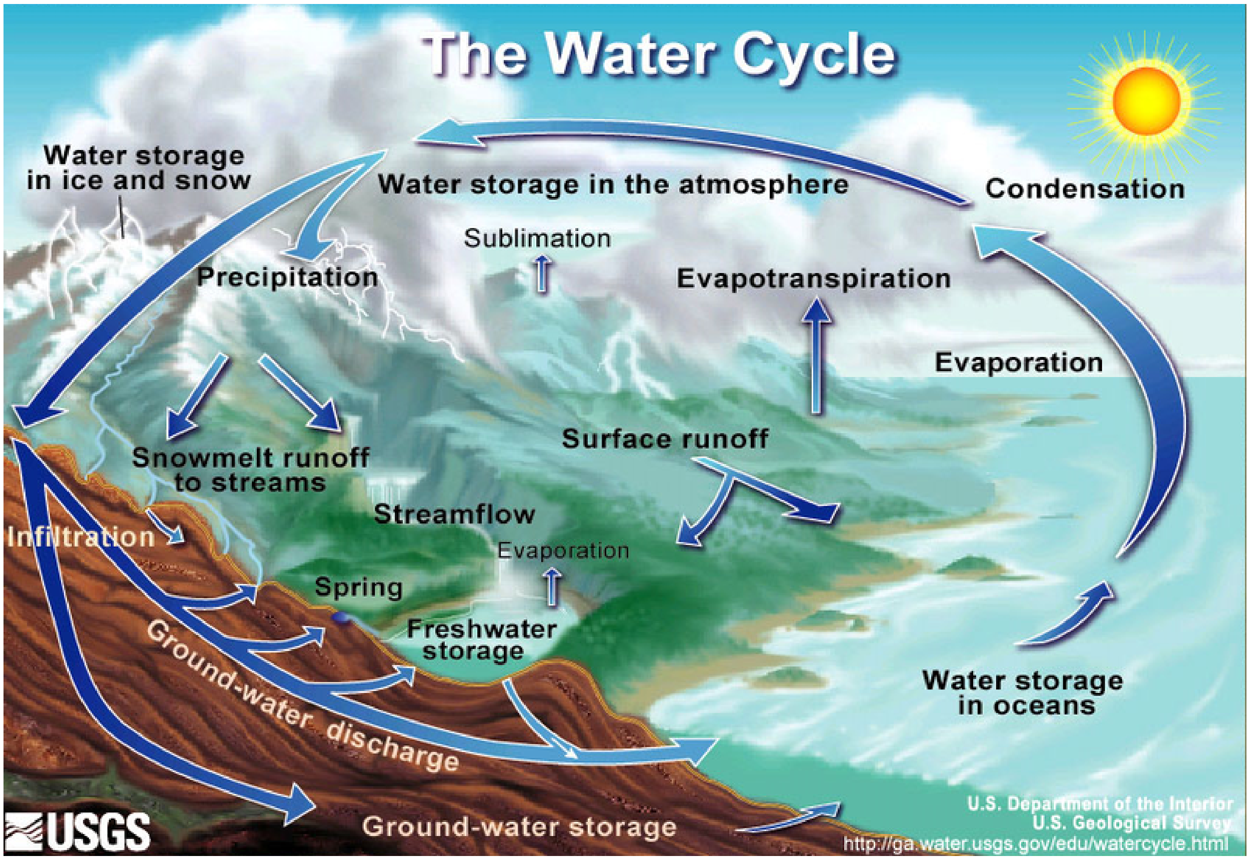

Figure 15.1: The Water Cycle. (20)

All **weather** takes place in the atmosphere, virtually all of it in the lower atmosphere. Weather describes what the atmosphere is like at a specific time and place, and may include temperature, wind and precipitation. It is the changes we experience from day to day. **Climate** is the long-term average of weather in a particular spot. Although the weather for a particular winter day in Tucson, Arizona may include snow, the climate of Tucson is generally warm and dry.

The physical and chemical changes that happen on Earth's surface due to precipitation, wind and reactions with the gases in our atmosphere are called **weathering**. Weathering alters rocks and minerals and shapes landforms at the Earth's surface. Without weathering, Earth's surface would not change much at all. For example, the Moon has no atmosphere, water or winds, so it does not have weathering. The footprints that astronauts made on the Moon decades ago will remain there until someone (human or alien) smooths them out! You would only need to spend a few minutes at the beach to know that Earth's surface is changing all the time.

Ozone in the Upper Atmosphere Makes Life on Earth Possible

Ozone is a molecule composed of three oxygen atoms, (O_3). Ozone in the upper atmosphere absorbs high energy **ultraviolet radiation** (UV) coming from the Sun. This protects living things on Earth's surface from the Sun's most harmful rays. Without ozone for protection, only the simplest life forms would be able to live on Earth.

The Atmosphere Keeps Earth's Temperature Moderate

Our atmosphere keeps Earth's temperatures within an acceptable range; the difference between the very coldest places on Earth and the very hottest is about 150°C (270°F). Without our atmosphere, Earth's temperatures would be frigid at night and scorching during the day. Our daily temperatures would resemble those seen on the Moon, where the temperature range is 310°C (560°F) because there is no atmosphere. **Greenhouse gases** trap heat in the atmosphere. Important greenhouse gases include carbon dioxide, methane, water vapor and ozone.

Atmospheric Gases Provide the Substance for Waves to Travel Through

The atmosphere is made of gases, mostly nitrogen and oxygen. Even though you can't see them, gases take up space and can transmit energy. Sound waves are among the types of energy that can travel though the atmosphere. Without an atmosphere, we could not hear a single sound. Earth would be as silent as outer space. Of course, no insect, bird or airplane would be able to fly since there would be no atmosphere to hold it up!

Composition of Air

Air is made almost entirely of two gases. The most common gas is nitrogen, and the second most common gas is oxygen (O_2). Nitrogen and oxygen together make up 99% of the planet's atmosphere. All other gases together make up the remaining 1%. Although each of these trace gases are only found in tiny quantities, many such as ozone, serve important roles for the planet and its life. One very important minor gas is carbon dioxide, CO_2, which is essential for photosynthesis and is also a very important greenhouse gas (**Table** (15.1).

Table 15.1: **Concentrations of Atmospheric Gases**

Gas	Symbol	Concentration (%)
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Neon	Ne	0.0018
Helium	He	0.0005
Hydrogen	H	0.00006
Xenon	Xe	0.000009
Water vapor	H_2O	0 to 4
Carbon dioxide	CO_2	0.038
Methane	CH_4	0.00017
Krypton	Kr	0.00011
Nitrous oxide	N_2O	0.00005
Ozone	O_3	0.000004
Particles (dust, soot)		0.000001
Chlorofluorocarbons (CFCs)		0.00000002

(*Source:* http://upload.wikimedia.org/wikipedia/commons/7/7a/Atmosphere_gas_proportions.svg, *License:* GNU-FDL)

In nature, air is never completely dry. Up to 4% of the volume of air can be water vapor. **Humidity** is the amount of water vapor in air. The humidity of the air varies from place to place and season to season. This fact is obvious if you compare a summer day in Atlanta,Georgia where humidity is very high, with a winter day in Phoenix, Arizona where humidity is very low. When the air is very humid, it feels heavy or sticky. Your hair might get really curly or frizzy when it is very humid outside. Most people feel more comfortable when the air is dry. The percentage of water vapor in our atmosphere is listed with a wide range of values in the table above because air can be both very humid or dry.

Argon, neon, helium, xenon, and krypton are **noble gases**. They are colorless, odorless, tasteless, and they do not become part of ordinary chemical reactions because they are chemically inert. The noble gases simply exist in the atmosphere.

Some of what is in the atmosphere is not a gas. Particles of dust, soil, fecal matter, metals, salt, smoke, ash and other solids make up a small percentage of the atmosphere. This percentage is variable, as anyone who has spent a windy day in the desert knows (**Figure** 15.2). Particles are important because they provide starting points (or nuclei) for water vapor to condense on, which then forms raindrops. Some particles are pollutants, which are discussed in the chapter on human actions and the atmosphere.

Figure 15.2: A dust storm in Al Asad, Iraq. (6)

Pressure and Density

The atmosphere has different properties at different elevations above sea level, or **altitudes**. The **density** of the atmosphere (the number of molecules in a given volume) decreases the higher you go. This is why explorers who climb tall mountains, like Mt. Everest, have to set up camp at different elevations to let their bodies get used to the changes. What the atmosphere is made of, or the composition of the first 100 kilometers of the atmosphere stays the same with altitude, with one exception: the ozone layer at about 20 - 40 kilometers above the Earth. In the ozone layer, there is a greater concentration of ozone than in other portions of the atmosphere (**Figure** 15.3).

The molecules in gases are able to move freely. If no force acted on a gas at all, it would just escape or spread out forever. Gravity pulls gas molecules in towards the Earth's surface, pulling stronger closer to sea level. This means that atmospheric gases are denser at sea level, where the gravitational pull is greater. Gases at sea level are also compressed by the weight of the atmosphere above them. The weight of the atmosphere on a person's shoulders is equal to more than one ton. The force of the air weighing down over a unit of area is known as its atmospheric pressure, or **air pressure**. People and animals are not crushed because molecules inside our bodies are pushing outward to compensate. Air pressure is felt from all directions, not just from above.

The atmosphere has lower atmospheric pressure and is less dense at higher altitudes. There is less pull from gravity and there is less gas to push down from above. Without as much weight above them, the gases expand, so the air is lighter. For each 6 km (3.7 mile) increase in altitude, the air pressure decreases by half. At 5,500 meters (18,000 feet) above sea level, the air pressure is just less than half of what it is at sea level. This means that the weight of the air on a person's shoulders at that altitude is only one-half ton. At a high enough

Figure 15.3: The difference in air pressure between 2,000 meters and sea level caused this bottle to collapse. The bottle was originally at higher elevation, where air pressure is lower. When it was brought down to sea level, the higher air pressure at sea level caused the bottle to collapse. (25)

altitude, there is no gas left. The density of the atmosphere at 30 km (19 miles) above sea level is only 1% that of sea level. By 700 km (435 miles) from the planet's surface, the air pressure is almost the same as that in the vacuum of deep space.

If your ears have ever 'popped,' you have experienced a change in air pressure. This occurs when you go up or down in altitude quickly, such as flying in an airplane or riding in a car as it goes up or down a mountain. Gas molecules are found inside and outside your ears. When you change altitude quickly, your inner ear keeps the density of molecules at the original altitude. The popping occurs when the air molecules inside your ear suddenly move through a small tube in your ear equalizing the pressure. This sudden rush of air is felt as a popping sensation.

Colder, drier places on Earth usually have higher air pressure, while warmer, more humid places usually have lower air pressure. This happens because large areas of air move up or down by convection. Air pressure also often changes over time, as low and high pressure systems change locations. These phenomena will be discussed when we learn about weather.

Lesson Summary

- Without its atmosphere, Earth would be a very different planet. Gases in the atmosphere allow plants to photosynthesize and animals and plants to engage in respiration.
- Water vapor, which is an atmospheric gas, is an essential part of the water cycle.
- All weather takes place in the atmosphere.
- While the amount of gases do not vary relative to each other in the atmosphere, there is one exception: the ozone layer. Ozone in the upper atmosphere protects life from the Sun's high energy ultraviolet radiation.
- Air pressure varies with altitude, temperature and location.

Review Questions

1. What gas is used and what gas is created during photosynthesis? What gas is used and what gas is created during respiration?
2. Describe two reasons why photosynthesis is important.
3. Briefly describe the movement of water through the water cycle.
4. What is evapotranspiration?
5. What will happen if the humidity of the atmosphere increases?
6. Is weathering more effective in a humid or a dry climate?
7. On an unusual February day in Portland, Oregon, the temperature is 18°C (65°F) and it is dry and sunny. The winter climate in Portland is usually chilly and rainy. How could you explain a warm, dry day in Portland in winter?
8. What important role do greenhouse gases play in the atmosphere?
9. Why do your ears pop when you are in an airplane and the plane descends for a

landing?

10. If air pressure at sea level is one ton and at 5,500 m (18,000 feet) is one-half ton, what is air pressure at 11,000 m (36,000 feet)?

Vocabulary

air pressure The force of air pressing on a given area.

altitude Distance above sea level.

climate The long-term average of weather.

condenses Changes state from a gas to a liquid; in the case of water, from water vapor to liquid water.

evaporation The change in state of a substance from a liquid to a gas; in the case of water, from liquid water to water vapor.

evapotranspiration Water loss by plants to the atmosphere.

greenhouse gases Gases that trap heat in the atmosphere; these include water vapor, carbon dioxide, methane and ozone.

groundwater Fresh water found beneath the ground surface.

humidity The amount of water vapor held in the air; usually refers to relative humidity, meaning the amount of water the air holds relative to the total amount it could hold.

noble gases Gases that usually do not react chemically and have no color, taste, or odor; these are helium, neon, argon, xenon and krypton.

ozone A molecule made of three oxygen atoms; ozone in the lower atmosphere is a pollutant, but in the upper atmosphere it filters out the sun's most harmful ultraviolet radiation.

photosynthesis The process in which plants produce simple sugars (food energy) from solar energy; the process of photosynthesis changes carbon dioxide to oxygen.

precipitation Condensed moisture including rain, sleet, hail, snow, frost or dew.

respiration The process in which animals and plants use oxygen and produce carbon dioxide; in respiration, organisms convert sugar into food energy they can use.

water vapor The gas form of water.

weather The temporary state of the atmosphere in a region; the weather in a location depends on the air temperature, humidity, precipitation, wind and other features of the atmosphere.

Points to Consider

- How would Earth be different if it did not have an atmosphere?
- What are the most important components of the atmosphere?
- How does the atmosphere vary with altitude?

15.2 Atmospheric Layers

Lesson Objectives

- List the major layers of the atmosphere and their temperatures.
- Discuss why all weather takes place in the troposphere.
- Discuss how the ozone layer protects the surface from harmful radiation.

Introduction

The atmosphere is layered, and these layers correspond with how the atmosphere's temperature changes with altitude. By understanding the way temperature changes with altitude, we can learn a lot about how the atmosphere works. For example, the reason that weather takes place in the lowest layer is that the Earth's surface is the atmosphere's primary heat source. Heating the lowest part of the atmosphere places warm air beneath colder air, an unstable situation that can produce violent weather. Interesting things happen higher in the atmosphere, like the beautiful aurora, which light up the sky with brilliant flashes, streaks and rolls of white or colored light.

Air Temperature

Warm air rises: that's a saying just about everyone has heard. But maybe not everyone knows why this is true. Gas molecules are free to move around, and the molecules can take up as much space as they need. When the molecules are cool, they are sluggish and do not move as much, so they do not take up as much space. When the molecules are warm, they move vigorously and take up more space. With the same number of molecules in this larger volume, the air is less dense and air pressure is lower. This warmer, lighter air is more buoyant than the cooler air above it, so it rises. The cooler air then sinks down, since it is more dense than the air beneath it. The rising of warmer air and sinking of cooler air is a very important concept for understanding the atmosphere.

As you learned in the previous section, the composition of gases is mostly the same throughout the first 100 km of our atmosphere. This means if we measure the percentages of different gases throughout the atmosphere, it will stay basically the same. However the density of the gases and the air pressure do change with altitude; they basically decrease with increasing altitude. The property that changes most strikingly with altitude is air temperature. Unlike the change in pressure and density, changes in air temperature are not regular. A change in temperature with distance is called a **temperature gradient**.

The atmosphere is divided into layers based on how the temperature in that layer changes with altitude, the layer's temperature gradient (**Figure** 15.4). The temperature gradient of each layer is different. In some layers, temperature increases with altitude and in others it decreases. The temperature gradient in each layer is determined by the heat source of the layer. The different temperature gradients in each of the four main layers create the thermal structure of the atmosphere.

There are several layers of the atmosphere. The first layer is the **troposphere**. It is the closest to the ground and is sometimes referred to as the lower atmosphere. The second layer is the **stratosphere**, and is sometimes referred to as the upper atmosphere. Most of the important processes of the atmosphere take place in one of these two layers.

Troposphere

About three-fourths of the gases of the atmosphere are found in the troposphere because gravity pulls most of the gases close to the Earth's surface. As with the rest of the atmosphere, 99% of the gases are nitrogen and oxygen.

The thickness of the troposphere varies around the planet. Near the equator, the troposphere is thicker than at the poles, since the spinning of the Earth tends to shift air towards the equator. The thickness of the troposphere also varies with season. The troposphere is thicker in the summer and thinner in the winter all around the planet. At the poles in winter, the atmosphere is uniformly very cold and the troposphere cannot be distinguished from other layers. The importance of this feature of the atmosphere will become clear when we learn about ozone depletion.

Earth's surface is a major source of heat for the troposphere. Where does the heat come from? Nearly all the heat comes from the sun, either directly or indirectly. Some incoming sunlight warms the gases in the atmosphere directly. But more sunlight strikes the Earth's

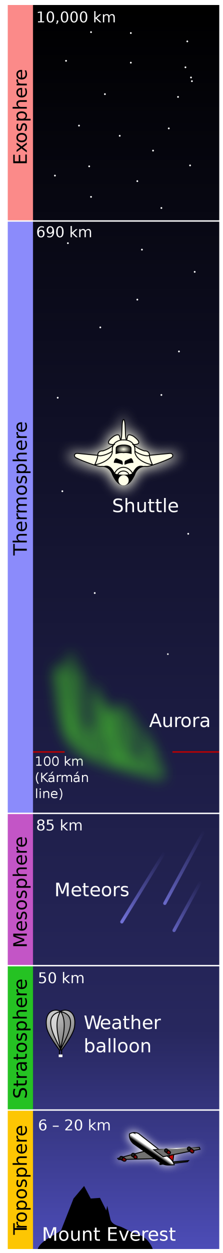

Figure 15.4: The layers of the atmosphere with altitude. (10)

rock, soil, and water, which radiate it back into the atmosphere as heat, further warming the troposphere. The temperature of the troposphere is highest near the surface of the Earth and declines with altitude. On average, the temperature gradient of the troposphere is 6.5°C per 1,000 m (3.6°F per 1,000 feet) of altitude.

Notice that in the troposphere, warm air is beneath cold air. Since warm air is less dense and tries to rise, this condition is unstable. So the warm air at the base of the troposphere rises and cool air higher in the troposphere sinks. For this reason, air in the troposphere does a lot of mixing. This mixing causes the temperature gradient to vary with time and place. For reasons that will be discussed in the next section, rising air cannot rise above the top of the troposphere. The rising and sinking of air in the troposphere means that all of the planet's weather takes place in the troposphere.

When there is a temperature **inversion**, air temperature in the troposphere *increases* with altitude and warm air sits over cold air. This is called an inversion because the usual situation is reversed or inverted. Inversions are very stable and they often last for several days or even weeks. Inversions commonly form over land at night or in winter. At these times, the ground is cold because there is little solar energy reaching it. At night, the Sun isn't out and in winter, the Sun is at a low angle, so little solar radiation reaches the ground. This cold ground cools the air that sits above it, making this low layer of air denser than the air above it. An inversion also forms on the coast where cold seawater cools the air above it. When that denser air moves inland, it slides beneath the warmer air over the land. Since temperature inversions are stable, they often trap pollutants and produce unhealthy air conditions in cities (**Figure** 15.5).

Figure 15.5: Smoke makes a temperature inversion visible. The smoke is trapped in cold dense air that lies beneath a cap of warmer air. (22)

At the top of the troposphere is a thin layer called the **tropopause**. Temperature in the tropopause does not change with height. This means that the cooler, denser air of the troposphere is trapped beneath the warmer, less dense air of the stratosphere. So the tropopause is a barrier that keeps air from moving from the troposphere to the stratosphere. Sometimes breaks are found in the tropopause and air from the troposphere and stratosphere can mix.

Stratosphere

The **stratosphere** rises above the tropopause. When a volcano erupts dust and gas that makes its way into the stratosphere, it remains suspended there for many years. This is because there is so little mixing between the stratosphere and troposphere. Pilots like to fly in the lower portions of the stratosphere because there is little air turbulence.

In the stratosphere, temperature increases with altitude. The reason is that the direct heat source for the stratosphere is the Sun. A layer of ozone molecules absorbs solar radiation, which heats the stratosphere. Unlike in the troposphere, air in the stratosphere is stable because warmer, less dense air sits over cooler, denser air. As a result, there is little mixing of air within the layer.

The stratosphere has the same composition of gases as the rest of the atmosphere, with the exception of the **ozone layer**. The ozone layer is found within the stratosphere at between 15 to 30 km (9 to 19 miles) altitude. The thickness of the ozone layer varies by the season and also by the latitude. The amount of ozone present in the ozone layer is tiny, only a few molecules per million air molecules. Still, the concentration of ozone is much greater than in the rest of the atmosphere. The ozone layer is extremely important because ozone gas in the stratosphere absorbs most of the Sun's harmful ultraviolet (UV) radiation.

How does ozone do this? High energy ultraviolet light, traveling through the ozone layer, breaks apart the ozone molecule, O_3 into one oxygen molecule (O_2) and one oxygen atom (O). This process absorbs the Sun's most harmful UV rays. Ozone is also reformed in the ozone layer: Oxygen atoms bond with O_2 molecules to make O_3. Under natural circumstances, the same amount of ozone is continually being created and destroyed and so the amount of ozone in the ozone layer remains the same.

The ozone layer is so effective that the highest energy ultraviolet, the UVC, does not reach the planet's surface at all. Some of the second highest energy ultraviolet, UVB, is stopped as well. The lowest energy ultraviolet, UVA, travels through the atmosphere to the ground. In this way, the ozone layer protects life on Earth. High energy ultraviolet light penetrates cells and damages DNA, leading to cell death (which we know as a bad sunburn). Organisms on Earth are not adapted to heavy UV exposure, which kills or damages them. Without the ozone layer to reflect UVC and UVB, most complex life on Earth would not survive long.

Above the stratosphere is the thin **stratopause**, which is the boundary between the stratosphere below and the mesosphere above. The stratopause is at about 50 km above the Earth's surface.

Mesosphere

Temperatures in the **mesosphere** decrease with altitude. Since there are very few gas molecules in the mesosphere to absorb the Sun's radiation, the heat source here is the stratosphere below. The mesosphere is extremely cold, especially at its top, about -90°C (-130°F).

The air in the mesosphere is extremely thin: 99.9% of the mass of the atmosphere is below the mesosphere. As a result, air pressure is very low. Although the amount of oxygen relative to other gases is the same as at sea level, there is very little gas and so very little oxygen. A person traveling through the mesosphere would experience severe burns from ultraviolet light since the ozone layer which provides UV protection is in the stratosphere below them. And there would be almost no oxygen for breathing! Stranger yet, an unprotected traveler's blood would boil at normal body temperature because the pressure is so low.

Despite the thin air, the mesosphere has enough gas that meteors burn as they enter the atmosphere (**Figure** 15.6). The gas causes friction with the descending meteor, producing its tail. Some people call them "shooting stars." Above the mesosphere is the **mesopause**. Astronauts are the only people who travel through the mesopause.

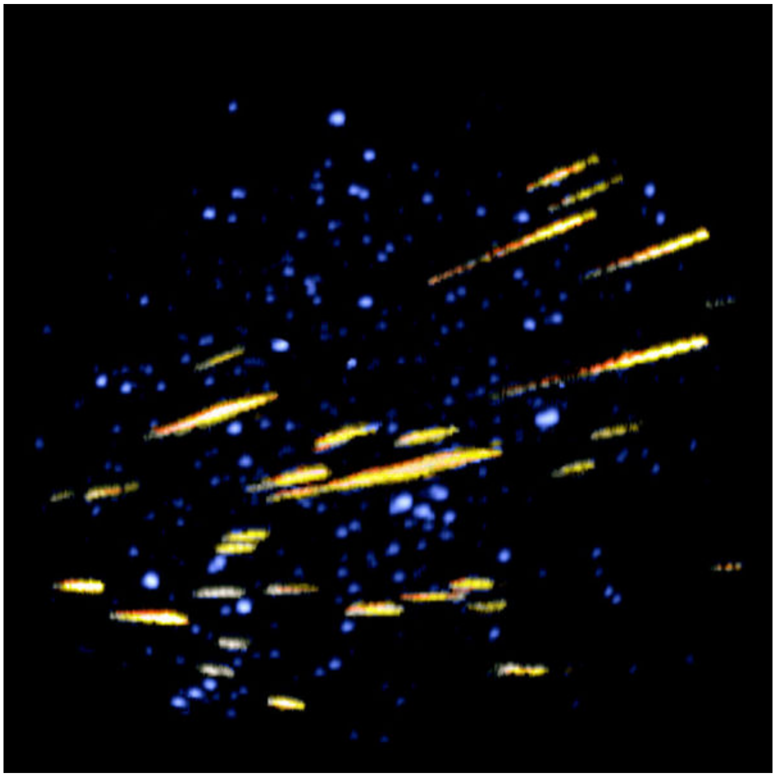

Figure 15.6: Meteors burn up as they hit the mesosphere. (23)

Thermosphere and Beyond

The **thermosphere** rises from the mesopause. The International Space Station (ISS) orbits within the upper part of the thermosphere, at about 320 to 380 km above the Earth (**Figure** 15.7).

Figure 15.7: The International Space Station. (18)

What does an astronaut experience in the thermosphere? Temperatures in the thermosphere can exceed 1000°C (1800°F) because oxygen molecules in the layer absorb short wavelength solar energy. Yet despite these high temperatures, the atmosphere outside the ISS feels cold. This is because gas molecules are so few and far between that they very rarely collide with other atoms and so little energy is transferred. The density of molecules is so low that one gas molecule can go about 1 km before it collides with another molecule.

Within the thermosphere is the **ionosphere**. The ionosphere gets its name because nitrogen and oxygen molecules are ionized by solar radiation. In the process of ionization, the neutrally-charged molecules absorb high-energy, short-wavelength energy from the Sun. This causes the molecules to lose one or more electrons and become positively-charged ions. The freed electrons travel within the ionosphere as electric currents. Because of the free ions, the ionosphere has many interesting characteristics.

Have you ever been out on an open road and found a radio station on the AM dial that is transmitted from hundreds of kilometers away? The reason radio waves can travel so far at night involves the ionosphere. During the day, the lower part of the ionosphere absorbs some of the energy from the radio waves and reflects some back to Earth. But at night the waves bounce off of the ionosphere, go back down to the ground, and then bounce back up again. This does not happen during the day due to ionization in the ionosphere. This bouncing up and down allows radio waves to travel long distances.

The most spectacular feature of the ionosphere is the nighttime **aurora**. Spectacular light displays with streamers, arcs, or foglike glows are visible on many nights in the polar regions. The lights can be white, green, blue, red or purple. The display is called the *aurora borealis* or northern lights in the Northern Hemisphere (**Figure** 15.8). It is called the *aurora australis* or southern lights in the Southern Hemisphere.

Figure 15.8: The Northern Lights above Bear Lake, Alaska. (7)

The aurora is caused by massive storms on the Sun that release great quantities of protons and electrons. These electrically charged particles fly through space and spiral in along lines of Earth's magnetic field. Earth's magnetic field guides the charged particles toward the poles, which explains why the auroras are seen primarily in the polar regions. When the protons and electrons enter the ionosphere, they energize oxygen and nitrogen gas molecules and cause them to light up. Each gas emits a particular color of light. Depending on where they are in the atmosphere, oxygen shines green or red and nitrogen shines red or blue. The frequency and intensity of the aurora increases when the Sun has more magnetic storms.

The outermost layer of the atmosphere is the **exosphere**. There is no real outer limit to the exosphere. If you continued traveling farther out from the Earth, the gas molecules would finally become so scarce that you would be in outer space. There is so little gravity holding gas molecules in the exosphere that they sometimes escape into outer space. Beyond the atmosphere is the **solar wind**. The solar wind is made of high-speed particles, mostly protons and electrons, traveling rapidly outward from the Sun.

Lesson Summary

- Different temperature gradients create different layers within the atmosphere. The lowest layer is the troposphere, where most of the atmospheric gases and all of the planet's weather are located.

- The troposphere gets its heat from the ground, and so temperature decreases with altitude. Warm air rises and cool air sinks and so the troposphere is unstable.
- In the stratosphere, temperature increases with altitude. The stratosphere contains the ozone layer, which protects the planet from the Sun's harmful UV. The higher layers contain few gas molecules and are very cold.

Review Questions

1. Why does warm air rise?
2. Why doesn't air temperature increase or decrease uniformly with altitude, just like air pressure decreases uniformly with altitude? Give examples of the different possible scenarios.
3. Where and when in the atmosphere is there no real layering at all? Why is this phenomenon important?
4. Describe how the ground acts as the heat source for the troposphere. What is the source of energy and what happens to that energy?
5. How stable is an inversion and why? How does an inversion form?
6. Why doesn't air from the troposphere and the stratosphere mix freely?
7. Where does the heat from the stratosphere come from and what is needed for that heat to be absorbed?
8. Describe the process of ozone creation and loss in the ozone layer. Under normal circumstances, does one occur more than the other?
9. How and where are 'shooting stars' created?
10. Why would an unprotected traveler's blood boil at normal body temperature in the mesosphere?

Further Reading / Supplemental Links

- http://www.youtube.com/watch?v=PaSFAbATPvk&feature=related

Vocabulary

aurora A spectacular light display that occurs in the ionosphere near the poles; called the aurora borealis or northern lights in the Northern Hemisphere, and the aurora australis or southern lights in the Southern Hemisphere.

exosphere The outermost layer of the atmosphere, where gas molecules are extremely far apart and some occasionally escape earth's gravity and fly off into outer space.

inversion A situation in the troposhere in which warm air lies above cold air.

ionosphere An ionized layer contained within the thermosphere; the second to the last layer of the atmosphere.

mesopause The thin transition layer in the atmosphere, the boundary between the mesosphere and the thermosphere.

mesosphere The layer of the atmosphere between the stratosphere and the thermosphere; temperature decreases with altitude.

ozone layer A layer of the stratosphere where ozone gas is more highly concentrated.

solar wind High-speed protons and electrons that fly through the solar system from the Sun.

stratopause The thin transitional layer of the atmosphere between the stratosphere and the mesosphere.

stratosphere The second layer of the atmosphere, where temperature increases with altitude due the presence of ozone.

temperature gradient The change in temperature with distance.

thermosphere The second to the last layer of the atmosphere where gases are extremely thinly distributed.

tropopause The thin transitional layer of the atmosphere between the troposphere and the stratosphere.

troposphere The lowermost layer of the atmosphere.

ultraviolet radiationn High energy radiation that comes from the Sun; there are three types of UV radiation, UVA, UVB and UVC. The shortest wavelength, and therefore the most dangerous, is UVC.

Points to Consider

- How does solar energy create the atmosphere's layers?
- How does solar energy create the weather?
- What would be the situation for life on Earth if there was less ozone in the ozone layer?

15.3 Energy in the Atmosphere

Lesson Objectives

- Describe how energy is transmitted.
- Describe the Earth's heat budget and what happens to the Sun's energy.
- Discuss the importance of convection in the atmosphere.
- Describe how a planet's heat budget can be balanced.
- Describe the greenhouse effect and why it is so important for life on Earth.

Introduction

Wind and precipitation, warming and cooling depend on how much energy is in the atmosphere and where that energy is located. Much more energy from the Sun reaches low latitudes (nearer the equator) than high latitudes (nearer the poles). These energy differences cause the winds, affect climate, and even drive ocean currents. Heat is held in the atmosphere by greenhouse gases.

Energy, Temperature, and Heat

Every material has **energy:** All the molecules within it vibrate. Gas molecules contain more energy than an equal number of liquid molecules (under the same temperature and pressure conditions) and move freely. Liquid molecules contain more energy than solids and move more freely than solids.

Energy travels through space or material. You know this because you can stand near a fire and feel the warmth. In this situation, energy is being transferred as invisible waves that can travel through air, glass, and even the vacuum of outer space. These waves have electrical and magnetic properties, so they are called **electromagnetic waves**. The transfer of energy from one object to another through electromagnetic waves is known as **radiation**. Different types of electromagnetic waves have different wavelengths. A wavelength is the horizontal distance from trough-to-trough or crest-to-crest of adjacent waves (**Figure** 15.9).

Humans are able to see some wavelengths of light, the wavelengths known as 'visible light.' These wavelengths appear to us as the colors of the rainbow (**Figure** 15.10). The longest wavelengths of visible light appear red and the shortest wavelengths appear violet. Wavelengths that are longer than visible red are infrared. Snakes can see infrared energy. We can record this with special equipment. Wavelengths that are shorter than violet are ultraviolet. Infrared and ultraviolet wavelengths of energy are just as important as the wavelengths in visible light; we just can't see them.

Some objects radiate electromagnetic waves in the visible light spectrum. Two familiar

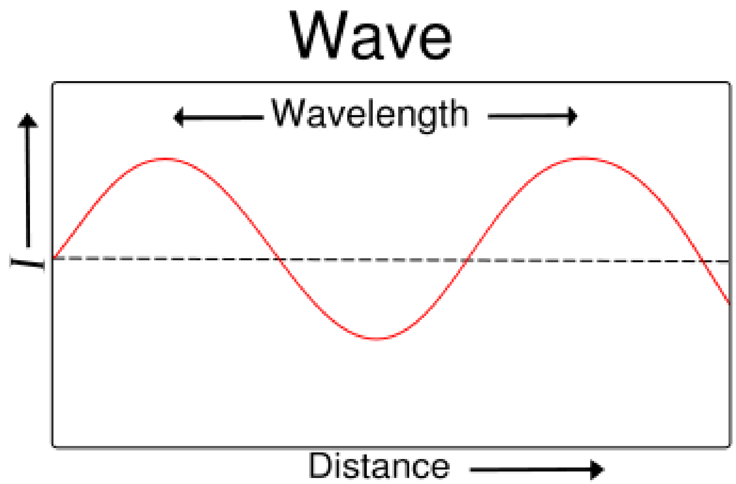

Figure 15.9: Waves. The high points are the crests, the low point is the trough. The wavelength is the distance from crest to crest. (27)

sources are the Sun and a light bulb. Some objects radiate electromagnetic waves at wavelengths that we cannot see. The glass of water sitting next to you does not radiate visible light, but it does radiate a tiny amount of heat.

You should be aware that some objects appear to radiate visible light, but they actually do not. The moon and the planets, for example, do not emit light of their own. They reflect the light of the Sun. **Reflection** is when light bounces back from a surface. **Albedo** is a measure of how well a surface reflects light. A surface that reflects a high percentage of the light that strikes it has high albedo and one that reflects a small percentage has low albedo.

One important fact to remember is that energy cannot be created or destroyed. It can only be changed from one form to another. In photosynthesis, for example, plants convert the Sun's energy into food energy. They do not create new energy. When energy is transformed, often some becomes heat. Heat transfers between materials easily, from warmer objects to cooler ones. If no more heat is added, eventually all of a material will reach the same temperature.

Temperature is a measure of how fast the atoms in a material are vibrating. High temperature particles vibrate faster than low temperature particles. Rapidly vibrating atoms smash together, which generates heat. As a material cools down, the atoms vibrate more slowly and collide less frequently. As a result, they emit less heat.

What is the difference between heat and temperature? Temperature measures how fast a material's atoms are vibrating. Heat measures the material's total energy. Think of a candle flame and a bathtub full of hot water. Which has a higher heat and which has a higher temperature? Surprisingly, the flame has a higher temperature, but much less heat because the hot region is very small. The bathtub has lower temperature but contains much more

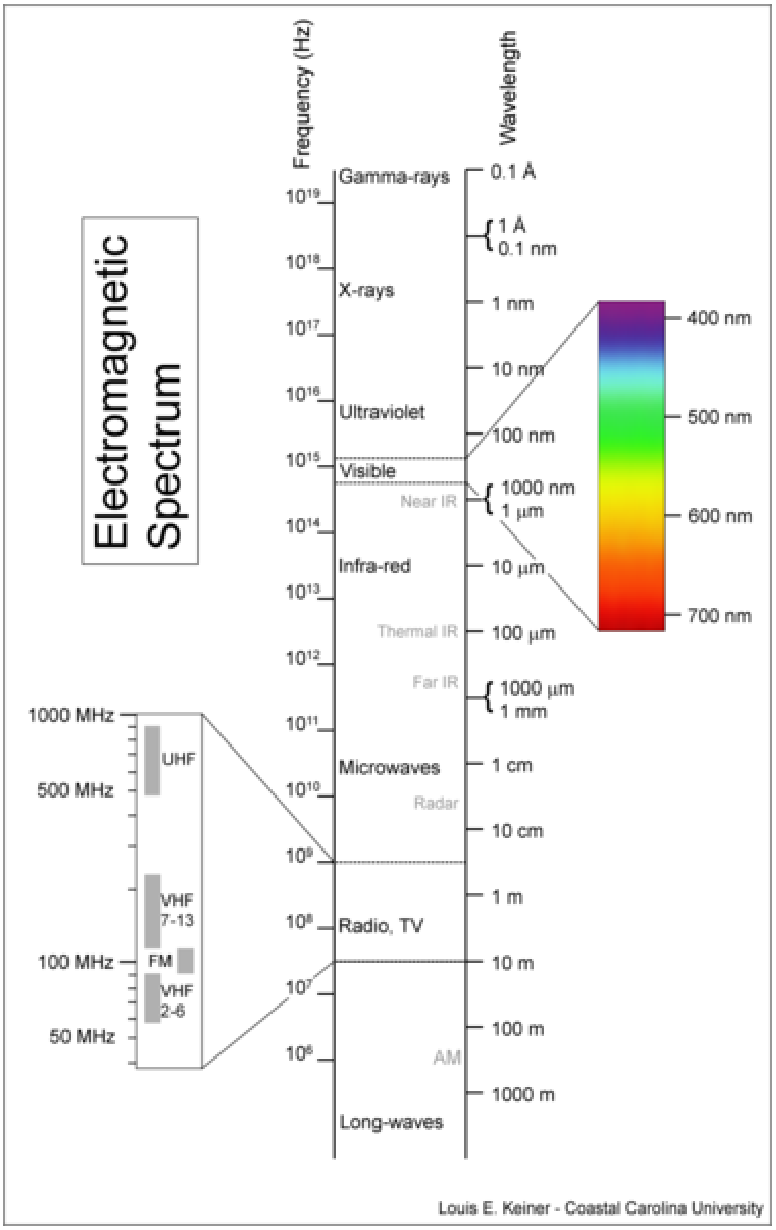

Figure 15.10: The electromagnetic spectrum showing the wavelengths of energy. Solar radiation that reaches the outer atmosphere includes radio waves, along with visible light plus the ultraviolet range nearest to violet and the near infrared. Other wavelengths of electromagnetic radiation are blocked by different parts of Earth's atmosphere. (2)

heat because it has many more vibrating atoms. Even though it's at a lower temperature, the bathtub has a greater total energy.

Heat is taken in or released when an object changes state, or changes from a gas to a liquid or a liquid to a solid. This heat is called **latent heat**. When a substance changes state, latent heat is released or absorbed. A substance that is changing its state of matter does not change temperature. All of the energy that is released or absorbed goes toward changing the material's state.

For example, imagine a pot of boiling water on the stove: that water is at 100ºC (212ºF). If a cook increases the temperature of the burner beneath the pot, more heat enters the water. But still the water remains at its boiling temperature. The additional energy goes into changing the water from liquid to gas. This allows the water to evaporate more rapidly. When water changes from a liquid to a gas it takes in heat. Since evaporation takes in heat, this is called evaporative cooling. Evaporative cooling is an inexpensive way to cool homes in hot, dry areas.

Substances also differ in their **specific heat,** the amount of energy needed to raise the temperature of one gram of the material by 1.0ºC (1.8ºF). Water has a very high specific heat, which means it takes a lot of energy to change the temperature of water. Let's compare a puddle and asphalt, for example. If you are walking barefoot on a sunny day, which would you rather walk across, the shallow puddle or an asphalt parking lot? Due to its high specific heat, the water stays cooler than the asphalt, even though it receives the same amount of solar radiation.

Energy From the Sun

Most of the energy that reaches the Earth's surface comes from the Sun. The Sun emits energy in a continuous stream of wavelengths (**Figure** 15.11). These wavelengths include visible light, infrared, ultraviolet radiation, and others. About 44% of solar radiation is in the visible light wavelengths. When viewed together, all of the wavelengths of visible light appear white. But a prism or water droplets, for example, can break the white light into different wavelengths so that you can see separate colors (**Figure** 15.12).

Only about 7% of solar radiation is in the ultraviolet (UV) wavelengths. Of the solar energy that reaches the outer atmosphere, UV wavelengths have the greatest energy. There are three types of UV energy: UVC has the shortest wavelengths and is the most energetic; UVA is the longest wavelengths and is the least energetic; and UBV is in the middle of the two. UV radiation will tan or burn human skin. The remaining solar radiation is the longest wavelength, infrared. Most objects radiate infrared energy, which we feel as heat (**Figure** 15.13).

Some of the wavelengths of solar radiation traveling through the atmosphere may be lost because they are absorbed by various gases (**Figure** 15.14). Ozone, for example, completely

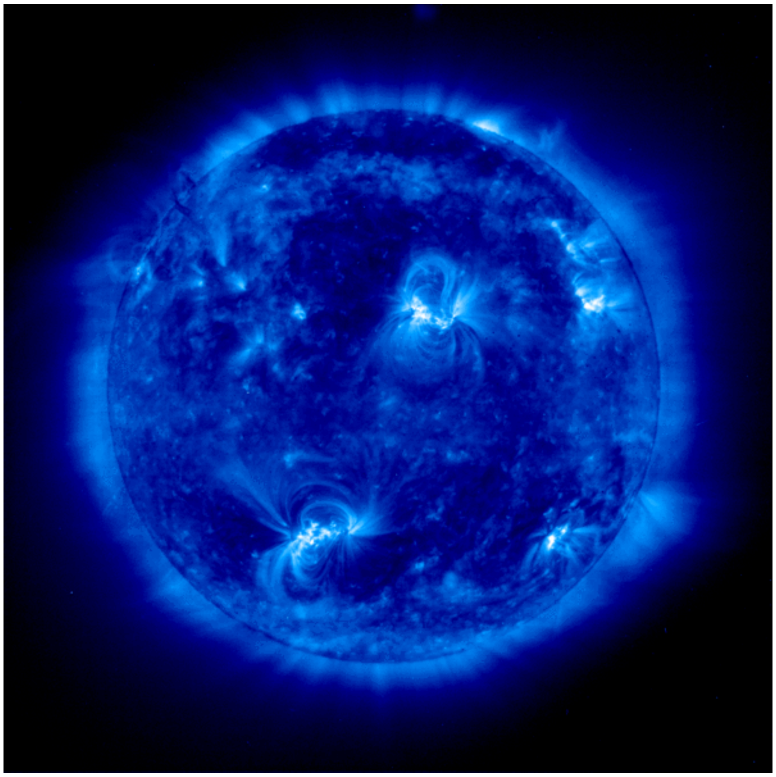

Figure 15.11: An image of the sun taken by the SOHO spacecraft. The sensor is picking up only the 17.1 nm wavelength, in the ultraviolet wavelengths. (9)

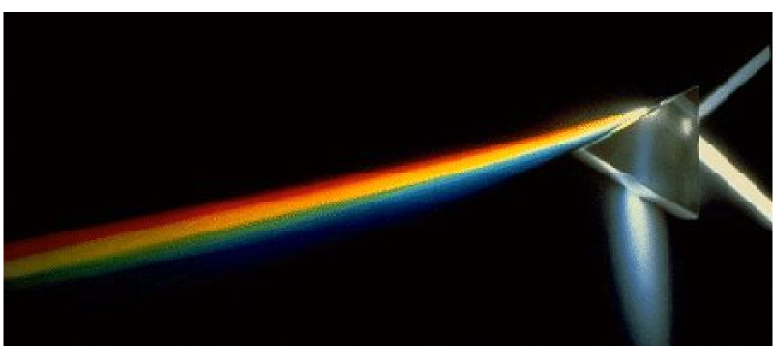

Figure 15.12: A prism breaks apart white light by wavelength so that you can see all the colors of the rainbow. (12)

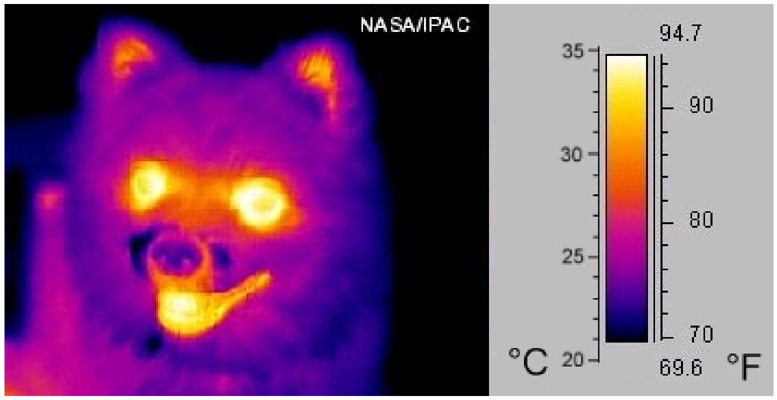

Figure 15.13: An image of a dog taken by an infrared sensor. The image shows the different amounts of heat radiating from the dog. (19)

removes UVC, most UVB and some UVA from incoming sunlight. O_2 , CO_2 and H_2O also filter out other wavelengths from solar energy.

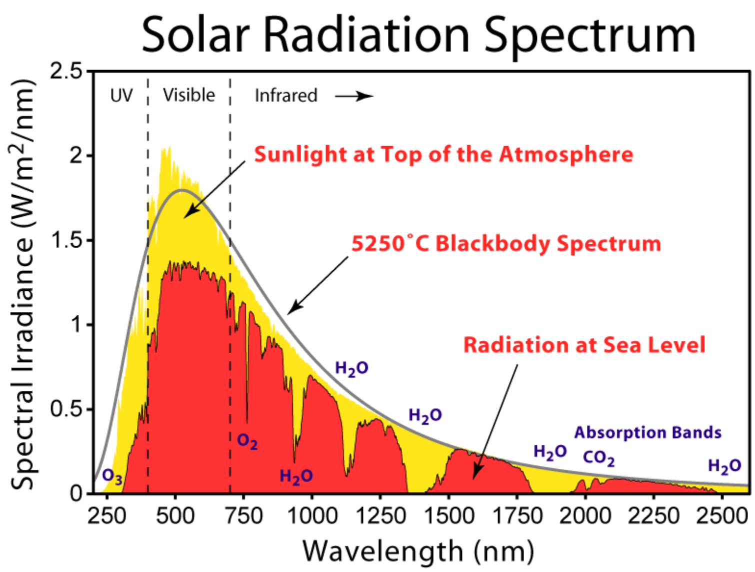

Figure 15.14: In the atmosphere, gases filter some wavelengths from incoming solar energy. The yellow field shows the wavelengths of energy that reach the top of the atmosphere. The red field shows the wavelengths that reach sea level. The amount of radiation is reduced overall as different gases filter out different wavelengths. Ozone filters out the shortest wavelength ultraviolet and oxygen filters out most infrared, at about 750 nm. (15)

Different parts of the Earth receive different amounts of solar radiation. This is because the Sun's rays strike the Earth's surface most directly at the equator. As you move away from the equator, you will notice that different areas also receive different amounts of sunlight in different seasons. But what causes the seasons?

The Earth revolves around the Sun once each year and spins on its axis of rotation once each day. This axis of rotation is tilted 23.5° relative to its plane of orbit around the Sun. The axis of rotation happens to be pointed to the star Polaris, or the North star. As the Earth orbits the Sun, the tilt of Earth's axis stays lined up with the North star. This means that the North Pole is tilted towards the Sun and the Sun's rays strike the Northern Hemisphere more directly in summer. At the summer solstice, June 21 or 22 of each year, the Sun's rays are hit the Earth most directly along the Tropic of Cancer. This is a circle of latitude exactly 23.5 ° north of the equator. When it is summer solstice in the Northern Hemisphere, it is winter solstice in the Southern Hemisphere. Winter solstice for the Northern Hemisphere happens on December 21 or 22. The tilt of Earth's axis points away from the sun in the winter and the Sun's rays strike most directly at the Tropic of Capricorn (**Figure** 15.15). The Tropic of Capricorn is a line of latitude exactly 23.5 ° south of the equator. The light from the Sun gets spread out over a larger area, so that area isn't heated as much. There are also fewer daylight hours in winter, so there is also less time for the Sun to warm that place. When it is winter in the Northern Hemisphere, it is summer in the Southern Hemisphere.

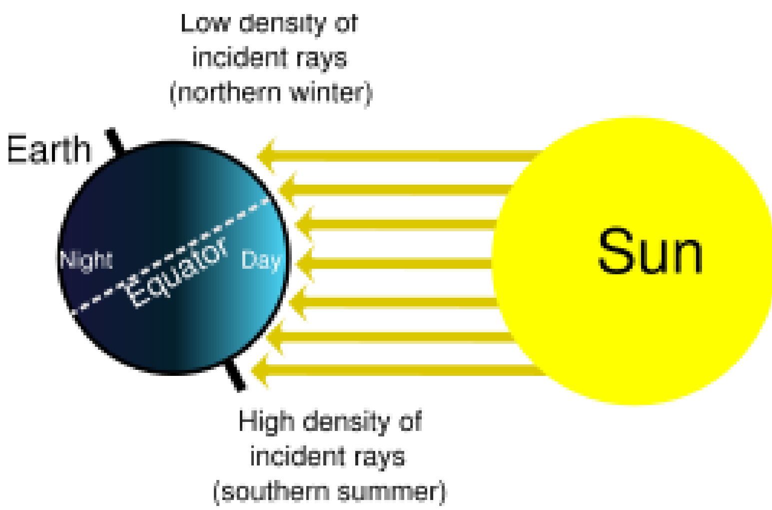

Figure 15.15: Arctic winter solstice. The sun's rays are directly overhead at the Tropic of Capricorn. Sunlight is striking the south pole, but it is spread out. No sunlight is getting to the North pole. (14)

Halfway between the two solstices, the Sun's rays shine most directly at the equator. We call these times an 'equinox' (**Figure** 15.16). The daylight and nighttime hours are exactly equal on an equinox. The autumnal equinox happens on September 22 or 23 and the *vernal* or spring equinox happens March 21 or 22 in the Northern Hemisphere. Thus the seasons are caused by the direction Earth's axis is pointing relative to the Sun.

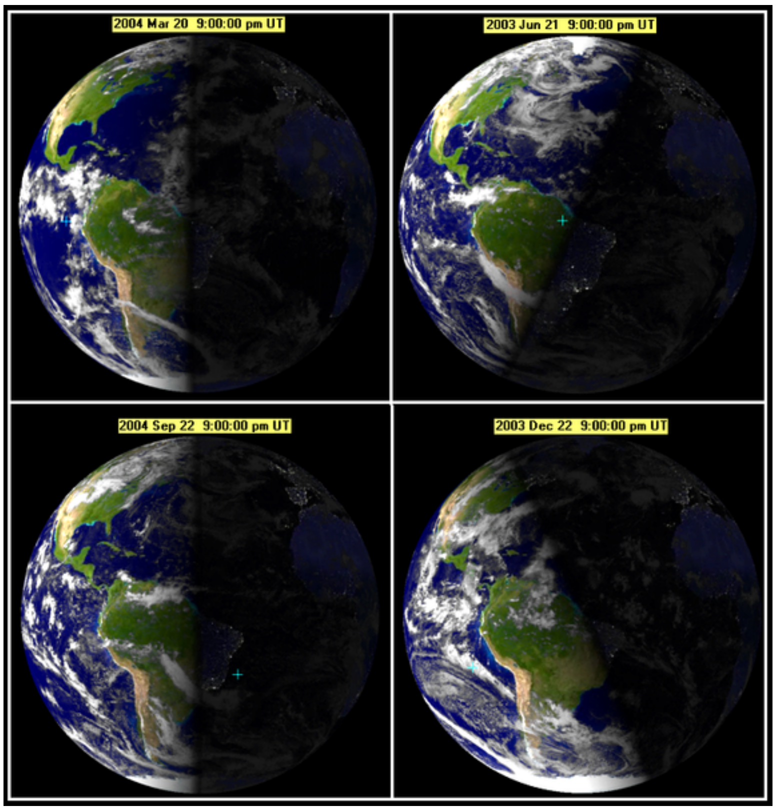

Figure 15.16: Where sunlight reaches on spring equinox, summer solstice, vernal equinox, and winter solstice. The time is 9:00 pm Universal Time, at Greenwich, England. (26)

Heat Transfer in the Atmosphere

Heat can move in three different ways. We've already examined radiation, in which electromagnetic waves transfer heat between two objects. **Conduction** is a type of heat transfer that occurs when heat moves from areas of more heat to areas of less heat by direct contact. Warmer molecules vibrate more rapidly than cooler molecules. They collide directly with other nearby molecules, giving them some of their energy, which transfers heat. When all the molecules are moving at the same rate, the substance is the same temperature throughout. Heat in the atmosphere is transferred by conduction. This is more effective at lower altitudes where air molecules are packed more densely together. Conduction can transfer heat upward to where the molecules are spread further apart. It can also transfer heat laterally from a warmer to a cooler spot, where the molecules are moving less vigorously.

The most important way heat is transferred in the atmosphere is by convection currents. Convection is the transfer of heat by movement of heated materials. The radiation of heat from the ground warms the air above it. This warmer air is less dense than the air above it and so it rises. As the heated air rises it begins to cool, since it is further from the heat source. As it cools, it contracts, becomes denser and sinks. Air moves horizontally between warm, rising air and cooler, sinking air. This entire structure is a **convection cell**.

Heat at Earth's Surface

Not all energy coming in from the Sun makes it to the Earth's surface. About half is filtered out by the atmosphere. Besides being absorbed by gases, energy is reflected by clouds or is scattered. Scattering occurs when a light wave strikes a particle and bounces off in some other direction. Of the energy that strikes the ground, about 3% is reflected back into the atmosphere. The rest warms the soil, rock or water that it reaches. Some of the absorbed energy radiates back into the air as heat. These infrared wavelengths can only be seen by infrared sensors.

It might occur to you that if solar energy continually enters the Earth's atmosphere and ground surface, then the planet must always be getting hotter. This is not true, because energy from the Earth escapes into space through the top of the atmosphere, just as energy from the Sun enters through the top of the atmosphere. If the amount that exits is equal to the amount that comes in, then there is no increase or decrease in average global temperature. This means that the planet's heat budget is in balance. If more energy comes in than goes out, the planet warms. If more energy goes out than comes in, the planet cools.

To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy varies at different latitudes (**Figure** 15.17). This is partly due to the seasons. At the equator, days are about the same length all year and the Sun is high in the sky. More sunlight hits the regions around the equator and air temperatures are warmer. At the poles, the Sun does not rise for months each year. Even when the Sun is out all day and night in the summer, it is at a very low angle in the sky. This means that not much solar radiation reaches the ground near the poles. Because of this, during a large part of the year, the polar areas are covered with ice and snow. These brilliant white substances have a high albedo and reflect solar energy back into the atmosphere. For all of these reasons, the region around the equator is much warmer than the areas at the poles.

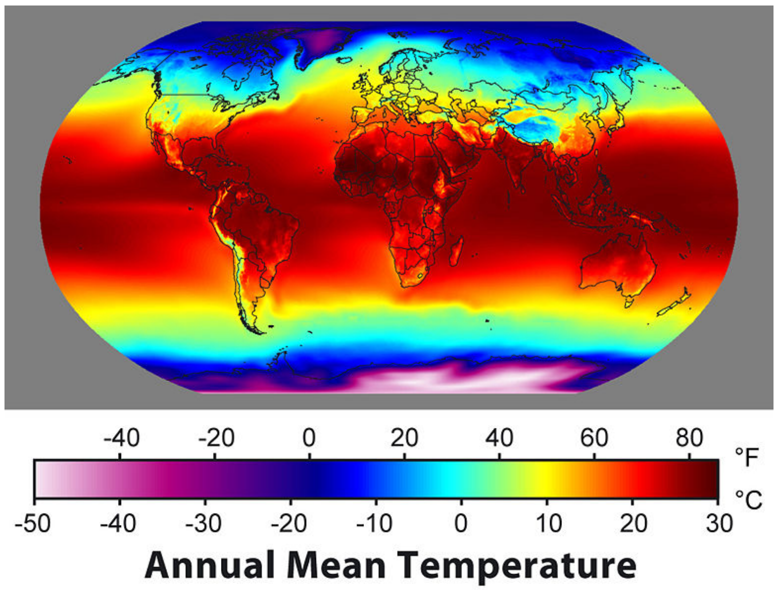

Figure 15.17: The average annual temperature of the Earth, showing that the equatorial region is much warmer than the polar regions. There is a roughly gradual temperature gradient from the low to the high latitudes. (4)

The difference in the amount of solar energy that the planet receives at different latitudes drives much of the activity that takes place at the Earth's surface. This includes the wind, water cycle, and ocean currents. The differences in solar energy around the globe drive the way the atmosphere circulates.

The Greenhouse Effect

The remaining factor in the Earth's heat budget s the role of greenhouse gases. Greenhouse gases warm the atmosphere by trapping heat. Sunlight strikes the ground, is converted to heat, and radiates back into the lower atmosphere. Some of the heat is trapped by greenhouse gases in the troposphere, and cannot exit into space. Like a blanket on a sleeping person, greenhouse gases act as **insulation** for the planet. The warming of the atmosphere due to insulation by greenhouse gases is called the **greenhouse effect** (**Figure** 15.18).

The greenhouse effect is very important, since without it the average temperature of the atmosphere would be about -18ºC (0ºF). With the greenhouse effect, the average temperature

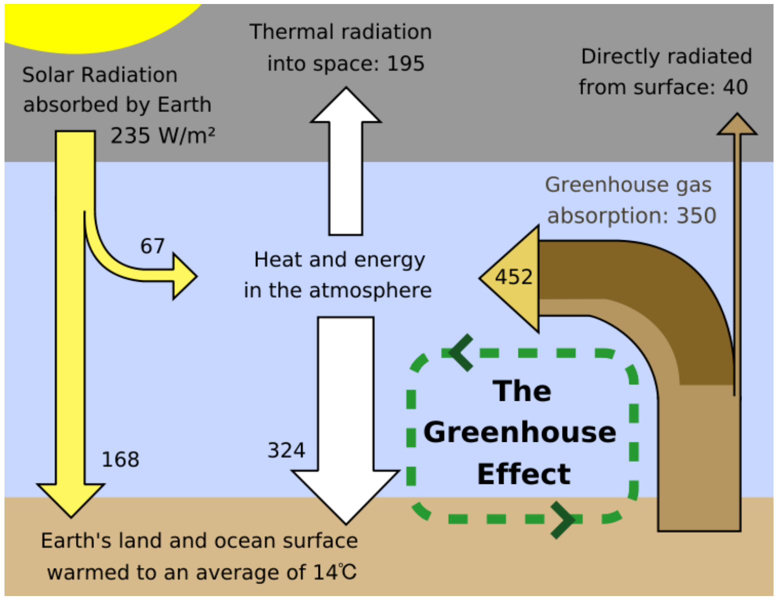

Figure 15.18: The Earth's heat budget, showing the amount of energy coming into and going out of the Earth system and the importance of the greenhouse effect. The numbers are the amount of energy that is found in one square meter of that location. (11)

of the atmosphere is a pleasant 15°C (59°F). Without insulation, daytime temperatures would be very high and nighttime temperatures would be extremely low. This is the situation on all of the planets and moons that have no atmosphere. If the Earth did not have insulation, temperatures would likely be too cold and too variable for complex life forms.

There are many important greenhouse gases in the atmosphere including CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All of these gases are a normal part of the atmosphere except CFCs, which are human-made. However, human activity has significantly raised the levels of many of these gases; for example, methane levels are about 2 1/2 times higher as a result of human activity. **Table** 15.2 shows how each greenhouse gas naturally enters the atmosphere.

Different greenhouse gases have different abilities to trap heat. For example, one methane molecule can trap 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) can trap 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere than the others.

Table 15.2:

Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels

Table 15.2: (continued)

Greenhouse Gas	Where It Comes From
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxides	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

The greenhouse effect is very important for another reason. If greenhouse gases in the atmosphere increase, they trap more heat and warm the atmosphere. If greenhouse gases in the atmosphere decrease, less heat is trapped and the atmosphere cools. The increase or decrease of greenhouse gases in the atmosphere affect climate and weather the world over.

Lesson Summary

- All materials contain energy, which can radiate through space as electromagnetic waves. The wavelengths of energy that come from the Sun include visible light, which appears white but can be broken up into many colors.
- Ultraviolet waves are very high energy. The highest energy UV, UVC and some UVB, gets filtered out of incoming sunlight by ozone.
- More solar energy reaches the low latitudes and the redistribution of heat by convection drives the planet's air currents.

Review Questions

1. What is the difference between temperature and heat?
2. Give a complete description of these three categories of energy relative to each other in terms of their wavelengths and energy: infrared, visible light, and ultraviolet.
3. Why do the polar regions have high albedo?
4. Give an example of the saying "energy can't be created or destroyed.
5. Describe what happens to the temperature of a pot of water and to the state of the water as the dial on the stove is changed from no heat to the highest heat.
6. Describe where the Sun is relative to the Earth on summer solstice, autumnal equinox, winter solstice and spring equinox. How much sunlight is the North pole getting on June 21? How much is the South pole getting on that same day?
7. What is the difference between conduction and convection?
8. What is a planet's heat budget? Is Earth's heat budget balanced or not?
9. On a map of average annual temperature, why are the lower latitudes so much warmer than the higher latitudes?

10. Why is carbon dioxide the most important greenhouse gas?
11. How does the amount of greenhouse gases in the atmosphere affect the atmosphere's temperature?

Vocabulary

albedo The amount of light that reflects back off a surface; snow and ice have high albedo.

conduction Heat transfer between molecules in motion.

convection Heat transfer by the movement of currents.

convection cell A heat transfer unit in which warm material rises, cold material sinks, and material moves between the two to create a cell.

electromagnetic waves Radiation travels in electromagnetic waves; waves that have both electrical and magnetic properties.

energy The ability to work; energy is not created or destroyed but can be transferred from one form to another.

greenhouse effect The trapping of heat that is radiated out from the planet's surface by greenhouse gases in the atmosphere and moderates a planet's temperatures.

insulation A material that inhibits heat or electricity conduction so that the insulated object stays at its current temperature for longer.

latent heat The energy taken in or released as a substance changes state from solid to liquid or liquid to gas.

radiation The movement of energy through a material or through space, as carried by electromagnetic waves.

reflection The return of a wave from a surface, such as a light wave from a mirror.

specific heat The amount of energy needed to raise the temperature of 1 gram of material by 1°C (1.8°F).

Points to Consider

- How does the difference in solar radiation that reaches the lower and upper latitudes explain the way the atmosphere circulates?
- How does the atmosphere protect life on Earth from harmful radiation and from extreme temperatures?
- What would the consequences be if the Earth's overall heat budget were not balanced?

15.4 Air Movement

Lesson Objectives

- List the parts of an atmospheric convection cell and the properties of the air currents within it.
- Describe how high and low pressure cells create local winds and explain how several types of local winds form.
- Discuss how global convection cells lead to the global wind belts.

Preview Questions

1. How do high and low pressure zones determine where winds blow?
2. How are land and sea breezes related to monsoon winds?
3. What determines the directions in which the global wind belts blow?

Introduction

Knowing a few basic principles can give a person a good understanding of how and why air moves. Warm air rises, creating a low pressure region, and cool air sinks, creating a high pressure zone. Air flowing from areas of high pressure to low pressure creates winds. Air moving at the bases of the three major convection cells in each hemisphere north and south of the equator creates the global wind belts.

Air Pressure and Winds

Think back to what you learned about convection cells in the previous lesson. Warm air rises, creating an upward-flowing limb of a convection cell (**Figure** 15.19). Upward flowing air lowers the air pressure of the area, forming a **low pressure zone.** The rising air sucks in air from the surrounding area, creating wind.

Figure 15.19: Papers being held up by rising air currents above a furnace demonstrate the important principle that warm air rises. (16)

At the top of the troposphere, the air travels horizontally from a high pressure zone to a low pressure zone. Since it is at the top of the troposphere, the air cools as it moves. This cold, dense air creates the downward flowing limb of the convection cell. Where the sinking air strikes the ground, air pressure is relatively high. This creates a **high pressure zone**. The sinking air is relatively cool, since it has traveled across the tropopause.

Air that moves horizontally between high and low pressure cells makes wind. The winds will race from the high to low zones if the pressure difference between them is large. If the difference is smaller, the winds will be slower.

Convection in the atmosphere creates the planet's weather. It's important to know that warm air can hold more moisture than cold air. When warm air near the ground rises in a low pressure zone, it cools. If the air is humid, it may not be able to hold all the water it contains as vapor. Some water vapor may condense to form clouds or even precipitation. Where cooler air descends at a high pressure zone, it warms. Since it can then hold more moisture, the descending air will evaporate water on the ground.

Air moving between large high and low pressure systems creates the global wind belts that profoundly affect regional climate. Smaller pressure systems create localized winds that affect the weather and climate of a local area.

Local Winds

Local winds are created when air moves from small high pressure systems to small low pressure systems. High and low pressure cells are created by a variety of conditions. Some of these winds have very important effects on the weather and climate of some regions.

Land and Sea Breezes

You learned that water has a very high specific heat: it maintains its temperature well. This means that water heats and cools more slowly than land. Sometimes there is a large temperature difference between the surface of the sea (or a large lake) and the land next to it. This temperature difference causes small high and low pressure regions to form, which creates local winds.

In the summer, and to a lesser degree in the day, a low pressure cell forms over the warm land and a high pressure cell forms over the cooler ocean. During warm summer afternoons, winds called **sea breezes** blow from the cooler ocean over the warmer land (**Figure** 15.20). Sea breezes often have a speed of about 10 to 20 km (6 to 12 miles) per hour and can lower air temperature much as 5 to 10°C (9 to 18°F). The effect of land and sea breezes is felt only about 50 to 100 km (30 to 60 miles) inland.

The opposite occurs in the winter, the land is colder than the nearby water due to its lower specific heat. The cold land cools the air above it. This causes the air to become dense and sink, which creates a high pressure cell. Meanwhile, the warmer ocean warms the air above it and creates a low pressure cell. This occurs to a smaller degree at night, since land cools off faster than the ocean. Winds called **land breezes** blow from the high to the low pressure cell. These local winds blow from the cooler land to the warmer ocean. Some warmer air from the ocean rises and then sinks on land, causing the temperature over the land to become warmer.

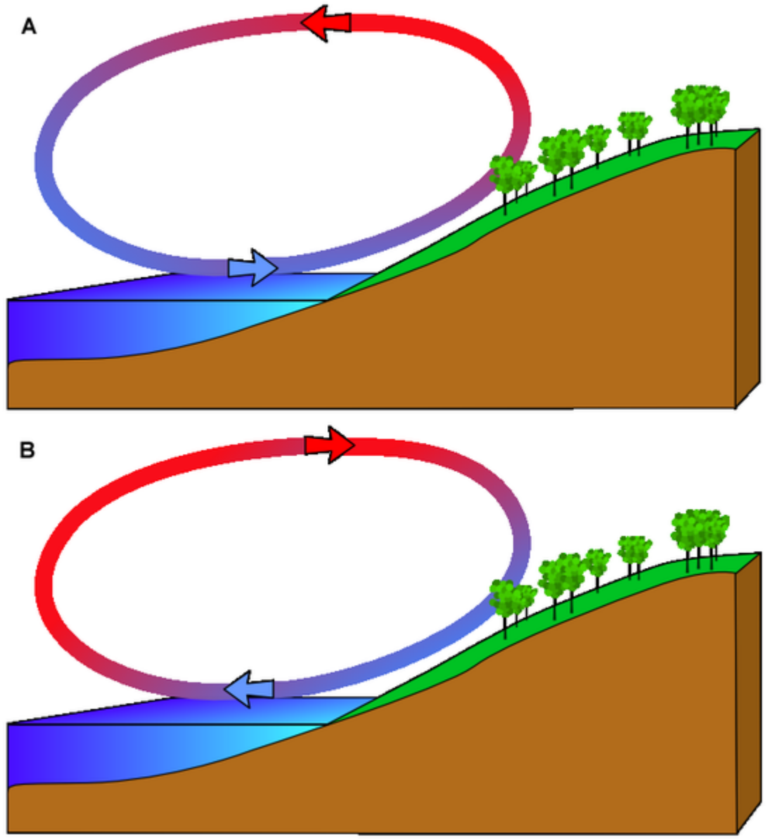

Figure 15.20: Sea and land breezes. (A) Sea breezes blow from the cooler sea to the warmer land. This cools the land near shore in summer and in the daytime and moderates coastal temperatures. (B) Land breezes blow from the cooler land to the warmer sea. This warms the land near shore in winter and at night and moderates coastal temperatures. (21)

Land and sea breezes are very important because they moderate coastal climates. In the hot summer, sea breezes cool the coastal area. In the cold winter, land breezes blow cold air seaward. These breezes moderate coastal temperatures. Land and sea breezes create the pleasant climate for which Southern California is known.

Monsoon Winds

Monsoon winds are larger scale versions of land and sea breezes; they blow from the sea onto the land in summer and from the land onto the sea in winter. Monsoon winds are incredibly strong because they occur in coastal areas with extremely high summer temperatures. Monsoons are common wherever very hot summer lands are next to the sea. The southwestern United States has summer monsoon rains when relatively cool moist air sucked in from the Gulf of Mexico and the Gulf of California meets air that has been heated by scorching desert temperatures (**Figure** 15.21).

Figure 15.21: The Arizona summer monsoon. (5)

The most important monsoon in the world occurs each year over the Indian subcontinent. More than two billion residents of India and southeastern Asia depend on monsoon rains for their drinking and irrigation water. In the summer, air over the Indian subcontinent becomes extremely hot, so it rises. Warm, humid air from the northern Indian Ocean enters the region, and it too is heated and rises. As the rising wet air cools, it drops heavy monsoon rains. In the winter, cool air from over the land moves seaward. Back in the days of sailing ships, seasonal shifts in the monsoon winds carried goods back and forth between India and Africa.

Mountain and Valley Breezes

Temperature differences between mountains and valleys create mountain and valley breezes. During the day, air on mountain slopes is heated more than air at the same elevation over an adjacent valley. As the day progresses, warm air rises off the slopes and draws the cool air up from the valley. This uphill airflow is called a **valley breeze.** When the Sun goes down, the mountain slopes cool more quickly than the air in the nearby valley. This cool air sinks, which causes a **mountain breeze** to flow downhill.

Katabatic Winds

Katabatic winds also move up and down slopes, but they are stronger mountain and valley breezes. Katabatic winds form over a high land area, such as on a high plateau. The plateau is usually surrounded on almost all sides by mountains. In winter, the plateau grows cold, making the air above it extremely cold. This dense air sinks down from the plateau through gaps in the mountains. Wind speeds depend on the difference in air pressure over the plateau and over the surroundings. If a storm, which has low pressure, forms outside the plateau, there is a big difference in wind pressure and the winds will race rapidly downslope. Katabatic winds form over many continental areas. Extremely cold katabatic winds blow over Antarctica and Greenland.

Foehn Wind (Chinook Winds)

Foehn winds or **Chinook winds** develop when air is forced up over a mountain range. This takes place, for example, when the westerly winds bring air from the Pacific Ocean over the Sierra Nevada Mountains in California. As the relatively warm, moist air rises over the windward side of the mountains, it cools and contracts. If the air is humid, it may form clouds and drop rain or snow. When the air sinks on the leeward side of the mountains, it forms a high pressure zone. The windward side of a mountain range is the side that receives the wind; the leeward side is the side where air sinks.

The descending air warms and creates very strong, dry winds. Foehn winds can raise temperatures more than 20°C (36°F) in an hour and cause humidity to decrease. If there is snow on the leeward side of the mountain, it may disappear by quickly melting and evaporating in the dry winds. If precipitation falls as the air rises over the mountains, the air will be very dry as it sinks on the leeward size of the mountains. This dry, sinking air causes a **rainshadow effect** (**Figure** 15.22). Many deserts are found on the leeward side of mountains due to rainshadow effect.

The name of these winds is a bit confusing. Some people refer to all of these winds as Foehn winds, others as Chinook winds, and still others as orogenic winds. The names Foehn and Chinook are sometimes used for any of these types of winds, but are also used regionally. Foehn winds are found in the European Alps, and Chinook winds are found in the Rocky Mountains of North America. Although the description is apt, Chinook does not mean “snow eater”.

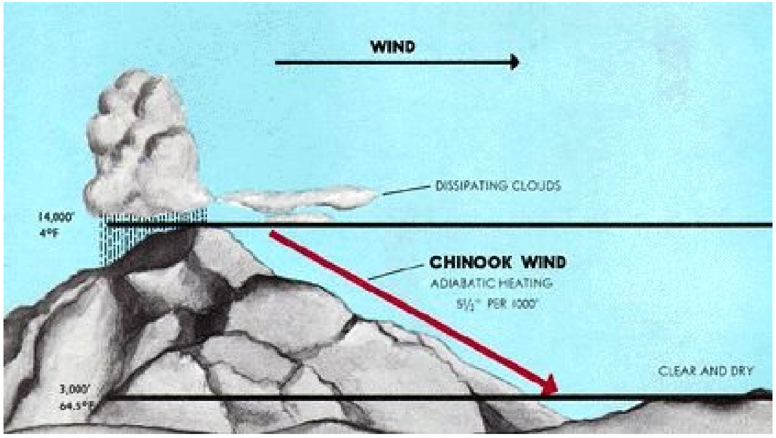

Figure 15.22: Air cools and loses moisture as it rises over a mountain. It descends on the leeward side and warms by compression. The resulting warm and dry winds are Foehn winds or Chinook winds. If the air loses precipitation over the mountain, the leeward side of the mountain will be dry, experiencing rainshadow effect. (13)

Santa Ana Winds

"Deadly" is a term often used to describe the **Santa Ana winds** in Southern California (**Figure** 15.23). These winds are created in the late fall and winter when the Great Basin east of the Sierra Nevada cools. The high pressure is created when the Great Basin cools forces winds downhill and in a clockwise direction. The air sinks rapidly, so that its pressure rises. At the same time, the air's temperature rises and its humidity falls. The winds blow across the Southwestern deserts and then race downhill and westward toward the ocean. Air is forced through canyons cutting the San Gabriel and San Bernadino mountains. The winds are especially fast through Santa Ana Canyon, which gives them their name.

The Santa Ana winds often arrive at the end of California's long summer drought season. The hot dry winds dry out the landscape even more. If a fire starts, it can spread quickly, causing large-scale devastation. In late October 2007, Santa Ana winds fueled many fires that together burned 426,000 acres of wild land and more than 1500 homes (**Figure** 15.24). The 2003 Santa Ana winds contributed to the loss of 721,791 acres to wild fires.

Desert Winds

The image of a lonely traveler battling a dust storm in the desert is one most people have seen, at least in cartoon form. Desert winds pick up dust because there is not as much vegetation to hold down the dirt and sand. Hot winds blow across many deserts and most are given local names. Across the Sahara there are winds known as leveche, sirocco and sharav.

Figure 15.23: Santa Ana winds blow dust and smoke westward over the Pacific from Southern California. (3)

Figure 15.24: The Harris Fire burning downward on Mount Miguel, San Diego County on October 23, 2007. The fire is being pushed along by Santa Ana winds. (1)

High summer temperatures on the desert create high winds, which are often associated with monsoon storms. A **haboob** forms in the downdrafts on the front of a thunderstorm (**Figure** 15.25). Air spins and lifts dust and sand into a cloud of dirt that may include dust devils or tornadoes. Haboobs cause many sandstorms.

Figure 15.25: A haboob in the Phoenix metropolitan area, Arizona. (24)

Dust devils, also called whirlwinds, may also form on hot, clear desert days. The ground becomes so hot that the air above it heats and rises. Air flows into the low pressure and begins to spin. Dust devils are small and short-lived but they may cause damage.

Atmospheric Circulation

You have already learned that more solar energy hits the equator than the polar areas. The excess heat forms a low pressure cell at the equator. Warm air rises to the top of the troposphere where half of the warmed air moves toward the North Pole and half toward the South Pole. The air cools as it rises and moves along the top of the troposphere. When the cooled air reaches a high pressure zone, it sinks. Back on the ground, the air then travels toward the low pressure at the equator. The air rising at the low pressure zone at the equator and sinking at a high pressure in the direction of the North or South Pole creates a convection cell.

If the Earth was just a ball in space and did not rotate, there would be only one low pressure zone and it would be at the equator. There would also be one high pressure at each pole. This would create one convection cell in the northern hemisphere and one in the southern. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the Coriolis Effect must be taken into account.

The **Coriolis Effect** causes freely moving objects to appear to move right in the Northern

Hemisphere and to the left in the Southern Hemisphere. The objects themselves are actually moving straight, but the Earth is rotating beneath them, so they seem to bend or curve. An example might make the Coriolis Effect easier to visualize. If an airplane flies 500 miles due north, it will not arrive at the city that was due north of it when it began its journey. Over the time it takes for the airplane to fly 500 miles, that city moved, along with the Earth it sits on. The airplane will therefore arrive at a city to the west of the original city (in the Northern Hemisphere), unless the pilot has compensated for the change.

A common misconception of the Coriolis Effect is that water going down a drain rotates one way in the Northern Hemisphere and the other way in the Southern Hemisphere. This is not true because in a small container like a toilet bowl, other factors are more important. These factors include the shape of the bowl and the direction the water was moving when it first entered the bowl.

But on the scale of the atmosphere and oceans, the Coriolis Effect is very important. Let's look at atmospheric circulation in the Northern Hemisphere as a result of the Coriolis Effect (**Figure** 15.26). Air rises at the equator as described above. But as the air moves toward the pole at the top of the troposphere, it deflects to the right. (Remember that it just appears to deflect to the right because the ground beneath it moves.) At about 30ºN latitude, the air from the equator meets relatively cool air flowing toward the equator from the higher latitudes. This air is cool because it has come from higher latitudes. Both batches of air descend, creating a high pressure cell. Once on the ground, the air returns to the equator. This convection cell is called the Hadley Cell and is found between 0º and 30ºN.

There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30ºN and 50º to 60ºN. This cell shares its southern, descending side with the Hadley cell to its south. Its northern rising limb is shared with the Polar cell located between 50ºN to 60ºN and the North Pole, where cold air descends.

There are three mirror image circulation cells in the Southern Hemisphere. In that hemisphere, the Coriolis effect makes objects appear to deflect to the left.

Global Wind Belts

Global winds blow in belts encircling the planet. The global wind belts are enormous and the winds are relatively steady (**Figure** 15.27). We will be able to figure out how the wind in these belts blows using the information you just learned about atmospheric circulation.

In between each convection cell, where air moves vertically, there is little wind. But where air moves horizontally along the ground between the high and low pressure zones, steady winds form. The air movement of each large circulation cell creates the major wind belts. The wind belts are named for the directions from which the winds come. The westerly winds, for example, blow from west to east. Some names remain from the days when sailing ships depended on wind for their power.

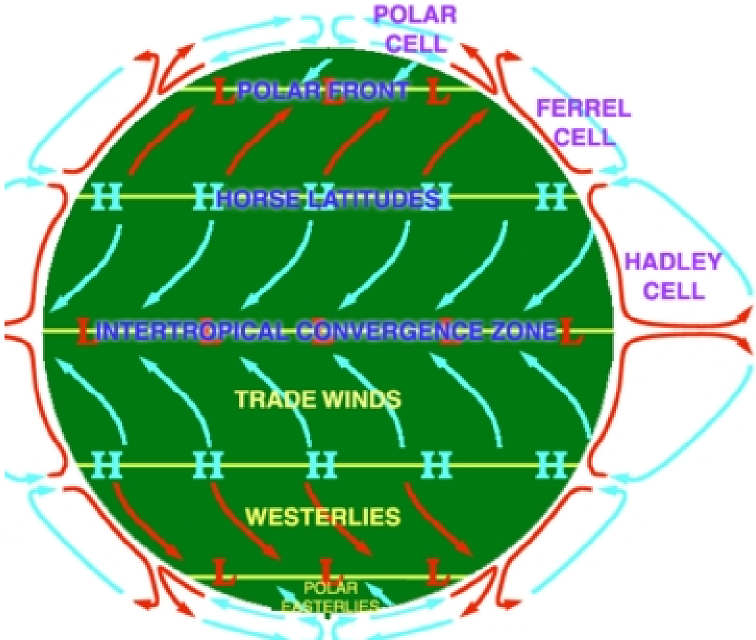

Figure 15.26: The atmospheric circulation cells, showing direction of winds at Earth's surface. (8)

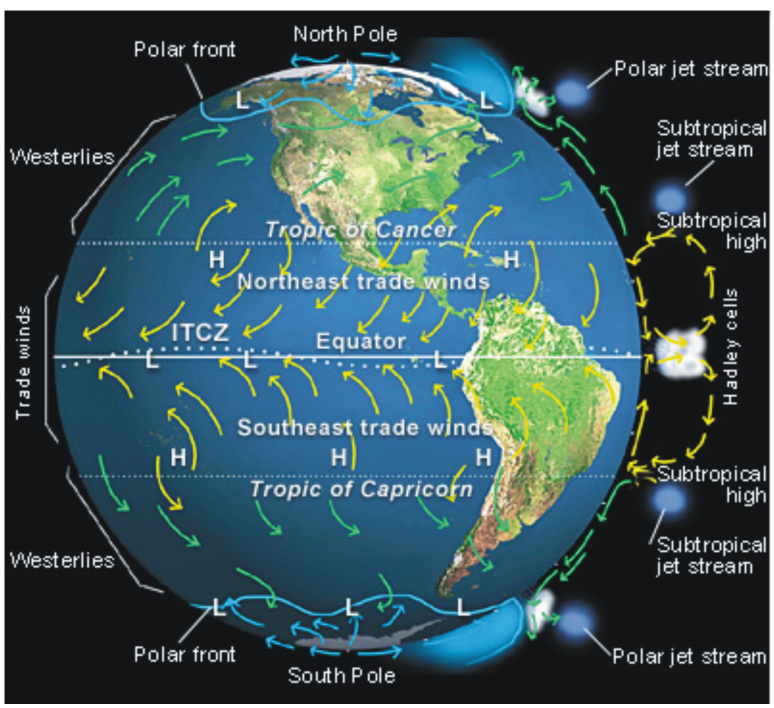

Figure 15.27: The major wind belts and the directions that they blow. (17)

Let's look at the global wind belts at the Earth's surface in the Northern Hemisphere. In the Hadley cell, air moves north to south, but is deflected to the right by the Coriolis Effect. These winds therefore blow from the northeast to the southwest. They are called the *trade winds* because at the time of sailing ships they were good for trade. Winds in the Ferrel cell blow from the southwest and are called the westerly winds or *westerlies.* The westerlies are the reason a flight across the United States from San Francisco to New York City takes less time than the reverse trip. On the outbound flight, the airplane is being pushed along by the westerlies, but on the reverse trip the airplane must fight against the air currents. In the Polar cell, the winds travel from the northeast and are called the *polar easterlies.* These names hold for the winds in the wind belts of the Southern Hemisphere as well.

The usual pattern of atmospheric circulation cells and the global wind belts determine normal global climate, but many other factors come into play locally. The high and low pressure areas created by the six atmospheric circulation cells generally determine the amount of precipitation a region receives. In low pressure regions, where air is rising, rain is common. In high pressure cells, the sinking air causes evaporation and the region is usually dry. More specific climate affects will be described in the chapter about climate.

The junction between the Ferrell and Polar cells is a low pressure zone. At this location, relatively warm, moist air that has circulated from the equator meets relatively cold, dry air that has come from the pole. The result is a place of extremely variable weather, known as the **polar front**. This weather is typical of much of North America and Europe.

The polar jet stream is found high up in the atmosphere where the two cells come together. A **jet stream** is a fast-flowing river of air at the boundary between the troposphere and the stratosphere. A jet stream can flow faster than 185 km/hr (115 mi/hr) and be thousands of kilometers long and a few hundred kilometers in width, but only a few kilometers thick. Jet streams form where there is a large temperature difference between two air masses. This explains why the polar jet stream is the world's most powerful.

Jet streams move seasonally as the angle of the Sun in the sky moves north and south. The polar jet stream moves south in the winter and north in the summer between about 30°N and 50° to 75°N. The location of the jet stream determines the weather a location on the ground will experience. Cities to the south of the polar jet stream will be under warmer, moister air than cities to its north. Directly beneath the jet stream, the weather is often stormy and there may be thunderstorms and tornadoes.

Lesson Summary

- Winds blow from high pressure zones to low pressure zones. The pressure zones are created when air near the ground becomes warmer or colder than the air nearby.
- Local winds may be found in a mountain valley or near a coast.
- Global wind patterns are long term, steady winds that prevail around a large portion of the planet.

- The location of the global wind belts has a great deal of influence on the weather and climate of an area.

Review Questions

1. Draw a picture of a convection cell in the atmosphere. Label the low and high pressure zones and where the wind is.
2. Under what circumstances will winds be very strong?
3. Given what you know about global-scale convection cells, where would you travel if you were interested in experiencing warm, plentiful rain?
4. Describe the atmospheric circulation for two places where you are likely to find deserts, and explain why these regions are relatively warm and dry.
5. How could the Indian and southeast Asian monsoons be reduced in magnitude? What effect would a reduction in these important monsoons have on that part of the world?
6. Why is the name "snow eater" an apt description of Chinook winds?
7. Why does the Coriolis Effect cause air (or water) to appear to move clockwise in the Northern Hemisphere? When would the Coriolis Effect cause air to appear to move counterclockwise?
8. Sailors once referred to a portion of the ocean as the doldrums. This is a region where there is frequently no wind, so ships would become becalmed for days or even weeks. Given what you know about atmospheric circulation, where do you think the doldrums might be in terms of latitude?
9. Imagine that the jet stream is located further south than usual for the summer. What will the weather be like in regions just north of the jet stream, as compared to a normal summer?
10. Give a general description of how winds form.

Further Reading / Supplemental Links

- High and Low Pressure Systems animations, Bureau of Meteorology, Australian Government `http://www.bom.gov.au/lam/Students_Teachers/pressure.shtml`

Vocabulary

Coriolis Effect The tendency of a freely moving object to appear to move right right in the Northern Hemisphere and left in the Southern Hemisphere.

Foehn winds (Chinook winds) Winds that form when low pressure draws air over a mountain range.

haboob Desert sandstorms that form in the downdrafts of a thunderstorm.

high pressure zone A region where relatively cool, dense air is sinking.

jet stream A fast-flowing river of air high in the atmosphere, where air masses with two very different sets of temperature and humidity characteristics move past each other.

katabatic winds Winds that move down a slope.

land breeze A wind that blows from land to sea in winter when the ocean is warmer than the land.

low pressure zone A region where relatively warm, less dense air is rising.

mountain breeze A wind that blows from up on a mountain down to the valley below in the late afternoon or at night when mountain air is cooler.

polar front The meeting zone between cold continental air and warmer subtropical air at around 50°N and 50°S.

Santa Ana winds Hot winds that blow east to west into Southern California in fall and winter.

sea breeze A wind that blows from sea to land in summer when the land is warmer than the ocean.

valley breeze An uphill airflow.

Points to Consider

- How do local winds affect the weather in an area?
- How do the global wind belts affect the climate in an area?
- What are the main principles that control how the atmosphere circulates?

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(24) http://en.wikipedia.org/wiki/Image:Haboob2.jpg. GNU-FDL.

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Chapter 16

Weather

16.1 Weather and Atmospheric Water

Lesson Objectives

- Discuss the difference between weather and climate.
- Describe the relationship between air temperature and humidity, including the concept of dew point.
- List the basics of the different cloud types and what they indicate about current and future weather.
- Explain how the different types of precipitation form.

Introduction

If someone across country asks you what the weather is like today, you need to consider several factors. Air temperature, humidity, wind speed, the amount and types of clouds and precipitation are all part of a thorough weather report. In this chapter, you will learn about these many of these features in more detail.

What is Weather?

Weather is what is going on in the atmosphere at a particular place at a particular time. Weather may be cold or hot, or wet or dry, and it changes rapidly. A warm sunny day may rapidly turn into a cold and stormy one, making you wish you had brought your jacket. There are many factors that influence the weather; a few examples include the air temperature over a region, whether there is a second air mass nearby, and how close high and low pressure cells are. A location's weather depends on air temperature, air pressure, humidity, cloud cover, precipitation, and wind speed and direction, which are all directly related to the amount of energy that is in the system and where that energy is. The ultimate source of this energy is the sun.

Climate is the average of a region's weather over time. The climate for a particular place is steady, and changes only very slowly. Portland, Oregon has a mild, moist climate and Fairbanks, Alaska has a frigid, dry one. Portland or Fairbanks may experience a warm sunny day in February, but that doesn't change their climate. Climate is determined by many factors, which are related to the amount of energy that is found in that location over time. Factors that determine the amount of energy include the angle of the sun, the likelihood of cloud cover, the air pressure, and many others.

Humidity

Humidity is the amount of water vapor in the air in a particular spot. We usually use the term to mean relative humidity, the percentage of water vapor a certain volume of air is holding relative to the maximum amount it can contain. If the humidity today is 80%, that does not mean that 80% of the molecules in the air are water vapor. It means that the air contains 80% of the total amount of water it can hold at that temperature. If the humidity increases to more than 100%, the excess water will condense from the air and form precipitation.

Humidity affects weather a great deal and is important for weather forecasting. When humidity is high, precipitation is more likely. The combination of high humidity and high temperatures can threaten people's health. People are more uncomfortable when both temperature and humidity are high. As people and some other animals sweat to cool themselves off; they lose heat as the sweat evaporates. But if the air is already saturated with water vapor, the sweat will not evaporate and the person will not cool. They will simply be hot and sweaty, and uncomfortable.

The National Weather Service has developed a **heat index** (HI). On an HI chart (**Table** 16.1), people can see what the temperature feels like, when the air temperature and humidity are known. For example, if the temperature is 85°F, but humidity is only 40%, the temperature feels like a pleasant 84°F. But if the temperature is 85°F, but the humidity is 90%, the air temperature feels like a very hot and sticky 101°F. This information is useful for people who are interested in outdoor activities. High humidity cause health problems, such as sunstroke or heatstroke, to occur more quickly.

Table 16.1: **Heat Index: Temperature (F) vs. Humidity (%)**

	90%	80%	70%	60%	50%	40%
80°F	85	84	82	81	80	79
85°F	101	96	92	90	86	84
90°F	121	113	105	99	94	90

Table 16.1: (continued)

	90%	80%	70%	60%	50%	40%
95°F		133	122	113	105	98
100°F			142	129	118	109
105°F				148	133	121
110°F						135

Since warm air can hold more water vapor than cool air, raising or lowering temperature can change air's relative humidity (**Figure** 16.1). The temperature at which air becomes saturated with water is called the air's **dew point.** This term makes sense, because water will condense from the air as dew, if the air cools down overnight and reaches 100% humidity.

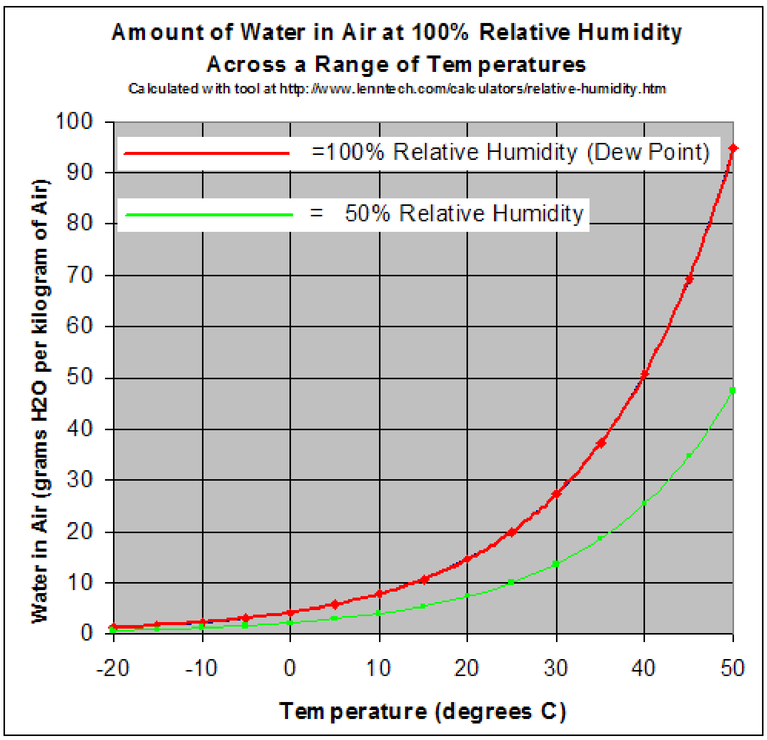

Figure 16.1: This diagram shows the amount of water air can hold at different temperatures. The temperatures are given in degrees Celsius. (25)

Clouds

Sometimes there are lots of clouds in the sky and sometimes you can't see a cloud anywhere. Either way, **clouds** have a big influence on weather. Clouds affect weather in three ways: (1)

preventing solar radiation from reaching the ground, (2) absorbing warmth that is re-emitted from the ground, and (3) as the source of precipitation. When there are no clouds, there is less insulation. As a result, cloudless days can be extremely hot, and cloudless nights can be very cold. For this reason, cloudy days tend to have a lower range of temperatures than clear days.

Clouds form when air reaches its **dew point**, the temperature when the air is saturated with water vapor. This can happen in two ways. First, the air temperature can stay the same while the humidity increases. This is common in locations that are warm and humid. Second, the humidity can remain the same, but the temperature decreases. When this happens, the air will eventually cool enough so that it reaches 100% humidity, and water droplets form. Air cools when it comes into contact with a cold surface or when it rises. There are three ways that rising air can create clouds: (1) It can be warmed at or near the ground level, (2) It can be pushed up over a mountain or mountain range, or (3) It can be thrust over a mass of cold, dense air.

Water vapor in the atmosphere is not visible, unless it condenses to become a cloud. Water vapor condenses around a nucleus, such as dust, smoke, or a salt crystal. This forms a tiny liquid droplet. Billions of these water droplets together make a cloud. If the atmosphere is very cold, the droplets freeze into ice. Most clouds appear white because sunlight reflects off the water droplets. If the clouds are thick, the droplets scatter or absorb the light and less solar radiation can travel through them. This is why storm clouds are dark black or gray.

Clouds have been classified in several ways. The most common classification used today divides clouds into four separate cloud groups, which are determined by their altitude (**Figure** 16.2). High clouds, which have the prefix 'cirro-,' are found above 6,000 m (20,000 feet) in altitude. Middle clouds, which have the prefix 'alto-,' are between 2,000 to 7,000 m (6,500 to 23,000 feet). Low clouds, which have the word 'stratus' in their names, occur beneath 2,000 m (6,500 feet). Each of the clouds that occur in these groups is layered, and they grow horizontally.

Another group of clouds, which have the prefix 'cumulo-,' describes clouds that grow vertically instead of horizontally. These impressive clouds have their bases at low altitude and their tops at high or middle altitude.

Table 16.2:

High clouds:	Cirrus (Ci)	Cirrostratus (Cs)	Cirrocumulus (Cc)
Middle clouds:	Altostratus (As)	Altocumulus (Ac)	
Low clouds:	Stratus (St)	Stratocumulus (Sc)	Nimbostratus (Ns)
Vertical clouds:	Cumulus (Cu)	Cumulonimbus (Cb)	

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High clouds form where the air is extremely cold and can hold little water vapor. The

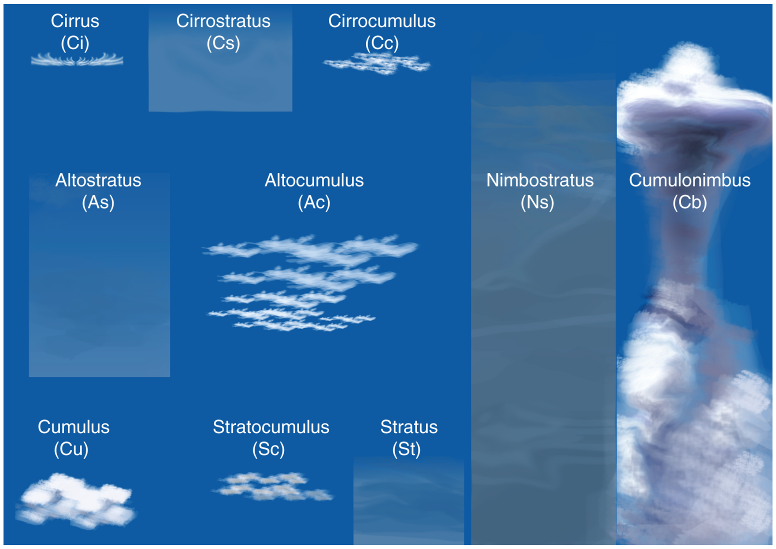

Figure 16.2: The four cloud types and where they are found in the atmosphere. The symbols are shown in **Table** 16.2: (45)

ice crystals that form create thin, wispy **cirrus** clouds (**Figure** 16.3). Cirrus clouds may indicate an oncoming storm.

Figure 16.3: Cirrus clouds are thin wisps of ice crystals found at high altitudes. (36)

Cirrocumulus clouds are small, white puffs that ripple across the sky, often in rows. **Cirrostratus** clouds are thin, white sheets of clouds, made up of ice crystals like cirrus clouds (**Figure** 16.4). Cirrostratus clouds are sometimes so thin that they cannot be seen, unless illuminated by the sun or moon.

Figure 16.4: Cirrostratus clouds are so thin they are sometimes invisible unless backlit by the Sun or Moon. (32)

Middle clouds may be made of water droplets, ice crystals or both, depending on the air temperatures. **Altocumulus** clouds appear as white to gray, puffy stripes rolling across the sky (**Figure** 16.5). These clouds often occur before thunderstorms. Thick and broad **altostratus** clouds are gray or blue-gray. They often cover the entire sky and usually mean a large storm, bearing a lot of precipitation is coming.

Low clouds usually hold droplets of liquid water, although they may also contain ice when temperatures are very cold. **Stratus** clouds are gray sheets that cover the entire sky (**Figure** 16.6). These clouds may produce a steady drizzle or mist, but do not carry hard rain. **Nimbostratus** clouds are thick and dark. They bring steady rain or snow. **Stratocumulus** clouds are rows of large, low puffs that may be white or gray. These clouds rarely bring precipitation. but

Clouds grow vertically when strong air currents are rising upward. **Cumulus** clouds resemble white or light gray cotton and have towering tops (**Figure** 16.7). On fair days, cumulus clouds may grow upward but produce no precipitation. On hot summer afternoons, though, cumulus clouds may mushroom into a form that looks like a head of cauliflower. These clouds may produce light showers.

If the vertical air currents are strong, a cumulus cloud will grow upward until it develops into a **cumulonimbus** cloud (**Figure** 16.8). Tall, dark and ominous cumulonimbus clouds are associated with lightning and intense thunderstorms.

Figure 16.5: Altocumulus clouds are white puffs found in the middle altitudes. (20)

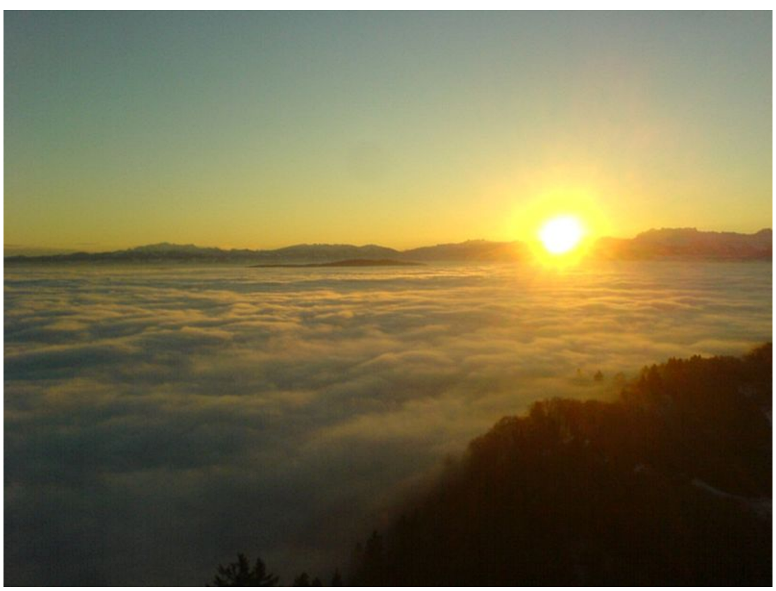

Figure 16.6: Stratus clouds with the Alps in the distance. (7)

Figure 16.7: Anvil-shaped cumulus clouds floating over Australia. (42)

Figure 16.8: Cumulonimbus cloud lit up by lightning. (12)

Fog

Fogs are clouds located at or near the ground. When humid air near the ground cools below its dew point, fog is formed. Fogs develop differently from the way clouds form. There are several types of fog, each of which forms in a different way.

Radiation fogs form at night when skies are clear and the relative humidity is high. As the ground cools, the bottom layer of air cools also. Eventually the air temperature may be lowered below its dew point. If there is a light breeze, the fog will be carried upward. Radiation fog can grow to 30 meters (100 feet) thick. One to three hours after sunrise, radiation fog burns off as the ground warms. The Central Valley of California frequently experiences radiation fog, which is called tule fog in this area. Tule fog can be so thick that drivers cannot see the car in front of them and their headlights just reflect back off the sheet of water droplets.

San Francisco, California is famous for its summertime **advection fog** (**Figure** 16.9). Warm, moist air from over the Pacific Ocean blows over the cold California current just offshore. This cools the eastward moving air below its dew point and thereby creates fog. Advection fog is brought onshore by sea breezes. If the fog is accompanied by light wind, a thicker layer of air cools and the fog can grow to be up to 600 m (2,000 feet) thick.

Figure 16.9: Advection fog fills the gap where the Golden Gate Bridge spans the San Francisco Bay inlet. (16)

Steam fog appears in autumn or early winter and can make a pond or lake appear to be steaming. The "steam" forms when cool air moves over a lake that still holds some of its summer heat. Water evaporates from the lake surface and condenses as it cools in the overlying air. Steam fog is rarely very thick.

When warm humid air travels up a hillside and cools below its dew point it creates an **upslope fog** (**Figure** 16.10).

Figure 16.10: Upslope fog around the peaks of Mt. Lushan in China. (37)

Precipitation

As you know from your daily life, precipitation is an extremely important part of weather. Precipitation most commonly falls as rain or snow, but can also be sleet, hail, dew or frost. Sleet is a mixture of rain and snow, and often forms when snow partially melts as it falls. Dew forms when moist air comes into contact with a cold surface, like the ground or a car windshield, and cools below its dew point. Frost forms under similar conditions, but when the air cools to below freezing (**Figure** 16.11).

Figure 16.11: Hoar frost. (43)

The other types of precipitation come from clouds. Rain or snow droplets fall when they become heavy enough to escape from the rising air currents that hold them up in the cloud. The most common way for rain or snow to droplets to grow, occurs in cold clouds, where the temperature is -10°C(14°F) or less (**Figure** 16.12). Here the water vapor freezes directly into ice crystals, which continue to grow as more water vapor freezes onto them. When the ice crystals become heavy enough, they fall. Even as they fall, the ice crystals collect more moisture. If temperatures are cold, the ice will hit the ground as a snowflake. If temperatures near the ground are greater than 4° C(39°F), the ice crystal may melt and become a raindrop. One million cloud droplets will combine to make only one rain drop!

Water may also precipitate from warm clouds. Here too, water droplets get trapped in rising and falling air currents. As the droplet travels around the convection cell, it collides with other small droplets. At some point, the droplet is large enough to escape the convecting air currents and it falls to the ground as rain. If the air currents are very strong, the droplets must be very large before they fall.

If a raindrop falls through warm air but hits a layer of freezing air near the ground, it becomes frozen into a small clear ice pellet known as **sleet**. Sleet usually is mixed with liquid water drops that did not freeze as they descended from the cloud. If the layer of frigid air near the

Figure 16.12: Snow storm in Cleveland, Ohio. (46)

ground is not thick enough for the raindrop to freeze before it reaches the ground, the drop may freeze on the ground, forming **glaze**. The weight of glaze covering a tree branch can make the branch fall.

Hail forms in cumulonimbus clouds with strong updrafts. An ice particle falling through a cloud is captured by an updraft and continues to grow as it travels around the convection cell. When it finally becomes too heavy, it drops to the ground. Although hail is usually less than 1 cm (about one-half inch), it's not uncommon to find hail that is 5 to 10 cm (2 to 4 inch) in diameter (**Figure** 16.13). The largest hailstone ever measured, 14 cm (5.5 inches) in diameter and weighing 766 grams (27 ounces), was collected in Coffeyville, Kansas in 1970.

Lesson Summary

- Air temperature causes differences in pressure so that convection cells form.
- Air rising in a convection cell may cool enough to reach its dew point and form clouds or precipitation if the humidity is high enough.
- Clouds or fog may form if warmer air meets a colder ground surface. Air temperature and humidity also determine what sorts of clouds and precipitation form.
- These factors play a role in creating a pleasant or uncomfortable day, such as when it might be warm and dry or hot and humid.

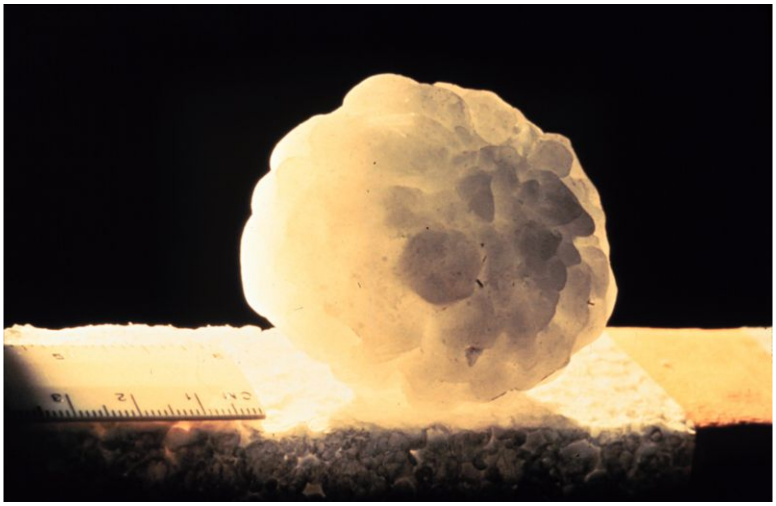

Figure 16.13: A large hail stone, about 6 cm (2.5 inches) in diameter. (15)

Review Questions

1. What factors need to be included in a thorough weather report?
2. If Phoenix, Arizona experiences a cool, wet day in June (when the weather is usually hot and dry), does that mean the region's climate is changing?
3. Look back at the table that shows heat index. Which day would most people find more pleasant: An 85°F day with 90% humidity or a 90°F day with 40% humidity?
4. What happens when a batch of air reaches its dew point? At what temperature does this occur?
5. What effect do clouds have on weather?
6. You are standing in a location which is clear in the morning, but in the afternoon there are thunderstorms. There is no wind during the day, so the thunderstorms build directly above you. Describe how this happens.
7. In what three ways can air rise to create clouds?
8. What are the four different cloud groups and how are they classified?
9. How does sleet form? How does glaze form?
10. What circumstances must be present for enormous balls of hail to grow and then fall to the ground?

Vocabulary

altocumulus Gray puffy stripes of globular clouds arranged in lines across the sky.

altostratus Thicker clouds than cirrostratus; like a gray veil, may completely hide Sun or Moon.

cirrocumulus High clouds that are small, white and puffy, arranged in groups or lines.

cirrostratus Thin, whitish, veil-like clouds that produce a halo around the Sun or Moon, but do not blur their outline.

cirrus High, wispy clouds made of ice crystals.

cloud Tiny water or ice particles that are grouped together in the atmosphere.

cumulonimbus Tall, dark clouds that produce thunderstorms.

dew point The temperature at which air is saturated with water vapor, or where the air has reached 100% humidity.

glaze A layer of smooth, transparent ice that forms when freezing rain or drizzle hit a cold surface.

hail Pellets of ice or ice and snow that form only in cumulonimbus clouds.

heat index A measurement that combine the effects of temperature and humidity; the heat index more accurately describes what weather will actually feel like.

humidity The amount of water vapor in the air, sometimes used synonymously with relative humidity.

nimbostratus Thick, dark, continuous, low clouds that brings continuous rain or snow.

radiation fog Fog caused by the radiation of heat on a cold, windless night.

relative humidity The amount of water vapor in the air relative to the maximum amount of water vapor that the air could contain at that temperature.

sleet Partly frozen rain or partly melted snow and ice.

stratocumulus Soft, globular, low clouds in groups or lines that rarely bring precipitation.

stratus Low clouds that are continuous and may produce drizzle but no hard rain.

upslope fog Fog that forms from winds that blow up a slope and cool.

Points to Consider

- When thinking about the weather, what factors do you consider important in the air that surrounds you?
- How do air temperature, humidity, and pressure differences create different sorts of weather?
- Think about the types of weather described in this lesson. Imagine types of weather that you have not experienced, look at photos, and ask friends and relatives who've lived in other places what their weather is like.

16.2 Changing Weather

Lesson Objectives

- Describe the characteristics air masses have and how they get those characteristics.
- Discuss what happens when air masses meet.
- List the differences between stationary, cold, warm, and occluded fronts.

Introduction

The weather in a location often depends on what type of air mass is over it. Another key factor revolves around whether or not the spot is beneath a **front,** the meeting place of two air masses. The characteristics of the air masses and their interactions can determine whether the weather is constant over an area, or whether there are rapid changes in air temperature, wind, precipitation and even thunderstorms.

Air Masses

An **air mass** is a batch of air that has nearly the same temperature and humidity (**Figure** 16.14). An air mass is created above an area of land or water known as its source region. Air masses come to have a distinct temperature and humidity when they remain over a region for several days or longer. The heat and moisture leave the ground and move into the air above it, until the overlying air takes on the temperature and humidity characteristics of that particular region.

Air masses are created primarily in high pressure zones. They most commonly form in polar and tropical regions, which have very distinctive temperature and humidity. The temperate zones are ordinarily too unstable for air masses to form. Instead, air masses move across them, making the middle latitudes the site of very interesting weather.

Air masses can be 1,600 km (1,000 miles) or more across and several kilometers thick.

Temperature and humidity may change a bit horizontally across the air mass, but not too much. An air mass may have more changes with altitude.

Meteorologists use symbols to describe the characteristics of an air mass. The first symbol tells whether the air mass had its origin over a continent (c) or over an ocean (m, for maritime). As you might expect, air masses that form over oceans contain more water vapor than those that form over land. The second symbol tells the general latitude where the air mass gained its temperature and humidity traits. The categories are arctic (A), polar (P,)tropical (T), and equatorial (E). Of course, air masses that form over polar areas are colder than those that form over tropical regions.

Globally, the major air masses are continental arctic or continental antarctic(cA or cAA); continental polar (cP); maritime polar (mP); continental tropical (cT); maritime tropical (mT); and maritime equatorial (mE). Maritime arctic and continental equatorial air masses rarely form.

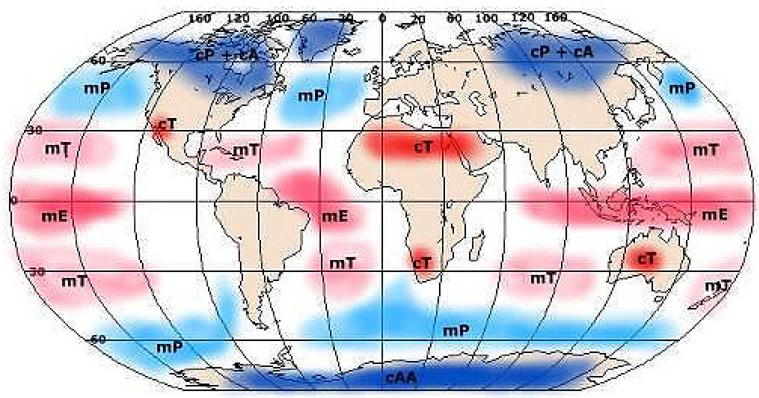

Figure 16.14: The source regions of air masses found around the world. (11)

A third symbol takes into account the properties of an air mass relative to the ground it moves over. If the air mass is colder than the ground, it is given the designation k, for cold. If it is warmer than the ground, it is given the designation w. For example, a cPk is an air mass with a continental polar source region that is colder than the region it is now moving over.

Air Mass Movement

Air masses are pushed along by high-level winds, although they move slower than the winds. An air mass gets its characteristics from the ground or water it is above, and it also shares those characteristics with the regions that it travels over. Therefore, the temperature and humidity of a particular location depends partly on the characteristics of the air mass that sits over it.

If the air mass is very different from the ground beneath it, storms may form. For example, when a colder air mass moves over warmer ground, the bottom layer of air is heated. That air rises, forming clouds, rain, and sometimes thunderstorms. When a warmer air mass travels over colder ground, the bottom layer of air is cooled. This forms a temperature **inversion**, since the cold air near the ground is trapped. Inversions may form stratus clouds, advection fogs, or they may trap a layer of pollution over a city.

In general, cold air masses tend to flow toward the equator and warm air masses tend to flow toward the poles. This brings heat to cold areas and cools down areas that are warm. It is one of the many processes that act towards balancing out the planet's temperatures.

Fronts

Two air masses meet at a front. Because the two air masses have different temperature and humidity, they have different densities. Air masses with different densities do not easily mix. Ordinarily, when fronts meet, one air mass is lifted above the other. Rising air creates a low pressure zone. If the lifted air is moist enough, there will be condensation and precipitation. Fronts usually also have winds in them. If the temperature difference between the two air masses is high, then the winds will be strong. Fronts are the main cause of stormy weather.

The map symbols for the different types of fronts are shown in (**Figure** 16.15): (**1**) cold front, (**2**) warm front, (**3**) stationary front, (**4**) occluded front, (**5**) surface trough, (**6**) squall line, (**7**) dry line, (**8**) tropical wave.

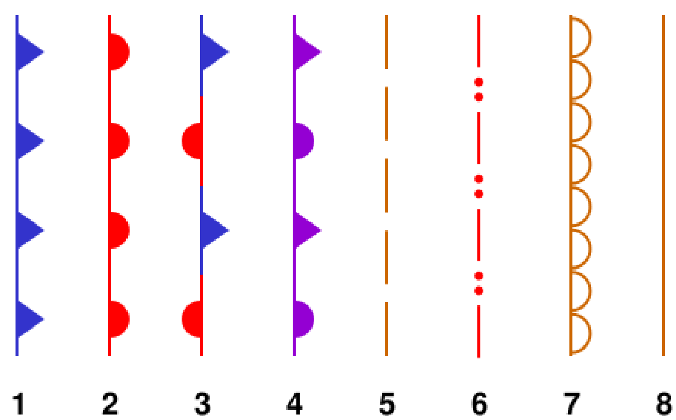

Figure 16.15: The map symbols for different types of fronts. (3)

The direction that fronts move is guided by pressure gradients and the Coriolis Effect. In the Northern Hemisphere, cold fronts and occluded fronts tend to move from northwest to southeast. Warm fronts move southwest to northeast. The direction the different types of fronts move in the Southern Hemisphere is the mirror image of how they move in the Northern Hemisphere. Fronts can be slowed or stopped by a barrier such as a mountain range.

The rest of this section will be devoted to four types of fronts. Three of these fronts move and one is stationary. With cold fronts and warm fronts, the air mass at the leading edge of the front gives the front its name. In other words, a cold front is right at the leading edge of moving cold air and a warm front marks the leading edge of moving warm air.

Stationary Front

Most fronts move across the landscape, but at **stationary fronts** (**3**) the air masses do not move. A front may become stationary if an air mass is stopped by a barrier. For example, cold air masses may be stopped by mountains, because the cold air mass is too dense to rise over them.

A region under a stationary front may experience days of rain, drizzle and fog. This weather may be present over a large area. Winds usually blow parallel to the front, but in opposite directions. This results in shear stress. Shear stresses result when objects are pushed past each other in opposite directions.

After several days, the front will break apart. The **temperature gradient** or temperature difference across the front may decrease, so the air masses start to mix. Shear stresses may force the front to break apart. Conditions may change so that the stationary front is overtaken by a cold front or a warm front. If the temperature gradient between the air masses increases, wind and rainy weather will result.

Cold Fronts

When a cold air mass takes the spot of a warm air mass, there is a **cold front** (**1**) (**Figure** 16.16). Since cold air is denser than the warm air, the cold air mass slides beneath the warm air mass and pushes it up. As the warm air rises, there are often storms.

When cold air moves underneath warm air, the ground temperature drops. The humidity may also decrease since the colder air may also be drier. Winds at a cold front can be strong because of the temperature difference between the two air masses. When a cold front is on its way, there may be a sharp change in dew point, changes in wind direction, changes in air pressure, and certain characteristic cloud and precipitation patterns.

Cold fronts often move rapidly across the landscape. Fast-moving cold fronts create a line of intense storms over a fairly short distance. A **squall line**(**6**) is a line of severe thunderstorms that forms along a cold front (**Figure** 16.17). If the front moves slowly, the storms may form over a larger area.

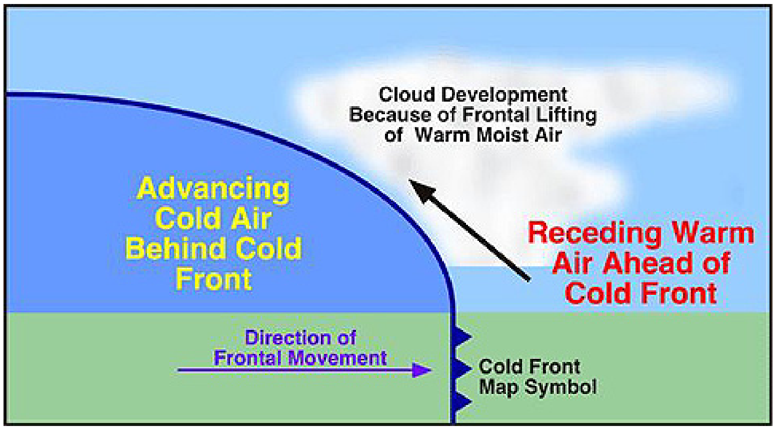

Figure 16.16: A cold front with cold air advancing to displace warm air. The warm air is pushed up over the cold air. (30)

Figure 16.17: A shelf line that commonly precedes a squall. (27)

Imagine that you are standing in one spot as a cold front approaches. Along the cold front, the denser, cold air pushes up the warm air, causing the air pressure to decrease. If the humidity is high enough, some types of cumulus clouds will grow. High in the atmosphere, winds blow ice crystals from the tops of these clouds to create cirrostratus and cirrus clouds. At the front, there will be a line of rain or snow showers or thunderstorms with blustery winds. Behind the front is the cold air mass. This mass is drier and so precipitation stops. The weather may be cold and clear or only partly cloudy. Winds may continue to blow into the low pressure zone at the front.

The weather at a cold front varies with the season. Thunderstorms or tornadoes may form in spring and summer, when the air is unstable. In the spring, the temperature gradient can be very high, causing strong winds to blow at the front. In the summer, thunderstorms may be severe and may also include hailstorms. In the autumn, strong rains fall over a large area. If the front moves slowly, enough rain may fall to cause flooding. Cold fronts in winter may bring frigid temperatures and heavy snows. The cold air mass is likely to have formed in the frigid arctic.

When the temperature gradient across a cold front is low, a cold front has little effect on the weather. This may occur at some locations in the summer. Along the western United States, the Pacific Ocean warms and moistens cold air masses so that the temperature gradient across a cold front is small.

Warm Fronts

A **warm front** (**2**) is found where warm air mass slides over a cold air mass (**Figure** 16.18). Since the warmer, less dense air is moving over the colder, denser air, the atmosphere is relatively stable. Warm fronts travel much more slowly than cold fronts because the leading cold air mass is dense and sluggish.

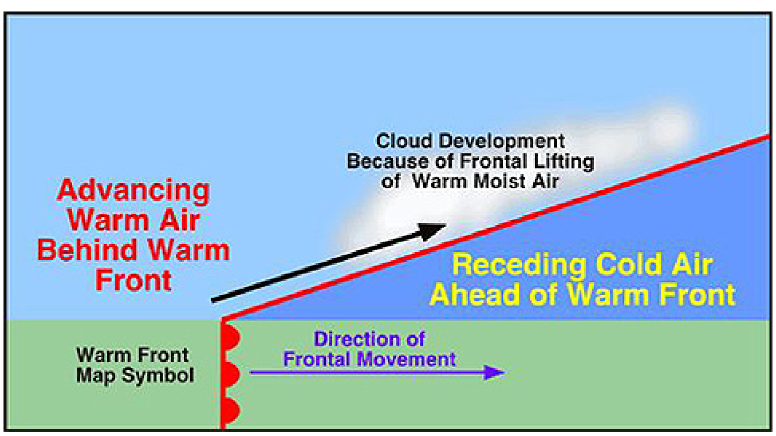

Figure 16.18: A warm front. Warm air moves forward to take over the position of colder air. (9)

Imagine that you are on the ground in the wintertime under a cold winter air mass with a warm front approaching. The transition between the cold air and the warm air takes place over a long distance. This means that the first signs of changing weather appear long before the front is actually over you. In fact, weather changes may appear hundreds of kilometers ahead of the front. Initially, the air is cold: the cold air mass is above you and the warm air mass is above it. High cirrus clouds mark the transition from one air mass to the other.

Over time, cirrus clouds become thicker and cirrostratus clouds form. As the front approaches, altocumulus and altostratus clouds appear and the sky turns gray. Since it is winter, snowflakes fall. Soon the clouds thicken and nimbostratus clouds form. Snowfall increases. Winds grow stronger as the low pressure approaches. As the front gets closer, the cold air mass is just above you but the warm air mass is not too far above that. The weather worsens. As the warm air mass approaches, temperatures rise and snow turns to sleet and freezing rain. Warm and cold air mix at the front, leading to the formation of stratus clouds and fog (**Figure** 16.19).

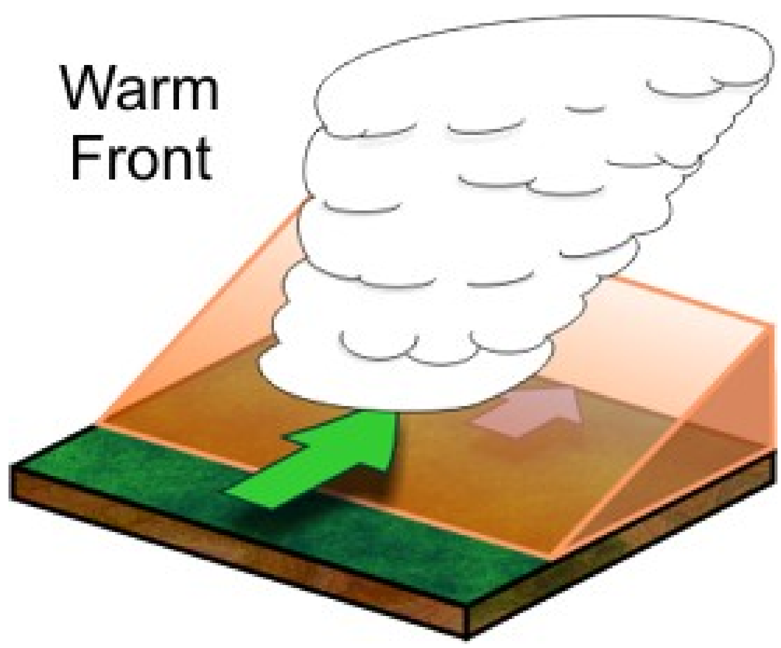

Figure 16.19: Cumulus clouds build at a warm front. (35)

As the front passes over you, the temperature and dew point rise and the rain likely ends. Winds change direction. The transition is not nearly as dramatic as when a cold front passes over, since there is more mixing of the two air masses occurring in a warm front.

The Pacific Ocean also plays a role in modifying the warm fronts that reach the west coast of the United States. These storms are so broad that it is very difficult to spot exactly where the warm front is!

Occluded Front

An **occluded front** or **occlusion** (**4**) usually forms around a low pressure system (**Figure** 16.20). The occlusion starts when a cold front catches up to a warm front. The air masses, in order from front to back, are cold, warm, and then cold again. The boundary line, where the two fronts meet, curves towards the pole because of the Coriolis effect. If the air mass that arrives third is colder than either of the first two air masses, that air mass will slip beneath the other two air masses. This is called a cold occlusion. If the air mass that arrives third is warm, that air mass will ride over the other air mass. This is called a warm occlusion.

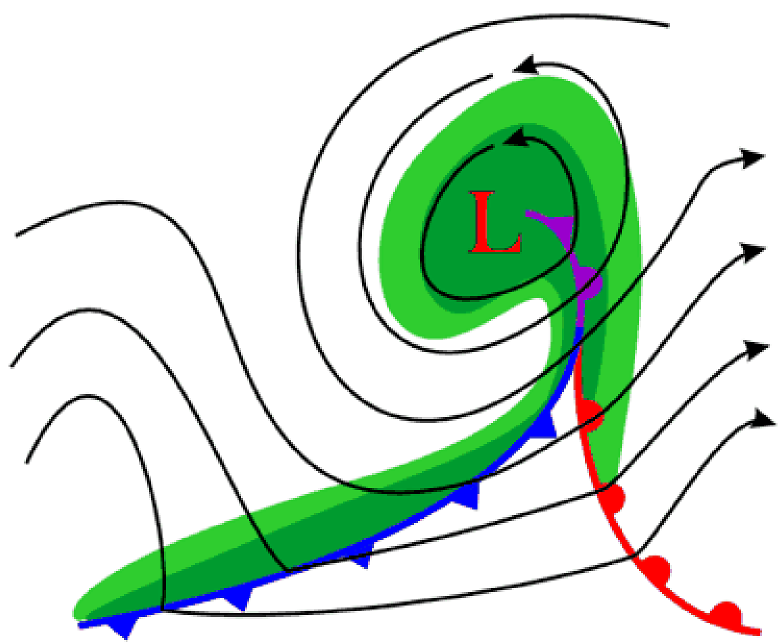

Figure 16.20: An occluded front with a warm front being advanced on by a cold front. The order of air masses from front to rear is cold, warm, and then cold. (33)

Occluded fronts can cause drying or storms. Precipitation and shifting winds are typical. The weather is especially fierce right at the occlusion. The Pacific coast has frequent occluded fronts. All of these fronts are part of the mid-latitude cyclone. These weather systems will be discussed in the next lesson.

Lesson Summary

- An air mass takes on the temperature and humidity characteristics of the location where it originates. Air masses meet at a front.
- Stationary fronts become trapped in place and the weather they bring may last for many days.

- At a cold front, a cold air mass takes the place of a warm air mass and forces the warm air upwards.
- The opposite occurs at a warm front, except that the warm air slips above the cold air mass.
- In an occluded front, a warm front is overtaken by a cold front, which creates variable weather.

Review Questions

1. What type of air mass will be created if a batch of air sits over the equatorial Pacific Ocean for a few days? What is the symbol for this type of air mass?
2. What conditions must be present for air to sit over a location long enough to acquire the characteristics of the land or water beneath it?
3. Discuss how latitude affects the creation of air masses in the tropical, temperate and polar zones.
4. Phoenix, Arizona is a city in the Southwestern desert. Summers are extremely hot. Winter days are often fairly warm but winter nights can be quite chilly. In December, inversions are quite common. How does an inversion form under these conditions and what are the consequences of an inversion to this sprawling, car-dependent city?
5. Why are the directions fronts move in the Southern Hemisphere a mirror image of the directions they move in the Northern Hemisphere?
6. How is a stationary front different from a cold or warm front?
7. What sorts of weather will you experience as a cold front passes over you?
8. What sorts of weather will you experience as a warm front passes over you?
9. How does an occlusion form?
10. What situation creates a cold occlusion and what creates a warm occlusion?

Further Reading / Supplemental Links

- Cold Front animation, Goddard Space Flight Center http://svs.gsfc.nasa.gov/vis/a000000/a002200/a002203/index.html

Vocabulary

air mass A large mass of air with the same temperature and humidity characteristics, although these characteristics may change with altitude.

cold front A front in which a cold air mass is replacing a warm air mass; the cold air mass pushes the warm air mass upward.

front The meeting place of two air masses with different characteristics.

occluded front A front in which a cold front overtakes a warm front.

squall line A line of thunderstorms that forms at the edge of a cold front.

stationary front A stalled front in which the air does not move.

temperature gradient A change in temperature over distance.

warm front A front in which a warm air mass is replacing a cold air mass.

Points to Consider

- How do the various types of fronts lead to different types of weather?
- Why are some regions prone to certain types of weather fronts and other regions prone to other types of weather fronts?
- Why does the weather sometimes change so rapidly and sometimes remain very similar for many days?

16.3 Storms

Lesson Objectives

- Describe how atmospheric circulation patterns cause storms to form and travel.
- Understand the weather patterns that lead to tornadoes, and identify the different types of cyclones.
- Know what causes a hurricane to form, what causes it to disappear, and what sorts of damage it can do.
- Know the damage that heat waves and droughts can cause.

Introduction

Weather happens every day, but only some days have storms. Storms vary immensely depending on whether they're warm or cold, coming off the ocean or off a continent, occurring in summer or winter, and many other factors. The effects of storms also vary depending on whether they strike a populated area or a natural landscape. Hurricane Katrina is a good example, since the flooding after the storm severely damaged New Orleans, while a similar storm in an unpopulated area would have done little damage.

Thunderstorms

Thunderstorms are extremely common. Across the globe, there are about 14 million per year; that's 40,000 per day! Most come and go quickly, dropping a lot of rain on a small area, but some are severe and highly damaging. Thunderstorms are most common when ground temperatures are high. This tends to be in the late afternoon or early evening in spring and summer. As temperatures increase, warm, moist air rises. These updrafts form first cumulus and then cumulonimbus clouds (**Figure** 16.21).

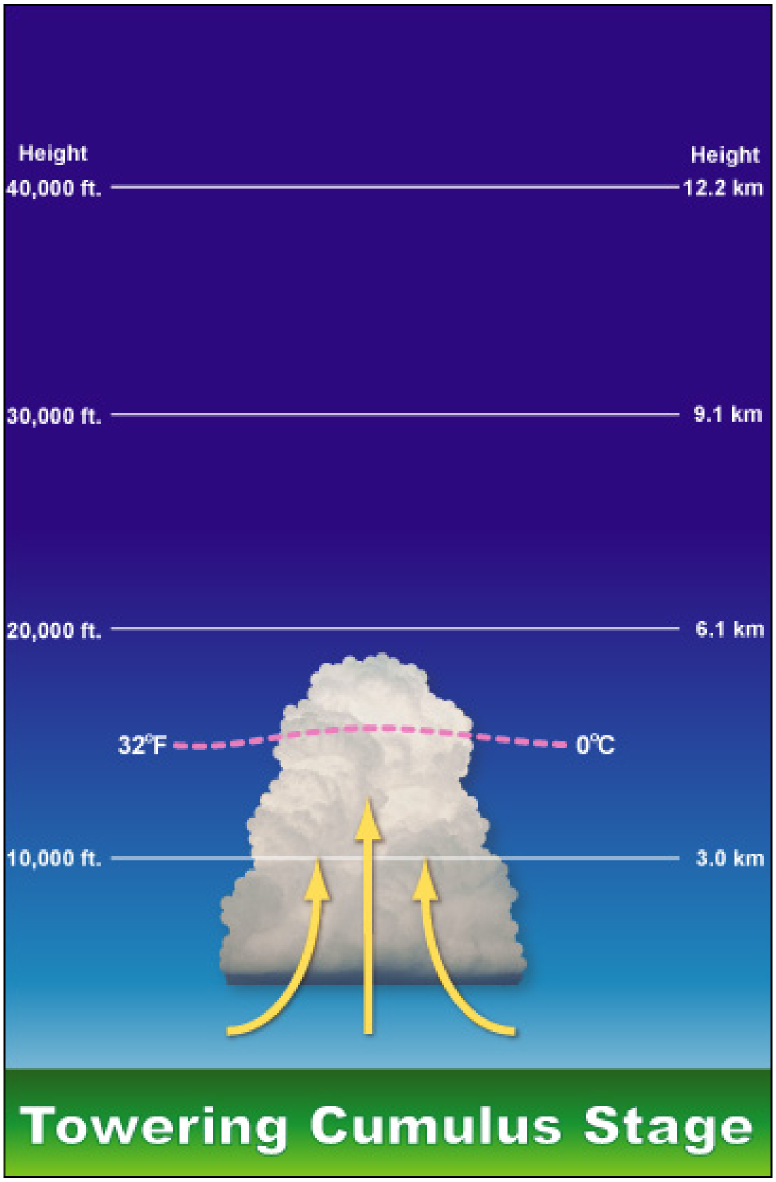

Figure 16.21: On a warm spring or summer day, air warmed near the ground rises and forms cumulus clouds. If warm air continues to rise, cumulonimbus clouds form. (19)

At the top of the stratosphere, upper level winds blow the cloud top sideways to make the anvil shape that characterizes a cloud as a thunderhead (**Figure** 16.22).

Figure 16.22: Winds at the top of the stratosphere blow the top of a cumulonimbus cloud sideways to create the classic anvil-shape of a thunderhead. (1)

Clouds form when water vapor condenses. Remember that when water changes state from a gas to a liquid, it releases latent heat. Latent heat makes the air in the cloud warmer than the air outside the cloud and supplies the cloud with a lot of energy. Water droplets and ice travel through the cloud in updrafts. When these droplets get heavy enough, they fall. This starts a downdraft, and soon there is a convection cell within the cloud. The cloud grows into a cumulonimbus giant. Droplets traveling through the convection cell grow. Eventually, they become large enough to fall to the ground. At this time, the thunderstorm is mature, it produces gusty winds, lightning, heavy precipitation and hail (**Figure** 16.23).

Once downdrafts have begun, the thunderstorm can no longer continue growing. The downdrafts cool the air at the base of the cloud, so the air is no longer warm enough to rise. As a result, convection shuts down. Without convection, water vapor does not condense, no latent heat is released, and the thunderhead runs out of energy. A thunderstorm usually ends only 15 to 30 minutes after it began, but other thunderstorms may start in the same area.

Severe thunderstorms grow larger because the downdrafts are so intense, they flow to the ground. This sends warm air from the ground upward into the storm. The warm air feeds the convection cells in the cloud and gives them more energy. Rain and hail grow huge before gravity pulls them to Earth. Hail that is 1.9 cm (0.75 inch) in diameter is not uncommon. Severe thunderstorms can last for hours and can cause a lot of damage due to high winds, flooding, intense hail, and tornadoes.

Thunderstorms can form individually or in squall lines, which can run along a cold front for hundreds of kilometers. Individual storms within the line may reach an altitude of more

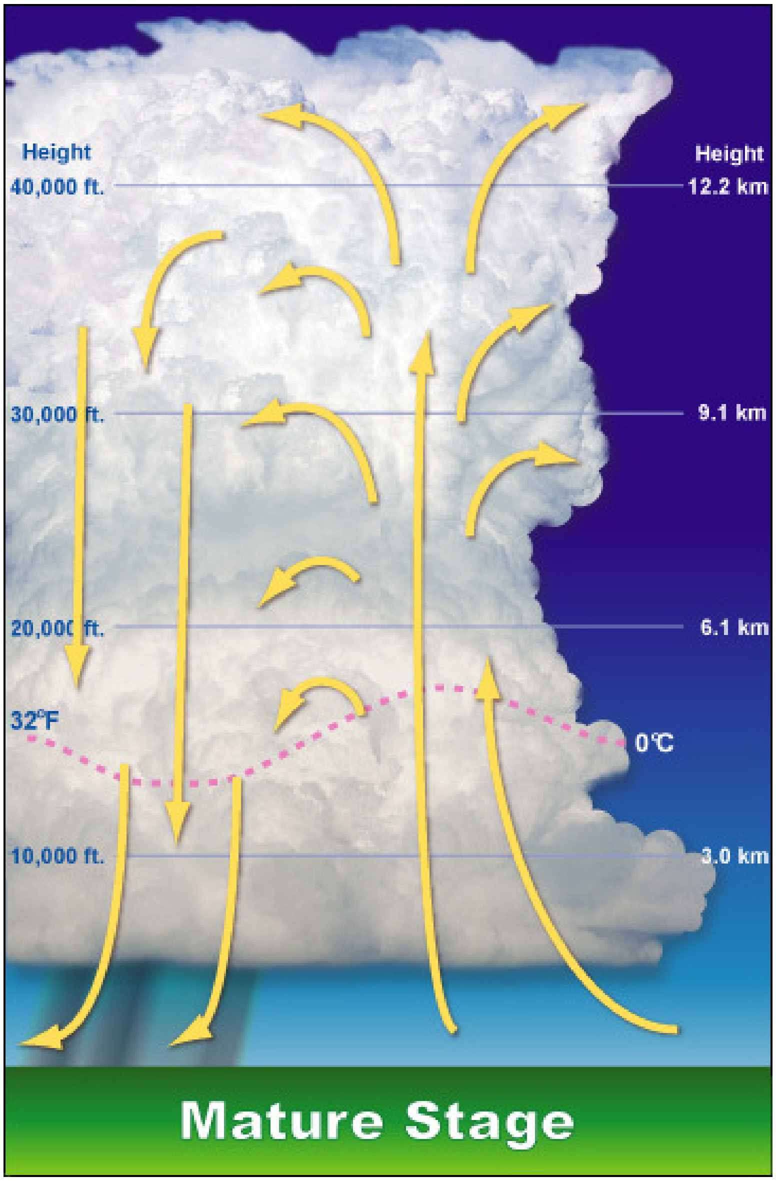

Figure 16.23: A mature thunderstorm showing updrafts and downdrafts that reach the ground. This thunderstorm will no longer grow, since the base of the cloud is being cooled too much for convection to continue. (18)

than 15 kilometers (50,000 feet). In the United States, squall lines form in spring and early summer where the maritime tropical (mT) air mass from the Gulf of Mexico meets the continental polar (cP) air mass from Canada. In the United States, severe thunderstorms are most common in the Midwest.

Lightning is a huge release of electricity that forms in cumulonimbus clouds (**Figure** 16.24). As water droplets in the cloud freeze, positive ions line the colder outside of the drop. Negative ions collect in the warmer inside. If the outside of the drop freezes, the water inside often shatters the outside ice shell. The small, positively-charged ice fragment rises in the updraft. The heavier, negatively-charged water droplet falls in the downdraft. Soon the base of the cloud is mostly negatively-charged and the top is mostly positively-charged. The negative ions at the base of the cloud drive away negative ions on the ground beneath it, so the ground builds up a positive charge. Eventually the opposite charges will attempt to equalize, creating ground to cloud lightning. Only about 20% of lightning bolts strike the ground. Lightning can also discharge into another part of the same cloud or another cloud.

Figure 16.24: Lightning over Pentagon City in Arlington, Virginia. (34)

Lightning heats the air so that it expands explosively. The loud clap is **thunder.** Light waves travel so rapidly that lightning is seen instantly. Sound waves travel much more slowly, about 330 m (1,000 feet) per second. If you were watching a lightning storm, the difference in the amount of time between seeing a lighting bolt and hearing its thunder clap in seconds times 1,000 gives the approximate distance in feet of the lightning strike. For example, if 5 seconds elapse between the lightning and the thunder, the lightning hit about

5,000 feet or about 1 mile (1,650 m) away.

Thunderstorms kill approximately 200 people in the United States and injure about 550 Americans per year, mostly from lightning strikes. Have you heard the common misconception that lightning doesn't strike the same place twice? In fact, lightning strikes the New York City's Empire State Building about 100 times per year (**Figure** 16.25).

Figure 16.25: Lightning strikes some places many times a year. Here, lightning is striking the Eiffel Tower in Paris. (14)

Tornadoes

Tornadoes, also called twisters, are the most fearsome products of severe thunderstorms (**Figure** 16.26). Tornadoes are created as air in a thunderstorm rises, and the surrounding air races in to fill the gap, forming a funnel. A tornado is a funnel shaped, whirling column of air extending downward from a cumulonimbus cloud.

A tornado can last anywhere from a few seconds to several hours. The most important measure of the strength of a tornado is its wind speed. The average is about 177 kph (110 mph), but some can be much higher. The average tornado is 150 to 600 m across (500 to 2,000 feet) across and 300 m (1,000 feet) from cloud to ground. A tornado travels over the ground at about 45 km per hour (28 miles per hour) and travels about 25 km (16 miles) before losing energy and disappearing.

Figure 16.26: The formation of this tornado outside Dimmit, Texas in 1995 was well studied. (10)

Tornadoes strike a small area compared to other violent storms, but they can destroy everything in their path. Tornadoes uproot trees, rip boards from buildings, and fling cars up into the sky. The most violent two percent of tornadoes last more than three hours. These monster storms have winds up to 480 kph (300 mph). They cut paths more than 150 km (95 miles) long and 1 km (one-half mile) wide (**Figure** 16.27).

Figure 16.27: This tornado struck Seymour, Texas in 1979. (31)

Most injuries and deaths from tornadoes are caused by flying debris. In the United States, an average of 90 people are killed by tornadoes each year, according to data from the National Weather Service. The most violent two percent of tornadoes account for 70% of the deaths by tornadoes (**Figure** 16.28).

Figure 16.28: Tornado damage at Stoughton, Wisconsin in 2005. (41)

Tornadoes form at the front of severe thunderstorms, so these two dangerous weather events commonly occur together. In the United States, tornadoes form along the front where the maritime tropical (mT) and continental polar (cP) air masses meet. In a typical year, the location of tornadoes moves along with the front, from the central Gulf States in February, to the southeastern Atlantic states in March and April, and on to the northern Plains and Great Lakes in May and June. Although there is an average of 770 tornadoes annually, the number of tornadoes each year varies greatly (**Figure** 16.29).

Meteorologists can only predict tornado danger over a very wide region, a few hours in advance of the possible storm. Once a tornado is sighted on radar, its path is predicted

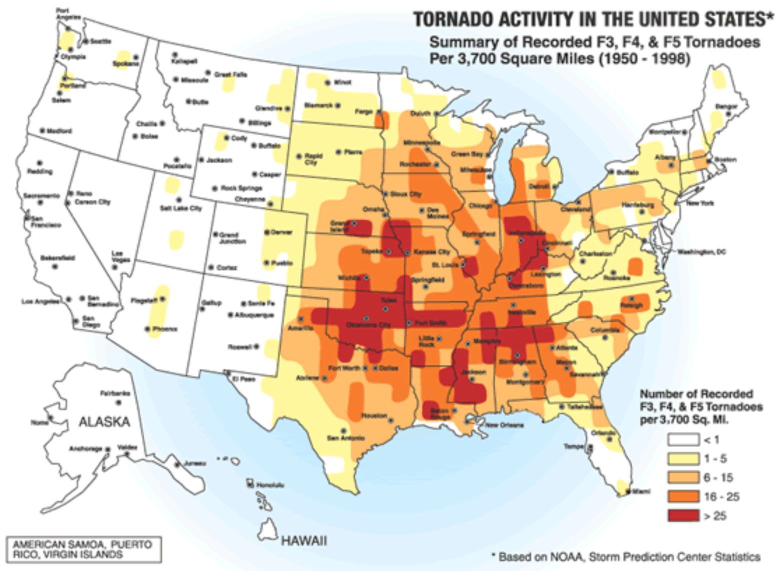

Figure 16.29: The frequency of F3, F4 and F5 tornadoes in the United States. The red region that starts in Texas and covers Oklahoma, Nebraska and South Dakota is called Tornado Alley because it is where most of the violent tornadoes occur. (44)

and a warning is issued to people in that area. The exact path is unknown because tornado movement is not very predictable. The intensity of tornadoes is measured on the Fujita Scale (see **Table** 16.3), which assigns a value based on wind speed and damage.

Table 16.3: **The Fujita Scale (F Scale) of Tornado Intensity**

F Scale	(km/hr)	(mph)	Damage
F0	64-116	40-72	Light - tree branches fall and chimneys may collapse
F1	117-180	73-112	Moderate - mobile homes, autos pushed aside
F2	181-253	113-157	Considerable - roofs torn off houses, large trees uprooted
F3	254-332	158-206	Severe - houses torn apart, trees uprooted, cars lifted

Table 16.3: (continued)

F Scale	(km/hr)	(mph)	Damage
F4	333-419	207-260	Devastating - houses leveled, cars thrown
F5	420-512	261-318	Incredible - structures fly, cars become missiles
F6	>512	>318	Maximum tornado wind speed

Cyclones

A **cyclone** is a system of winds rotating counterclockwise in the Northern Hemisphere around a low pressure center. On the east side, winds come from the south and so are warmer than those on the west side. The swirling air rises and cools, creating clouds and precipitation. Cyclones can be the most intense storms on Earth. There are two types of cyclones: middle latitude cyclones and tropical cyclones. Mid-latitude cyclones are the main cause of winter storms in the middle latitudes. Tropical cyclones are also known as hurricanes.

An **anticyclone**, as you might expect, is the opposite of a cyclone. An anticyclone's winds rotate around a center of high pressure. Air from above sinks to the ground to fill the space left when the air moved away. High pressure centers generally have fair weather. Anticyclone winds move clockwise in the Northern Hemisphere, exactly the opposite of a cyclone. Since winds on the east side of the anticyclone come from the north and those on the west side come from the south, the east side tends to be colder than the west side of the high.

Middle Latitude Cyclones

Middle latitude cyclones, sometimes called extratropical cyclones, form at the polar front when the temperature difference between two air masses is large. These air masses blow past each other in opposite directions. Winds are deflected by Coriolis Effect—to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This causes the winds to strike the polar front at an angle. Warm and cold fronts form next to each other. Most winter storms in the middle latitudes, including most of the United States and Europe, are caused by middle latitude cyclones (**Figure** 16.30).

The warm air at the cold front rises and creates a low pressure cell. Winds rush into the low pressure and create a rising column of air. The air twists, rotating counterclockwise in

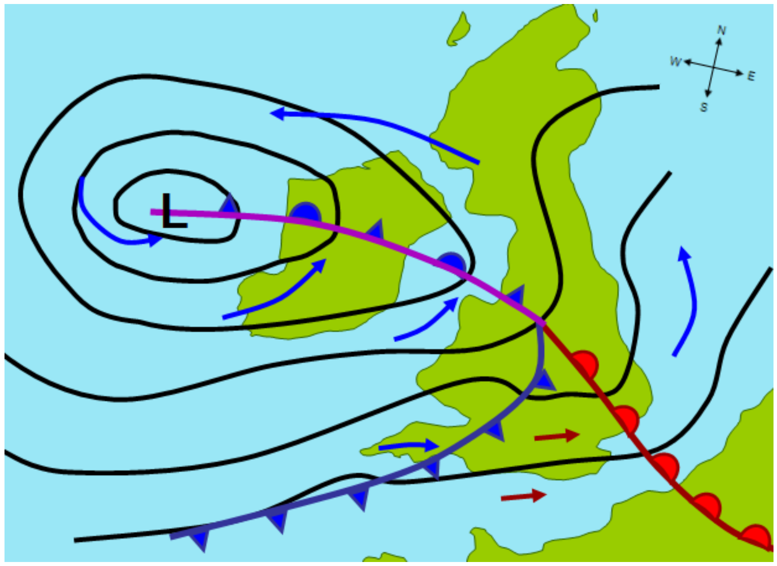

Figure 16.30: A hypothetical mid-latitude cyclone affecting the United Kingdom. The arrows indicate the wind direction and its relative temperature; **L** symbolizes the low pressure area. Notice the warm, cold, and occluded fronts. (21)

the Northern Hemisphere and clockwise in the Southern Hemisphere. Since the rising air is moist, rain or snow falls.

Mid-latitude cyclones form in winter in the mid-latitudes and move eastward with the westerly winds. These two to five day storms can reach 1,000 to 2500 km (625 to 1,600 miles) in diameter and produce winds up to 125 km (75 miles) per hour. Like tropical cyclones, they can cause extensive beach erosion and flooding.

Mid-latitude cyclones are especially fierce in the mid-Atlantic and New England states where they are called **nor'easters**, because they come from the northeast. About 30 nor'easters strike the region each year. Most do little harm, but some are deadly. The typical weather pattern of a nor'easter is familiar to anyone who has lived in this region. First, heavy snow and ice cover the ground. Then, air temperature warms and rain falls. The rain hits the frozen ground and freezes, cloaking everything in ice (**Figure** 16.31).

Hurricanes

Tropical cyclones have many names. They are called **hurricanes** in the North Atlantic and eastern Pacific oceans, *typhoons* in the western Pacific Ocean, *tropical cyclones* in the Indian Ocean, and *willi-willi's* in the waters near Australia (**Figure** 16.32). By any name, they are the most damaging storms on Earth.

For a hurricane to form, sea surface temperature must be 28°C (82°F) or higher. Hurricanes

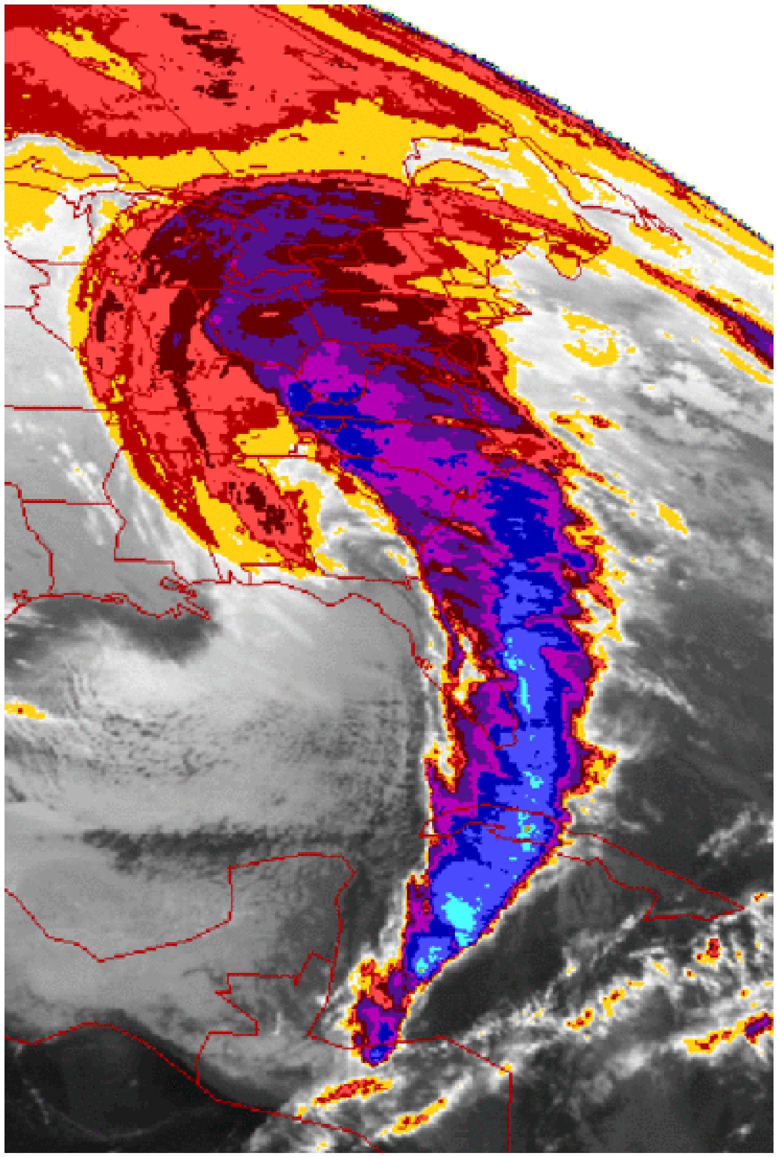

Figure 16.31: The 1993 “Storm of the Century” was a nor’easter that covered the entire eastern seaboard of the United States. (28)

arise in the tropical latitudes (between 10º and 25ºN) in summer and autumn. 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 within the cell reaches or exceeds 28ºC (82ºF) the air begins to rotate around the low pressure. The rotation is counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. As the air rises, water vapor condenses, releasing energy from latent heat. If winds frequently shift directions in the upper atmosphere, the storm cannot grow upward. If wind shear is low, the storm builds into a hurricane within two to three days.

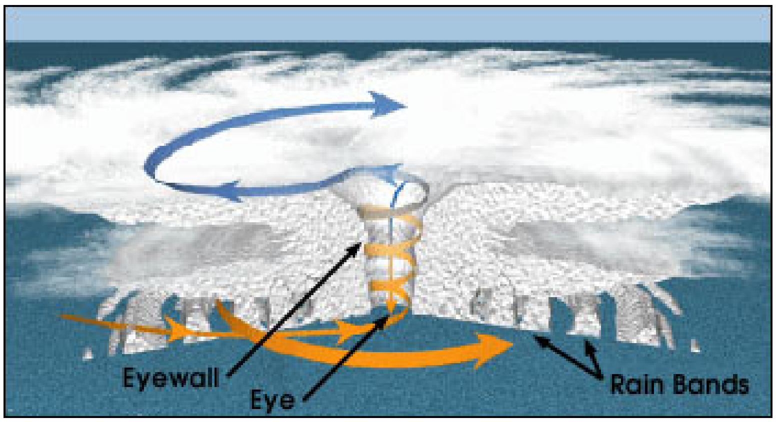

Figure 16.32: A cross-sectional view of a hurricane. (6)

Hurricanes are roughly 600 km (350 miles) across and 15 km (50,000 feet) high. Winds reach at least 118 km (74 miles) per hour. The exception is the relatively calm eye of the storm, which is about 13 to 16 km (8 to 10 miles) in diameter. The eye is calm because it is where air is rising upward.

Rainfall can be as high as 2.5 cm (1") per hour, resulting in about 20 billion metric tons of water released daily in a hurricane. The release of latent heat generates enormous amounts of energy, about 2,000 billion kilowatt hours per day. This amount of energy is nearly the total annual electrical power consumption of the United States. Hurricanes can also generate tornadoes.

Hurricanes are assigned to categories based on their wind speed. An estimate can be made as to the damage that will be caused based on the category of storm. The categories are listed on the Saffir-Simpson hurricane scale (**Table** 16.4).

Table 16.4: **Saffir - Simpson Hurricane Scale**

Category	Kph	Mph	Damage
1 (weak)	119-153	74-95	Above normal; no real damage to structures
2 (moderate)	154-177	96-110	Some roofing, door, and window damage, considerable damage to vegetation, mobile homes, and piers
3 (strong)	178-209	111-130	Some buildings damaged; mobile homes destroyed
4 (very strong)	210-251	131-156	Complete roof failure on small residences; major erosion of beach areas; major damage to lower floors of structures near shore
5 (devastating)	>251	>156	Complete roof failure on many residences and industrial buildings; some complete building failures

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 typically travel from 5 to 40 kph (3 to 25 mph) and can cover 800 km (500 miles) in one day. Their speed and direction depend on the conditions that surround them. This uncertainty makes it hard for meteorologists to accurately predict where a hurricane will go and how strong it will be when it reaches land.

Damage from hurricanes tends to come from the high winds and rainfall, which can cause flooding. Near the coast, flooding is also caused by **storm surge** (**Figure** 16.33). 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. Storm surge may rise as high as 7.0 to 7.5 m

(20 to 25 feet) for up to 160 km (100 miles) along a coastline. If a storm surge is channeled into a narrow bay, it will greatly increase in height.

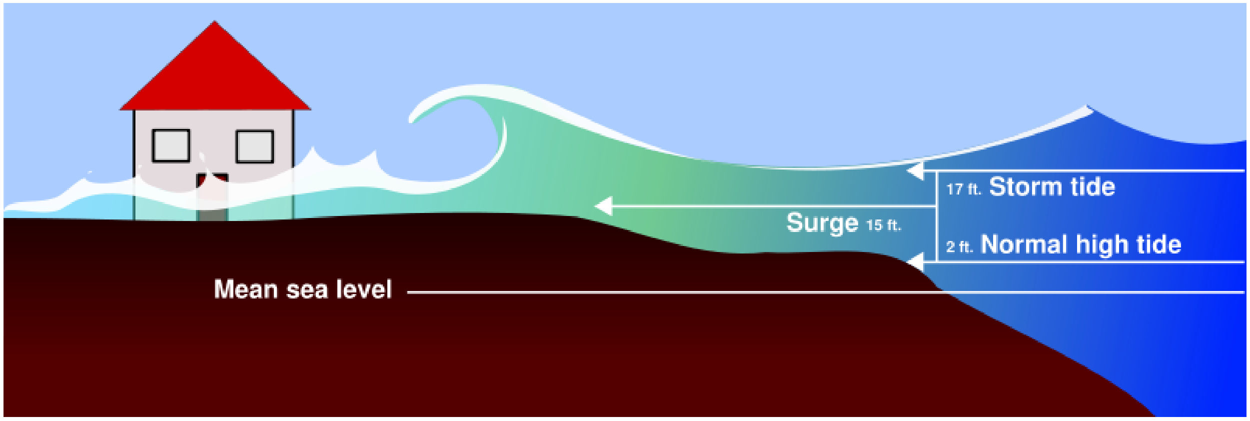

Figure 16.33: Storm surge effects on sea level. (17)

Waves created by a hurricane's high winds and high tide further increase water levels during a storm surge. Flooding can be devastating, especially along low-lying coastlines like 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.

Hurricanes can last from three hours to three weeks, but 5 to 10 days is typical. Once a hurricane travels over cooler water or onto land, its latent heat source is shut down and it will soon weaken. However, an intense, fast-moving storm can travel quite far inland before its demise. In September, 1938 a hurricane made it all the way to Montreal, Canada before breaking up. 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.

The 2005 Atlantic hurricane season was the longest, costliest, and deadliest hurricane season so far. Although the hurricane season officially runs from June 1 to November 30, the 2005 hurricane season was active into January 2006. Total damage from all the storms together was estimated at more than $128 billion, with more than 2,280 deaths. Of the 28 named storms, 15 were hurricanes, including five Category 4 storms and four Category 5 storms on the Saffir-Simpson Scale.

Hurricane Katrina was both the most destructive hurricane and the most costly (**Figure** 16.34). The storm was a Category 1 hurricane as it passed across the southern tip of Florida. It was pushed westward by the trade winds, blowing over the Gulf of Mexico where temperatures were as high as 32°C (89°F). The warm Gulf waters and latent heat fueled the storm until it grew into a Category 5. As it moved through the Gulf, the mayor of the historic city of New Orleans ordered a mandatory evacuation of the city. Not everyone was willing or able to comply.

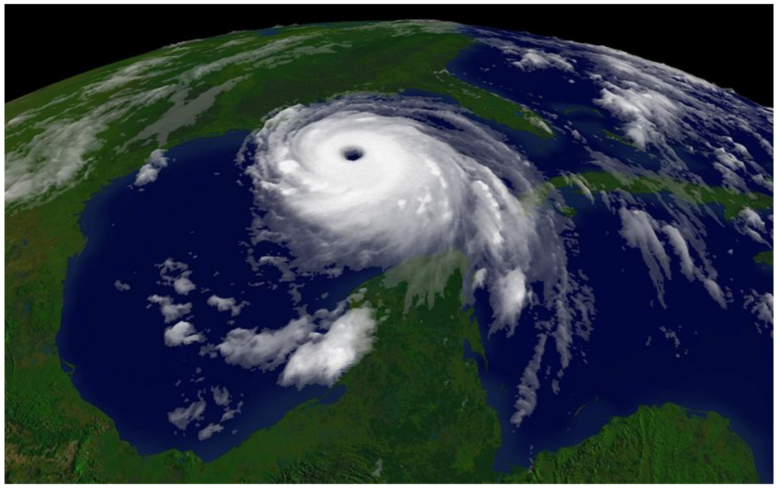

Figure 16.34: Hurricane Katrina nears its peak strength as it travels across the Gulf of Mexico. (24)

When Hurricane Katrina reached the Gulf Coast, it had weakened to a Category 4 storm. Even so, it was the third strongest hurricane to ever hit the United States. The eye of the storm struck a bit east of New Orleans, buffeting the area around Biloxi, Mississippi with the worst direct damage. The initial reports were that New Orleans had been spared. But as water began to rise in the lowest lying portions of the city, officials realized that the storm surge had caused the levee system to breach. Eventually 80% of the city was underwater (**Figure** 16.35). By the end of that horrible period, around 2,500 people were dead or missing from the Gulf Coast, most of them from New Orleans. Over two hundred thousand of people left New Orleans as a result of the hurricane, and many have not returned due to loss of their homes and livelihood.

Blizzards and Lake Effect Snow

A blizzard is distinguished by certain conditions (**Figure** 16.36):

- Temperatures below –7°C (20°F); –12°C (10°F) for a severe blizzard.
- Winds greater than 56 kmh (35 mph); 72 kmh (45 mph) for a severe blizzard.
- Snow so heavy that visibility is 2/5 km (1/4 mile) or less for at least three hours; near zero visibility for a severe blizzard.

Blizzards happen across the middle latitudes and toward the poles. They usually develop on the northwest side of a mid-latitude cyclone. Blizzards are most common in winter, when

Figure 16.35: Flooding in New Orleans after Hurricane Katrina caused the levees to break and water to pour through. (40)

Figure 16.36: A near white out in a blizzard in Minnesota. (22)

the jet stream has traveled south and a cold, northern air mass comes into contact with a warmer, semitropical air mass. The very strong winds develop because of the pressure gradient between the low pressure storm and the higher pressure west of the storm. Snow produced by the storm gets caught in the winds and blows nearly horizontally. Blizzards can also produce sleet or freezing rain.

The snowiest, metropolitan areas in the United States are Buffalo and Rochester, New York. These cities are prone to getting **lake-effect snow**. While other locations can have lake effect snow, the greatest amount is on the leeward side of the Great Lakes. In winter, a continental polar air mass travels down from Canada. As the frigid air travels across one of the Great Lakes, it warms and absorbs moisture. When the air mass reaches the leeward side of the lake, it is very unstable and it drops tremendous amounts of snow. Buffalo is on the leeward side of Lake Erie and Rochester is on the leeward side of Lake Ontario.

While lake effect snow is not a blizzard, the two can work together to create even greater snows. The Great Lakes Blizzard of 1977 was created mostly by the passage of a cold front over the area. The snowfall was aided by lake effect snow coming off of Lake Ontario, which had not yet frozen that winter.

Extreme Heat and Drought

Although not technically storms, extreme heat and drought are important weather phenomena. A heat wave is defined as extreme heat that lasts longer than normal for an area. During a heat wave, a high pressure zone sits over an area and hot air at the ground is trapped. A heat wave can occur because the position of the jet stream makes the area hotter than it is normally. For example, if the jet stream is further north than usual, hot weather can also be found north of where it is usual. Winds coming from a different direction can also make a region hotter than normal. Temperatures that would not ordinarily be too hot may create a heat wave if the humidity rises too high.

More people die from extreme heat on average each year than in any type of storm. The Chicago Heat Wave of 1995 killed about 600 people who did not have access to air conditioning. The world was shocked in July and August 2003, when between 20,000 and 35,000 died in a European heat wave, mostly in France (**Figure** 16.37).

Figure 16.37: Temperature anomalies (outside of the normal, expected range) across Europe in the summer of 2003. France was the hardest hit nation. (26)

Drought strikes a region if it has less rainfall than normal for days, weeks, or years, depending on its location. A normally wet city enters drought at a much greater rainfall level than a city located in the desert. A location may also be experiencing drought, even if it receives rain, if the rain falls so that it is useless to humans. For example, a heavy rain may run off a dried out landscape rather than sinking into the soil and nourishing the plants.

Lesson Summary

- Thunderstorms arise in warm weather when updrafts form cumulonimbus clouds that rain and hail.
- Lightning and thunder result when positive and negative electrical charges in different parts of the cloud and on the ground attempt to equalize.
- Tornadoes form most commonly from thunderstorms. Although they are shorter in duration and affect a smaller area than other severe storms, they do an enormous amount of damage where they strike.
- Cyclones of all sorts are large and damaging; they include nor'easters and hurricanes.
- Heat waves kill more people each year than any type of storm and mostly form in regions beneath an unusually high pressure zone.

Review Questions

1. Describe in detail how a thunderstorm forms and where the energy to fuel it comes from. Start with a warm day and no clouds.
2. How does a thunderstorm break apart and disappear?
3. When and why does a severe thunderstorm get more severe rather than losing energy and disappearing?
4. How do lightning and thunder form?
5. Discuss the pros and cons of living in an area that is prone to tornadoes versus one that is prone to hurricanes.

6. Where are tornadoes most common in the United States?
7. What is a cyclone? What are the two types of cyclone and how do they differ?
8. Describe in detail how a hurricane forms.
9. What level is the most damaging hurricane on the Saffir-Simpson scale? What sorts of damage do you expect from such a strong hurricane?
10. What causes damage from hurricanes?
11. What could have been done in New Orleans to lessen the damage and deaths from Hurricane Katrina?
12. Do you think New Orleans should be rebuilt in its current location?
13. Where do blizzards develop?

Vocabulary

cyclone Winds rotating around a low pressure center.

drought A situation in which there is less precipitation than normal for a matter of days, weeks, or years.

lake-effect snow Extreme snowfall caused by the evaporation of relatively warm, moist air into a cold front that then drops its snow on the leeward side of the lake.

lightning A huge discharge of electricity typical of thunderstorms.

hurricane Cyclones that form in the tropics and spin around a low-pressure center; they can be the world's most damaging storms.

mid-latitude cyclone A cyclone that forms in the middle latitudes at the polar front.

Nor'easter Mid-latitude cyclones that strike the northeastern United States.

storm surge A buildup of sea level due to wind blowing water up against the land and water being sucked upward by low pressure.

thunder The loud clap produced by lightning.

thunderstorm Storms caused by upwelling air and characterized by cumulonimbus clouds, thunder, and lightning.

tornado Violently rotating funnel shaped clouds that grow downward from a cumulonimbus cloud.

tropical depression A low pressure cell that rises in the tropics; thunderstorms materialize around the tropical depression

Points to Consider

- Why is predicting where tornadoes will go and how strong they will be so difficult?
- How would the damage done by Hurricane Katrina have been different if the storm had taken place 100 years ago?
- What knowledge do meteorologists need to better understand storms?

16.4 Weather Forecasting

Lesson Objectives

- List some of the instruments that meteorologists use to collect weather data.
- Describe how these instruments are used to collect weather data from many geographic locations and many altitudes.
- Discuss the role of satellites and computers in modern weather forecasting.
- Describe how meteorologists develop accurate weather forecasts.

Introduction

Weather forecasts are better than they ever have been. According to the World Meteorological Organization (WMO), a 5-day weather forecast today is as reliable as a 2-day forecast was 20 years ago! This is because forecasters now use advanced technologies to gather weather data, along with the world's most powerful computers. Together, the data and computers produce complex models that more accurately represent the conditions of the atmosphere. These models can be programmed to predict how the atmosphere and the weather will change. Despite these advances, weather forecasts are still often incorrect. Weather is extremely difficult to predict, because it is a very complex and chaotic system.

Collecting Weather Data

To make a weather forecast, the conditions of the atmosphere must be known for that location and for the surrounding area. Temperature, air pressure, and other characteristics of the atmosphere must be measured and the data collected. Thermometers measure temperature. One way to do this is to use a temperature-sensitive material, like mercury, placed in a long, very narrow tube with a bulb. When the temperature is warm, the mercury expands, causing it to rise up the tube. Cool temperatures cause the mercury to contract, bringing the level of the mercury lower in the tube. A scale on the outside of the thermometer matches up with the air temperature.

Because mercury is toxic, most meteorological thermometers no longer use mercury in a bulb. There are many ways to measure temperature. Some digital thermometers use a coiled strip composed of two kinds of metal, each of which conducts heat differently. As the temperature rises and falls, the coil unfolds or curls up tighter. Other modern thermometers measure infrared radiation or electrical resistance. Modern thermometers usually produce digital data that can be fed directly into a computer.

Meteorologists use **barometers** to measure air pressure (**Figure** 16.38). A barometer may contain water, air or mercury. Like thermometers, barometers are now mostly digital. Air pressure measurements are corrected so that the numbers are given as though the barometer were at sea level. This means that only the air pressure is measured instead of also measuring the effect of altitude on air pressure.

Figure 16.38: Barometers are Mercury columns used to measure air pressure. (13)

A change in barometric pressure indicates that a change in weather is coming. If air pressure rises, a high pressure cell is on the way and clear skies can be expected. If pressure falls, a low pressure is coming and will likely bring storm clouds. Barometric pressure data over a larger area can be used to identify pressure systems, fronts and other weather systems.

Other instruments measure different characteristics of the atmosphere. Below is a list of a few of these instruments, along with what they measures:

1. anemometers: wind speed
2. hygrometers: humidity
3. wind vane: wind direction
4. rain gauge: the amount of liquid precipitation over a period of time
5. snow gauge: the amount of solid precipitation over a period of time

These instruments are placed in various locations so that they can check the atmospheric characteristics of that location. Weather stations are located on land, the surface of the sea, and in orbit all around the world (**Figure** 16.39). According to the WMO, weather information is collected from 15 satellites, 100 stationary buoys, 600 drifting buoys, 3,000 aircraft, 7,300 ships and some 10,000 land-based stations.

Instruments are also sent into the atmosphere in weather balloons filled with helium or hydrogen. As the balloon ascends into the upper atmosphere, the gas in the balloon expands until the balloon bursts. The specific altitude at which the balloon bursts depends on its diameter and thickness, but is ordinarily about 40 km (25 miles) in altitude. The length of the flight is ordinarily about 90 minutes. Weather balloons are intended to be used only once, and the equipment they carry is usually not recovered.

Weather balloons contain **radiosondes** that measure atmospheric characteristics, such as temperature, pressure and humidity (**Figure** 16.40). Radiosondes in flight can be tracked to obtain wind speed and direction. Radiosondes use a radio to communicate the data they collect to a computer.

Radiosondes are launched from around 800 sites around the globe twice daily (at 0000 and 1200 UTC; UTC is Coordinated Universal Time; it is the same as Greenwich Mean Time — the time in the city of Greenwich, England) at the same time to provide a profile through the atmosphere. Special launches are done when needed for special projects. Radiosondes can be dropped from a balloon or airplane to make measurements as they fall. This is done to monitor storms, for example, since they are dangerous places for airplanes to fly.

Weather information can also come from remote sensing, particularly radar and satellites (**Figure** 16.41). **Radar** stands for *Ra*dio *D*etection *a*nd *R*anging. In radar, a transmitter sends out radio waves. The radio waves bounce off the nearest object and then return to a receiver. Weather radar can sense many characteristics of precipitation: its location, motion, intensity, and the likelihood of future precipitation. Most weather radar is Doppler radar,

Figure 16.39: A land-based weather station. Since some of the instruments must be protected from precipitation and direct heat, they are held behind a screen. (38)

Figure 16.40: A weather balloon with a radiosonde beneath it. The radiosonde is the bottom piece and the parachute that will bring it to the ground, is above it. (39)

which can also track how fast the precipitation falls. Radar can outline the structure of a storm and in doing so estimate the possibility that it will produce severe weather.

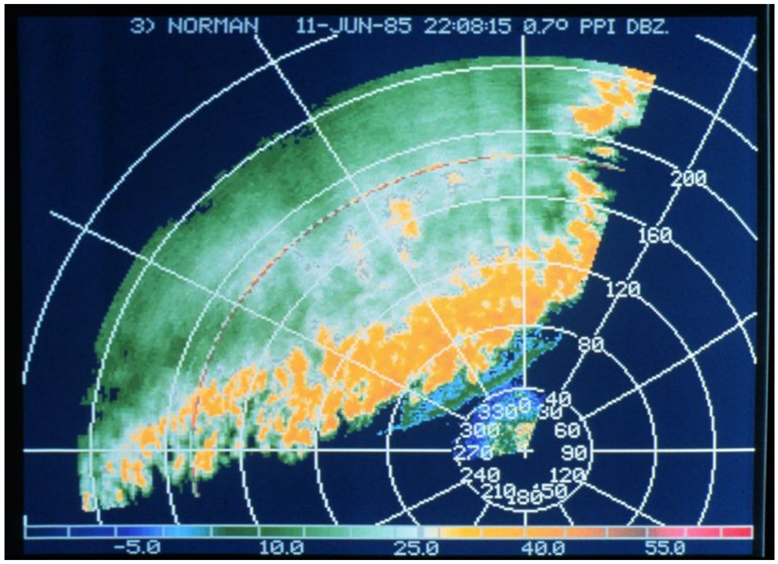

Figure 16.41: Radar view of a line of thunderstorms. (8)

Weather satellites have been increasingly important sources of weather data since the first one was launched in 1952. Weather satellites are the best way to monitor large scale systems, like storms. Satellites can also monitor the spread of ash from a volcanic eruption, smoke from fires, and pollution. They are able to record long-term changes, such as the amount of ice cover over the Arctic Ocean in September each year.

Weather satellites may observe all energy from all wavelengths in the electromagnetic spectrum. Most important are the visible light and infrared (heat) frequencies. Visible light images record images the way we would see them, including storms, clouds, fires, and smog. Infrared images measure heat. These images can record clouds, water and land temperatures, and features of the ocean, such as ocean currents. Weather patterns like the El Niño are monitored in infrared images of the equatorial Pacific Ocean.

Two types of weather satellites are geostationary and polar orbiting (**Figure** 16.42). Geostationary satellites orbit the Earth at the same rate that the Earth rotates; therefore, they remain fixed in a single location above the equator at an altitude of about 36,000 km (22,000 miles). This allows them to constantly monitor the hemisphere where they are located. A geostationary satellite positioned to monitor the United States will have a constant view of the mainland, plus the Pacific and Atlantic Oceans, as it looks for hurricanes and other potential hazards.

Polar orbiting satellites orbit much lower in the atmosphere, at about 850 km (530 miles) in altitude. They are not stationary but continuously orbit making loops around the poles, passing over the same point at around the same time twice each day. Since these satellites

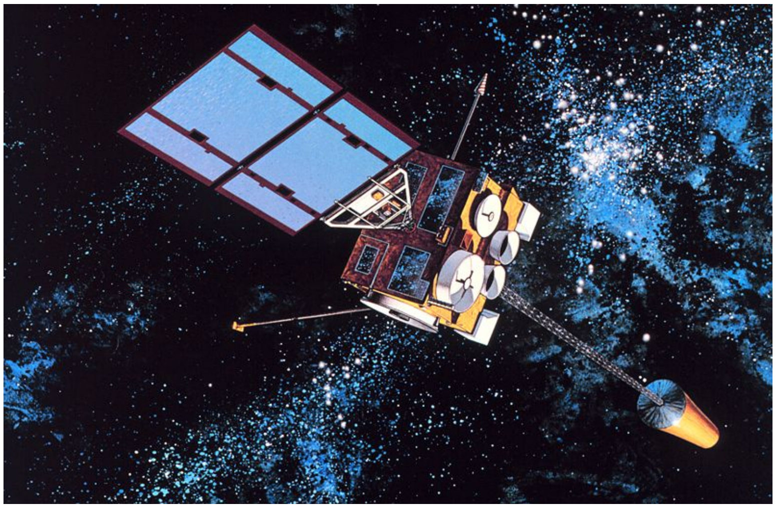

Figure 16.42: One of the geostationary satellites that monitors conditions over the United States. (2)

are lower, they get a more detailed view of the planet.

Forecasting Methods

There are many ways to create a forecast, some simple and some complex. Some use only current, local observations, while others deal with enormous amounts of data from many locations at different times. Some forecasting methods are discussed below.

Perhaps the easiest way to forecast weather is with the 'persistence' method. In this method, we assume that the weather tomorrow will be like the weather today. The persistence method works well if a region is under a stationary air mass or if the weather is consistent from day to day. For example, Southern California is nearly always warm and sunny on summer days, and so that is a fairly safe prediction to make. The persistence method can also be used for long-term forecasts in locations where a warm, dry month is likely to lead to another warm dry month, as in a Southern California summer.

The 'climatology 'method assumes that the weather will be the same on a given date as it was on that date in past years. This is often not very accurate. It may be snowing in Yosemite one New Year's Day and sunny and relatively warm on the next. Using the 'trend' method, forecasters look at the weather upwind of their location. If a cold front is moving in their direction at a regular speed, they calculate when the cold front will arrive. Of course, the front could slow down, speed up, or shift directions, so that it arrives late, early, in a strengthened or weakened state, or never arrives at all. Forecasters use the 'analog' method when they identify a pattern. Just like an analogy compares two similar things, if last week a certain pattern of atmospheric circulation led to a certain type of weather, the forecaster assumes that the same pattern this week will lead to the same weather. There are lots of possible variations in patterns and changes often occur, so this method is also not entirely accurate.

Numerical Weather Prediction

The most accurate weather forecasts are made by advanced computers, with analysis and interpretation added by experienced meteorologists. These computers have up-to-date mathematical models that can use much more data and make many more calculations than would ever be possible by scientists working with just maps and calculators. Meteorologists can use these results to give much more accurate weather forecasts and climate predictions.

In Numerical Weather Prediction (NWP), atmospheric data from many sources are plugged into supercomputers running complex mathematical models. The models then calculate what will happen over time at various altitudes for a grid of evenly spaced locations. The grid points are usually between 10 and 200 kilometers apart. Using the results calculated by the model, the program projects that weather further into the future. It then uses these results to project the weather still further into the future and so on, as far as the meteorologists want to go. The final forecast is called a **prognostic chart** or **prog**.

Certain types of progs are better at particular types of forecasts and experienced meteorologists know which to use to predict different types of weather. In addition to the prog, scientists use the other forecasting methods mentioned above. With so much data available, meteorologists use a computerized system for processing, storage, display and telecommunications. Once a forecast is made, it is broadcast by satellites to more than 1,000 sites around the world.

NWP produces the most accurate weather forecasts, but as anyone knows, even the best forecasts are not always right. Some of the reasons for this are listed below:

- Not enough data was initially entered into the program. This is most likely to happen for a region near an ocean or a remote area.
- The computer program makes certain assumptions about how the atmosphere operates, which may not always be correct.
- The programs only deal with weather locally, which means errors are likely at the edges of the area studied. A global model would be more accurate, but producing one would require an incredible number of calculations.
- The weather system may be too small to show up on the grid. If a system is small, like a thunderstorm, it will not be modeled. If distances between grid points are reduced, many more calculations and therefore more powerful computers are needed.
- There is always the possibility that conditions change unpredictably. Weather is a chaotic system and small, unpredictable things always happen. The farther into the future a model tries to forecast, the more unpredictable things arise to change the forecast.

Weather Maps

Weather maps simply and graphically depict meteorological conditions in the atmosphere. Weather maps may display only one feature of the atmosphere or multiple features. They can depict information from computer models or from human observations. Weather maps are found in newspapers, on television, and on the Internet.

On a weather map, each weather station will have important meteorological conditions plotted. These conditions may include temperature, current weather, dew point, the amount of cloud cover, sea level air pressure, and the wind speed and direction. On a weather map, meteorologists use many different symbols. These symbols give them a quick and easy way to put information onto the map. **Figure** 16.43 shows some of these symbols and explains what they mean (**Figure** 16.44).

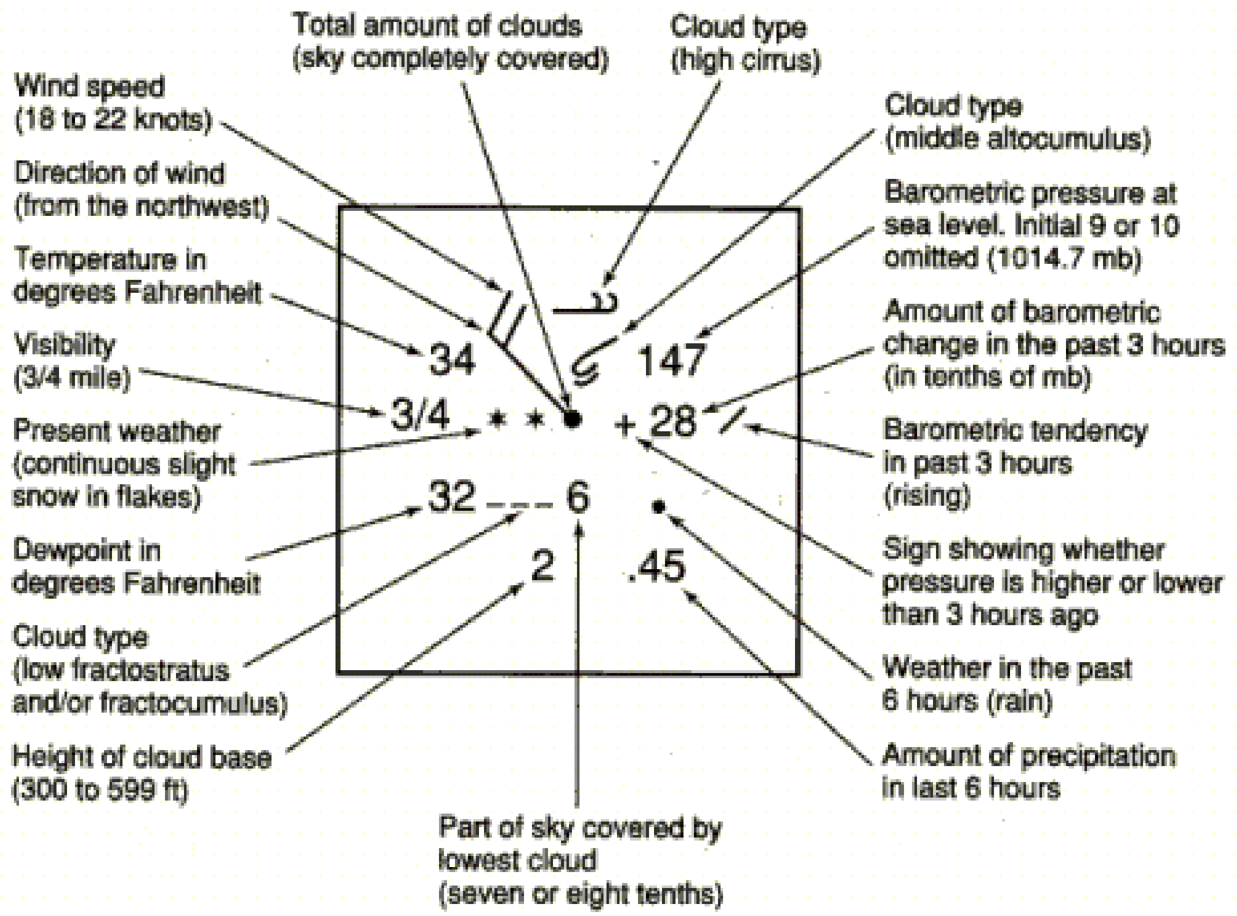

Figure 16.43: Explanation of some symbols that may appear on a weather map. (4)

Once conditions have been plotted, points of equal value can be connected. This is like the contour line on a topographic map, in which all points at a certain elevation are joined.

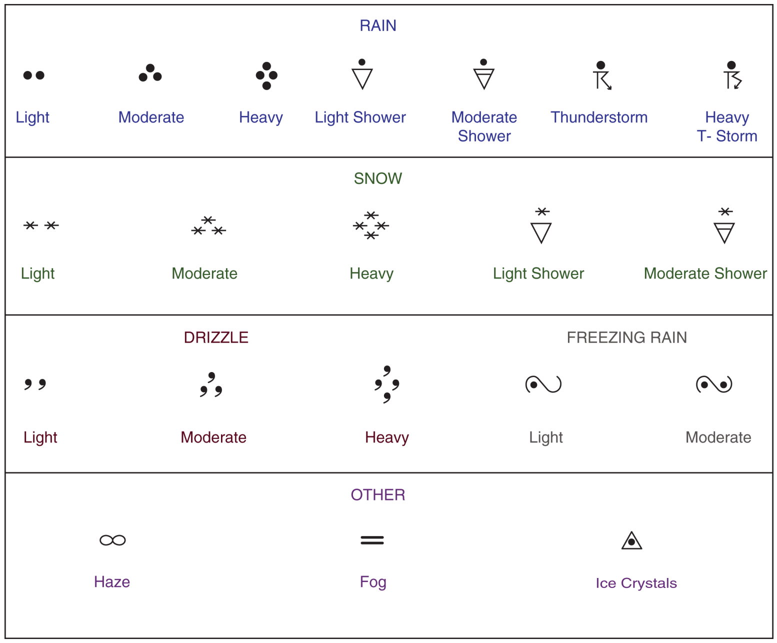

Figure 16.44: Different types of weather that can be shown using a weather symbol. (23)

Weather maps can have many types of connecting lines. For example:

- Lines of equal temperature are called **isotherms**. Isotherms show temperature gradients and can indicate the location of a front. The 0°C (32°F) isotherm will show where rain is likely to give way to snow.
- **Isobars** are lines of equal average air pressure at sea level (**Figure** 16.45). Closed isobars represent the locations of high and low pressure cells. High pressure cells are shown as **H**'s and low pressure cells as **L**'s. A thick, brown dashed line is often placed inside a long low pressure trough.

- **Isotachs** are lines of constant wind speed. Where the minimum values occur high in the atmosphere, tropical cyclones may develop. The highest wind speeds can be used to locate the jet stream.

Surface weather analysis maps are weather maps that only show conditions on the ground (**Figure** 16.46). These maps show sea level mean pressure, temperature and amount of cloud cover. This information will reveal features such as high and low pressure cells.

Weather maps can also depict conditions at higher altitudes. Aviation maps show conditions in the upper atmosphere, particularly those that are of interest to pilots. These include current weather, cloud cover, and regions where ice is likely to form.

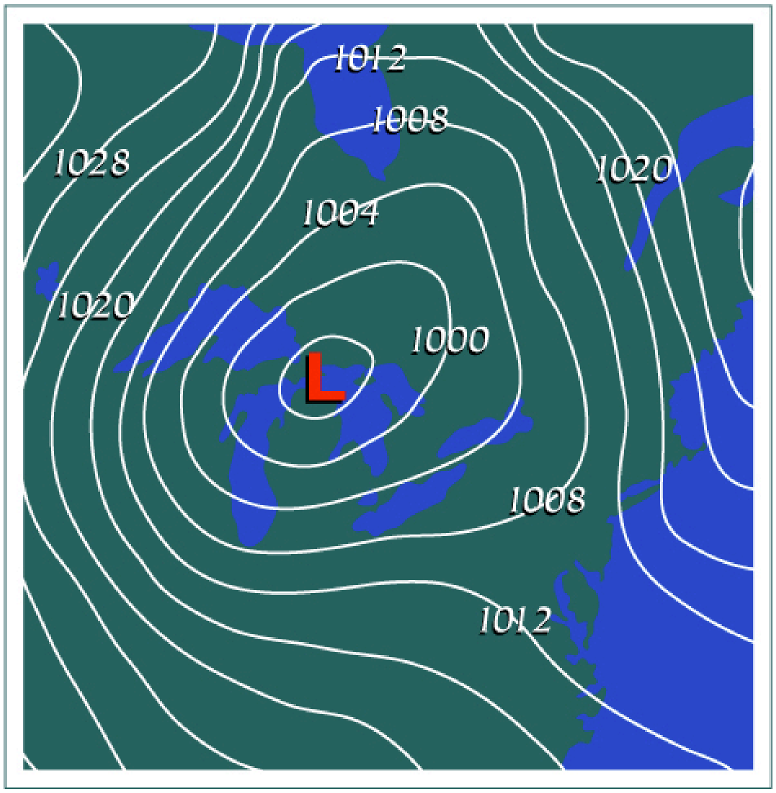

Figure 16.45: Lines of equal pressure drawn on a weather map are isobars. Isobars can be used to help visualize high and low pressure cells. (29)

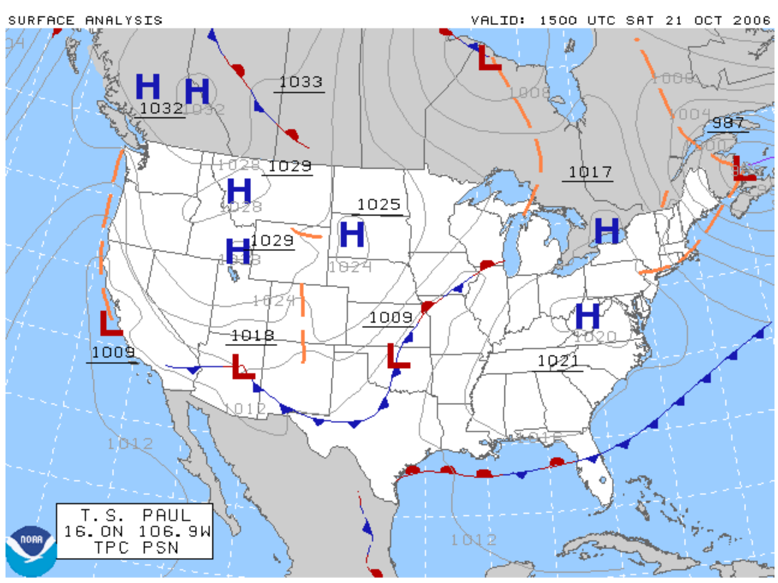

Figure 16.46: Surface analysis map of the contiguous United States and southern Canada. (5)

Lesson Summary

- Weather forecasts are more accurate than ever before. Older instruments and data collection methods such as radiosondes and weather balloons are still used.
- These techniques have now been joined by satellites and computers to create much more detailed and accurate forecasts.
- Still, forecasts are often wrong, particularly those that predict the weather for several days.
- Meteorologists are working hard to improve weather forecasts one to two weeks in advance of potentially hazardous weather.

Review Questions

1. What types of instruments would you expect to find at a weather station and what do these instruments measure?
2. How does a thermometer work?
3. How could a barometer at a single weather station be used to predict an approaching storm?
4. Why are weather balloons important for weather prediction? What information do they give that isn't obtainable in other ways?
5. How does radar work, and what is its value in weather prediction?
6. What type of weather satellite is best to use for monitoring hurricanes that may cause problems in the United States and why?
7. Imagine that your teacher asks you to predict what the weather will be like tomorrow. You can go outside, but can't use a TV or computer. What method will you use?
8. Imagine that you need to predict tomorrow's weather and you are allowed to use a telephone, but no other electronics. Who will you call and what method will you use?
9. Okay, now you need to predict tomorrow's weather and you have access to electronics, but not to weather forecasts. That is, you can look at information such as weather maps and radar images but you cannot look at the interpretations made by a meteorologist. Now what method are you using?
10. No rain is in the forecast, but it's pouring outside. How could the NWP weather forecast have missed this weather event?
11. What does it mean to say that weather is a chaotic system? How does this affect the ability to predict the weather?

Further Reading / Supplemental Links

- National Doppler Radar Sites http://radar.weather.gov/
- Google Earth Visualizations, Barnabu http://www.barnabu.co.uk/global-cloud-animations-upd

Vocabulary

barometer An instrument for measuring atmospheric pressure.

isobars Lines connecting locations that have equal air pressure.

isotachs Lines connecting locations that have equal wind speed.

isotherms Lines connecting locations that have equal temperatures.

prognostic chart (prog) A chart showing the state of the atmosphere at a given time in the future.

radar Radio detection and ranging device that emits radio waves and receives them after they bounce on the nearest surface. This creates an image of storms and other nearby objects.

radiosonde A group of instruments that measure the characteristics of the atmosphere—temperature, pressure, humidity, etc. — as they move through the air.

weather map A map showing weather conditions over a wide area at a given time, it collects data from many locations.

weather satellite A human made object that orbits the Earth and senses electromagnetic waves, mostly in the visible light and infrared spectra.

Points to Consider

- With so much advanced technology available, what is the role of meteorologists in creating accurate weather forecasts?
- With so much advanced technology available, why are weather forecasts so often wrong?
- What advances do you think will be necessary for meteorologists to create accurate weather forecasts one- to two-weeks in advance of a major weather event?

Image Sources

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Chapter 17

Climate

17.1 Climate and Its Causes

Lesson Objectives

- Describe the effect of latitude on the solar radiation a location receives and how this influences climate.
- Diagram the Hadley, Ferrell and Polar atmospheric circulation cells and show how they influence the climate of various locations.
- Discuss the other important location factors that influence a location's climate: position in the global wind belts, proximity to a large water body, position relative to a mountain range and others.

Introduction

While almost anything can happen with the weather, climate is more predictable. The weather on a particular winter day in San Diego may be colder than on the same day in Lake Tahoe, but, on average, Tahoe's winter climate is significantly colder than San Diego's. Climate then is the long-term average of weather. Good climate is why we choose to vacation in Hawaii in February, even though the weather is not guaranteed to be good!

What is Climate?

Weather is what is happening in the atmosphere at a particular location at the moment. Climate is the average of weather in that location over a long period of time, usually for at least 30 years. A location's climate can be described by its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation. The climate of a location depends on it position relative to many things. Most important is latitude, but other factors include global and local winds, closeness to an ocean or other large bodies of water, nearness to mountains, and altitude. Climate can change, but only over long periods of time.

The term climate also refers to Earth's entire climate system. The climate system is influenced by the movement of heat around the globe. Heat is carried by currents within the atmosphere and oceans. The type and amount of vegetation also affects climate. Plants absorb heat and retain water, which may increase or decrease rainfall. The composition of the atmosphere also controls climate. If the concentration of greenhouse gases increase or decrease, the heat-trapping abilities of the atmosphere rise or fall.

Latitude

The amount of solar energy a particular location receives is the most important factor in determining that location's temperature. The amount of sunlight that strikes the ground is different at each latitude. The lower the latitude, the more sunlight an area will receive. At the equator, days are equally long year-round and the sun is just about directly overhead at midday. At the poles, during the winter, nights are long and the sun never rises very high in the sky. Sunlight filters through a thick wedge of atmosphere, making the sunlight much less intense. Ice and snow at high latitudes also reflect a good portion of the sun's light, giving these regions much greater albedo.

This animation shows the average surface temperature across the planet as it changes through the year

Monthly Mean Temperatures (http://upload.wikimedia.org/wikipedia/commons/b/b3/MonthlyMeanT.gif)

From all this information you can understand why the tropics are warmer than the polar areas. The temperate regions are in between, both in latitude and average air temperature. The air in Earth's atmosphere moves as the Sun warms some areas more than others. The main reason we have different climates at various latitudes is also determined by the amount of sunlight that hits each place (**Figure** 17.1).

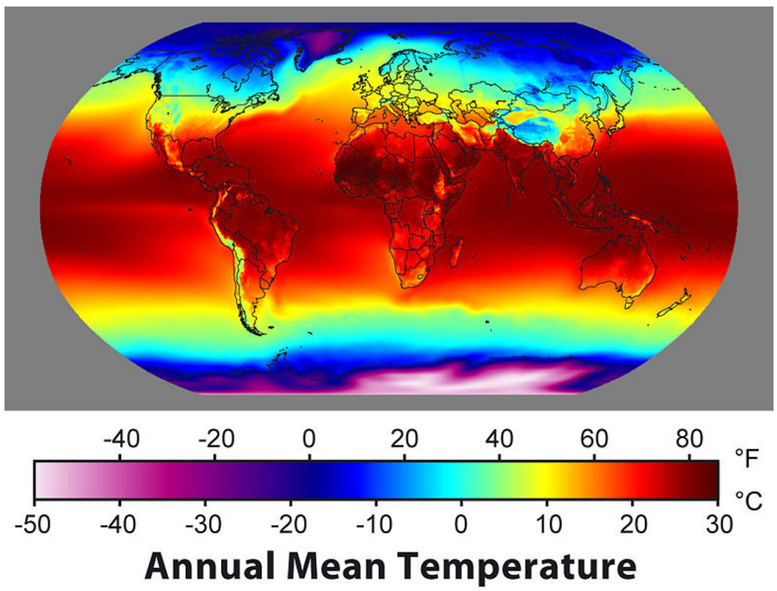

Figure 17.1: This map of annual average temperatures shows how dramatically temperature decreases from the low latitudes to the high latitudes. (21)

Prevailing Winds

There are winds that usually blow in one particular direction, called the global wind belts. These winds are called the trade winds, the westerlies and the polar easterlies. The direction these winds blow is different at various latitudes. In the Earth's Atmosphere chapter, you learned that air rises at low pressure areas, which form at 0° and again at 50° to 60° north and south of the equator. Air sinks at high pressure areas, which form at around 30° N and S and at the poles. These low and high pressure zones represent the upward and downward flowing regions of the Hadley, Ferrell and Polar atmospheric circulation cells (**Figure** 17.2). Low pressure areas form where air is moving upwards or rising. High pressure areas form where cooler, drier air sinks. Areas of high pressure often have climates that are cooler and drier. Low pressure zones often have climates that are warm and rainy.

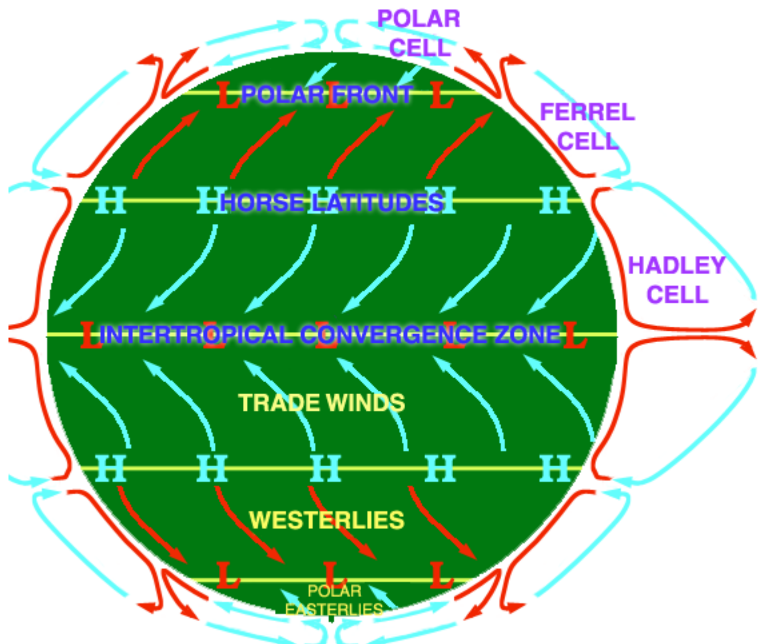

Figure 17.2: The atmospheric circulation cells and their relationships to air movement on the ground. (34)

The low pressure area near the equator is located at the boundary between the two Hadley Cells. In both these cells, air rises up at the equator and then travels away from the equator. This band of rising air is called the **Intertropical Convergence Zone (ITCZ)** (**Figure** 17.3). As the air rises, it cools and condenses to create clouds and rain. Climate along the ITCZ is therefore warm and wet. In an area where the air is mostly rising, there is not much wind. Early mariners called this region the doldrums because their ships were often unable to sail without steady winds.

The ITCZ migrates slightly with the season. Land areas heat more quickly than the oceans. Since there are more land areas in the Northern Hemisphere, the ITCZ is influenced by the heating effect of the land. In Northern Hemisphere summer, it is approximately 5 º north of the equator while in the winter, it shifts back and is approximately at the equator. As the ITCZ shifts, the major wind belts also shift slightly north in summer and south in winter, which causes the wet and dry seasons in this area (**Figure** 17.4).

At the high pressure zone where the Hadley cell and Ferrell cells meet, at about 30ºN and 30ºS, the air is fairly warm since much of it came from the equator. It is also very dry for two reasons: (1) The air lost much of its moisture at the ITCZ, and (2) Sinking air is more likely to cause evaporation than precipitation. Mariners had a very grim reason for naming this region the horse latitudes. Often the lack of wind would cause their ships to be delayed

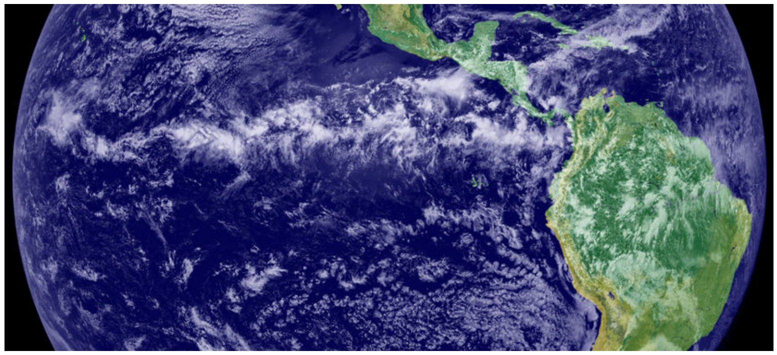

Figure 17.3: The ITCZ can be easily seen where thunderstorms are lined up north of the equator. (8)

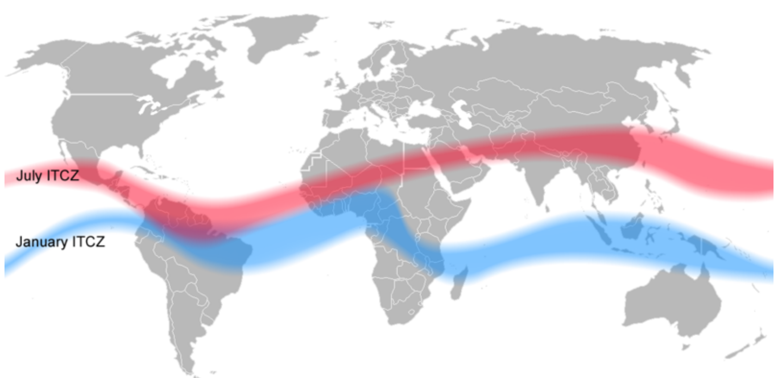

Figure 17.4: Seasonal differences in the location of the ITCZ are shown on this map. (7)

for so long that they would run out of water and food for their livestock. Sailors would toss horses and other animals over the side of the ship after they died. Sailors sometimes didn't make it either. On land, these high pressure regions mark the locations of many of the world's great deserts, including the Sahara in Africa and the Sonora in North America.

The other low pressure zone is between the Ferrell and Polar Cells at around 50-60º. This is the usual location of the polar jet stream, where cold air from the poles meets warmer air from the tropics and storms are common. As the Earth orbits the Sun, the angle of the Sun shifts between 23.5°N and 23.5°S; in turn, this shift causes the polar jet stream to move. Like the ITCZ, the position of the polar jet stream moves seasonally, creating seasonal weather changes in the mid-latitudes.

The direction of the prevailing winds greatly influences the climate of a region. These winds form the bases of the Hadley, Ferrell and Polar Cells. Winds often bring the weather from the locations they come from. For example, in California, the predominant winds are the westerlies. These winds blow in from the Pacific Ocean. The stability of the ocean's temperatures moderates California temperatures, so that summers are cooler and winters are warmer. In the middle of the continent, the winds bring more variable conditions. Local winds also influence local climate. For example, land breezes and sea breezes moderate coastal temperatures.

Continental Position

When a particular location is near an ocean or large lake, the body of water plays an extremely important role in affecting the region's climate. When a location has a **maritime climate** its climate is strongly influenced by the nearby sea: summers are not too hot and winters are not too cold. Temperatures also do not vary much between day and night. For a location to have a true maritime climate, the winds must most frequently come off the sea. A **continental climate** is more extreme, with greater temperature differences between day and night and between summer and winter.

The ocean's influence in moderating climate can be seen in the following temperature comparisons. Each of these cities is located at 37°N latitude, within the westerly winds. San Francisco is on the Pacific coast; Wichita, Kansas is in the middle of the North American continent; and Virginia Beach, Virginia is on the Atlantic coast. San Francisco is cooler in July and warmer in January than either of the other two cities. This is typical of a maritime climate; not too hot, not too cold. Wichita has the greatest range of temperatures; the hottest temperatures in July and coldest in January, which is typical for a continental climate. Although Virginia Beach is located on the Atlantic Ocean, it has a mostly continental climate since the westerly winds come off the continent (**Table** 17.1).

Table 17.1: **Average Temperature**

Location	City	July: high (°C/°F)	January: low (°C/°F)
West Coast	San Francisco, CA	19/66	8/46
Central United States	Wichita, KS	33/92	−7/20
East Coast	Virginia Beach, VA	32/89	1/31

(Source: wikipedia.org)

Ocean Currents

The temperature of the water offshore will influence the temperature of a coastal location, particularly if the winds come off the sea. The California Current runs from north to south along the length of the western coast of North America. The cool waters of the California Current bring cooler temperatures to the California coastal region. Coastal upwelling also brings cold, deep water up to the ocean surface off of California, which contributes to the cool, coastal temperatures. Further north, in southern Alaska, the upwelling actually raises the temperature of the surrounding land because the ocean water is much warmer than the land.

The California Current is part of the global system of surface ocean currents that spread the Sun's heat around the world. These currents bring cool water from high latitudes to the low latitudes and warm water from low latitudes to the high latitudes. Just as the California current brings cooler temperatures into the temperate regions, the Gulf Stream raises air temperatures along the southeastern United States as it brings warm equatorial water north along the Western Atlantic ocean (**Figure** 17.5).

The Gulf Stream even has a large effect on the climate of Northern Europe. After it travels past Canada, the current moves eastward across the Atlantic and then splits. One portion flows northward between Great Britain and Northern Europe, the other moves south along Europe and northern Africa. These warm waters raise temperatures in the North Sea, which raises air temperatures over land between 3 to 6°C (5 to 11°F). London, U.K. for example, is at the same latitude as Quebec, Canada. However, London's average January temperature is 3.8°C (38°F), while Quebec's is only -12°C (10°F). Because air traveling over the warm water in the Gulf Stream picks up a lot of water, London gets a lot of rain. In contrast, Quebec is much drier and receives its precipitation as snow.

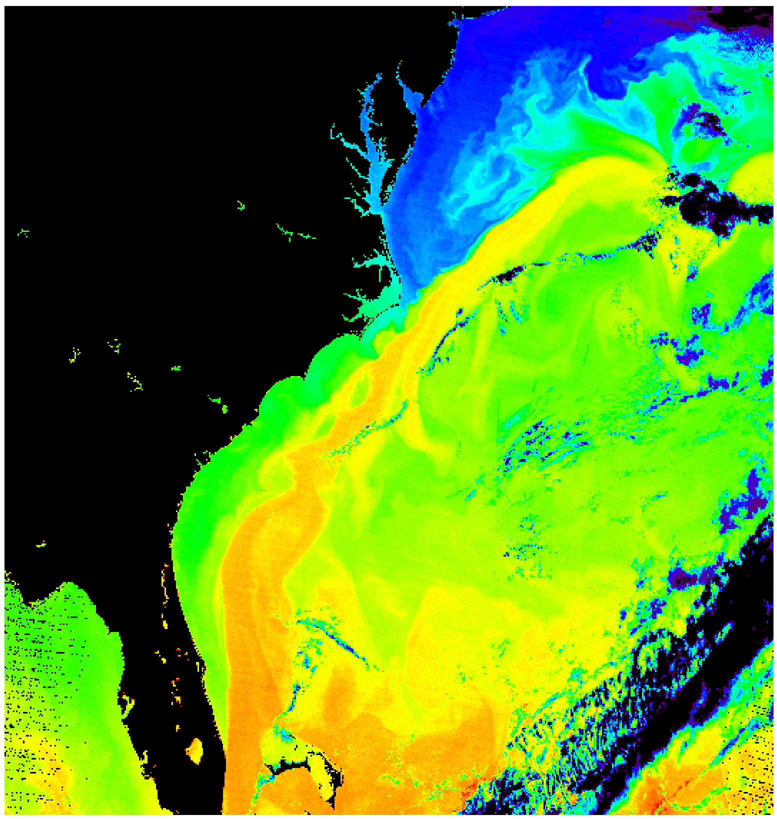

Figure 17.5: The Gulf Stream can be identified in this image of the Atlantic Ocean off of the eastern United States and Canada. The warm current appears in orange and yellow. (29)

Altitude and Mountain Ranges

All else being equal, air temperature decreases at higher altitudes. A town at 3000 meters in the mountains will be much cooler, on average, than a town at the base of the same mountains. Gravity pulls air molecules closer together at sea level than at higher altitudes. The closer molecules are packed together, the more likely they are to collide. Collisions between molecules give off heat, which warms the air. At higher altitudes, the air is less dense and air molecules are more spread out and less likely to collide.

Mountain ranges have two effects on the climate of the surrounding region. One is the rainshadow effect. As moist air rises over a mountain, it cools and drops precipitation. The air then descends down the leeward side of the range. This process creates a high pressure region on the back side of the mountain where evaporation exceeds precipitation. The result is that the windward side of the mountain range is wet but the leeward side is dry. The other effect occurs when the mountain range separates the coastal region from the rest of the continent. In this case, the ocean can only influence the coastal area before the mountain range. The coastal area near the ocean will have a maritime climate but just over the mountain, the inland area will have a continental climate.

California has two mountain ranges that exhibit both effects on climate: the Coast Range right along the coast and the Sierra Nevada, further east. The predominant winds here are the westerlies, winds that blow from the west over the ocean onto the continent. Both ranges trap cool air from the Pacific so that it has a difficult time moving eastward. As this moist ocean air rises over the Coast Range, it drops a lot of rain on the windward side. A rainshadow is created as the air then descends into the Central Valley, some of which receives so little rainfall it is classified as a desert. As the air continues eastward, it rises over the Sierra Nevada Mountains and drops more rain and snow on the west side of these mountains. On the leeward side, the air then descends into Nevada. The Sierra Nevada rain shadow creates the Great Basin desert, covering Nevada, western Utah and a small part of southeastern Oregon (**Figure** 17.6).

Lesson Summary

- Many factors influence the climate of a region, all of them somehow related to the region's position.
- Latitude determines how much solar energy a particular place receives during a day or a year.
- Latitude is directly related to location within one of the global wind belts, therefore latitude determines if a location is beneath a high or low pressure cell, where winds are low.
- If a region is near a large water body, its climate will be influenced by that water body.
- Mountain ranges can separate land areas from the oceans and can create rainshadow effects, which also influence climate.

Figure 17.6: The Bonneville Salt Flats are part of the very dry Great Basin. They receive so little rainfall because they are on the leeward side of the Sierra Nevada, part if its rainshadow. (17)

Review Questions

1. Describe the weather of the location where you are right now. How is the weather today typical or atypical of your usual climate?
2. In what two ways could a desert be found at 30°N?
3. Could a desert form at 45°N latitude?
4. Why is there so little wind in the locations where the atmospheric circulation cells meet?
5. If it is windy at 30°N where there is normally little wind, does that mean the model of the atmospheric circulation cells is wrong?
6. What is the Intertropical Convergence Zone (ITCZ)? What winds do you expect to find here?
7. How does the polar jet stream move from summer to winter? How would this affect the climate of the locations where it moves?
8. How would the climate of a city at 45°N near the Pacific Ocean differ from one at the same latitude near the Atlantic Coast?
9. Why does the ocean water off California cool the western portion of the state, while the water off the southeastern United States warms that region?
10. Think about what you know about surface ocean currents. How would you expect the climate of western South America to be influenced by the Pacific Ocean? Could this same effect happen in the Northern Hemisphere?
11. The Andes Mountains line western South America. How do you think they influence the climate of that region and the lands to the east of them?

Vocabulary

climate Weather averaged over a long period of time, usually about 30 years.

continental climate A location in which the climate is dominated by a vast expanse of land. Continental climates are more variable.

Intertropical Convergence Zone (ITCZ) A low pressure zone where the Hadley Cells in the northern and southern hemispheres meet. The trade winds meet at the ITCZ.

maritime climate A location in which the climate is dominated by a nearby ocean. Maritime climates are less variable than continental climates.

rainshadow Dry conditions that are created on the leeward side of a mountain range.

upwelling Upward flow of deep water to the surface because the deep water is less dense than the surface water.

Points to Consider

- Describe how two cities at the same latitude can have very different climates. For example, Tucson, Arizona has a hot, dry desert climate and New Orleans, Louisiana has a warm, muggy climate even though both cities are at approximately the same latitude.
- How does climate influence the plants and animals that live in a particular place?
- Would you expect climate at similar latitudes to be the same or different on the opposite side of the equator, e.g. how would the climate of a city at 45°N be similar or different to one at 45°S latitude?

17.2 World Climates

Lesson Objectives

- Describe the relationship between the climate zones and the factors that influence climate.
- Discuss the relationship between climate zones and biomes.
- Discuss the different biomes based on a general description.

Introduction

A climate zone results from the climate conditions of an area: its temperature, humidity, amount and type of precipitation, and the season. A climate zone is reflected in a region's natural vegetation. Perceptive travelers can figure out which climate zone they are in by looking at the vegetation, even if the weather is unusual for the climate on that day!

Climate Zones and Biomes

The major factors that influence climate also determine the different climate zones. The same type of climate zone will be found at similar latitudes and in similar positions on nearly all continents, both in the Northern and Southern Hemispheres. The one exception to this pattern is the climate zones called the continental climates, which are not found at higher latitudes in the Southern Hemisphere. This is because the Southern Hemisphere land masses are not wide enough to produce a continental climate.

Climate zones are classified by the Köppen classification system (**Figure** 17.7). This system is based on the temperature, the amount of precipitation and the times of year when precipitation occurs. Since climate determines the type of vegetation that grows in an area, vegetation is used as an indicator of climate type. A climate type and its plants and animals make up a **biome**. The organisms of a particular biome share certain characteristics around the world, because their environment has similar advantages and challenges. The organisms have adapted to that environment in similar ways over time. For example, different species of cactus live on different continents, but they have adapted to the harsh desert in similar ways.

The Köppen classification system recognizes five major climate groups, each with a distinct capital letter A through E. Each lettered group is divided into subcategories. Some of these subcategories are forest (f), monsoon (m), and wet/dry (w) types, based on the amount of precipitation and season when that precipitation occurs.

Tropical Moist Climates (Group A)

Tropical Moist (Group A) climates are found in a band about 15° to 25° N and S of the equator (**Figure** 17.8). Intense sunshine means that the tropics are warm year-round: each month has an average temperature of at least 18°C (64°F). Rainfall is abundant — at least 150 cm (59 inches) per year. The subcategories of this zone are based on when the rain falls.

Tropical Wet (Af)

The wet tropics lie in a band around the equator, covering about 10% of the Earth's land. The wet tropics are consistently warm, with almost no annual temperature variation. Great

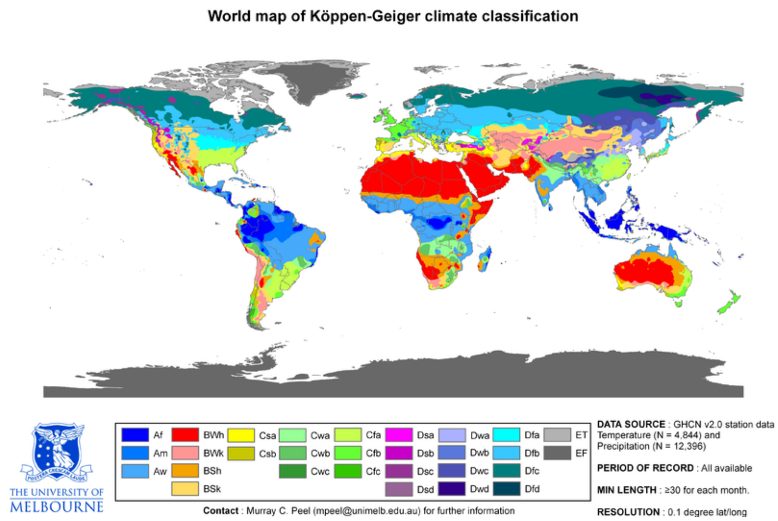

Figure 17.7: This world map of the Köppen classification system gives a good general idea of where the climate zones and major biomes are located. Where the groups are not represented by stripes (like in the western United States) the situation is complicated by geographic features such as mountains. All of the c (12)

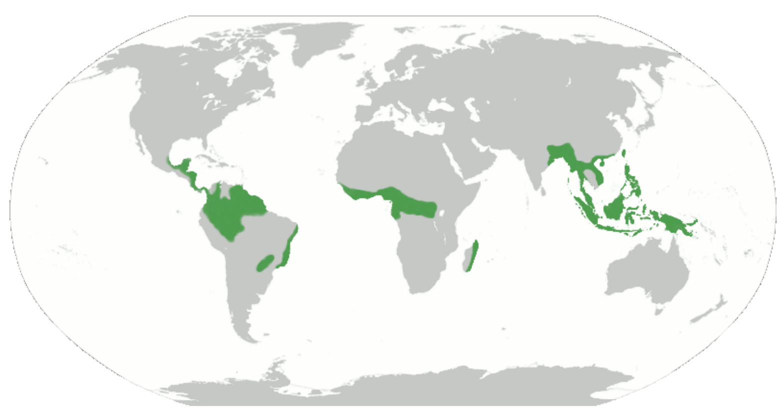

Figure 17.8: Tropical Moist Climates (Group A) are shown in green. The main vegetation for this climate is the tropical rainforest, which are found in the Amazon in South America, the Congo in Africa and the lands and islands of southeast Asia. (5)

amounts of rain fall year-round, between 175 and 250 cm (65 and 100 inches) per year. These conditions support the **tropical rainforest** biome (**Figure** 17.9). The forest is dominated by densely packed, broadleaf evergreen trees. Many habitats are found in rainforests, as a result of the high number of plant types and the different environments within the layers of the forest. Rainforests have the highest number of species or **biodiversity** of any ecosystem.

Figure 17.9: The Amazon river and rainforest in Brazil. (35)

Tropical Monsoon (Am)

The *tropical monsoon* climate resembles the tropical wet biome (Af) but has very low precipitation for one to two months each year. During these months, less than 6 cm (2.4 inches) of rain falls. Rainforests can grow here because the dry period is short, and the trees can be supported by moisture trapped in the soil. This climate is found where the monsoon winds blow, primarily in southern Asia, western Africa, and northeastern South America.

Tropical Wet and Dry (Aw)

The *tropical wet and dry* climate lies north and south of the tropical wet climate, between about 5° and 10° latitude to around 15° to 20° latitude. The average annual temperature is similar to the wet tropics, but the temperature range is greater. This climate zone receives less rain than the wet tropics, about 100 to 150 cm (40 to 60 inches). For more than two months each year, rainfall is less than 6 cm (2.4 inches). Wet and dry seasons are related to the location of the ITCZ. In the summer, when the ITCZ drifts northward, the zone is wet. In the winter, when the ITCZ moves back toward the equator, the region is dry. This climate exists where strong monsoon winds blow from land to sea, such as in India.

Rainforests cannot survive the months of low rainfall, so the typical vegetation is **savanna** (**Figure** 17.10). This biome consists mostly of grasses, with widely scattered deciduous trees and rare areas of denser forests. Central Africa is famous for its savanna and the unique animals that live there.

Figure 17.10: A male lion stalks the African savanna. (19)

Dry Climates (Group B)

The *Dry Climates* (Group B) generally have less precipitation than evaporation and are further from the equator than Tropical (Group A) climates. They have cooler winters and longer, harsher dry seasons. Rainfall is irregular; several years of drought are often followed by a single year of abundant rainfall. Summer temperatures are high, and much of the rain evaporates before it reaches the ground. Dry climate zones cover about 26% of the world's land area. Low latitude **deserts** form as a result of the Ferrell cell high pressure zone. Higher latitude deserts occur within continents or in rain shadows where the air has little humidity.

Arid Desert (Bw)

Low-latitude, arid deserts are found between 15° to 30° N and S latitudes. This is where warm dry air sinks at high pressure zones. True deserts make up around 12% of the world's lands. Deserts are found in southwestern North America, Africa, Australia and central Asia. Humidity is low, and as a result there are few clouds in the sky. The Sahara is the world's largest desert (**Figure** 17.11).

In the Sonora Desert of the southwestern United States and northern Mexico, most weather stations record sunshine 85% of the time, both in summer and winter (**Figure** 17.12). Clear skies allow the ground to heat rapidly during the day and cool rapidly at night. The summer

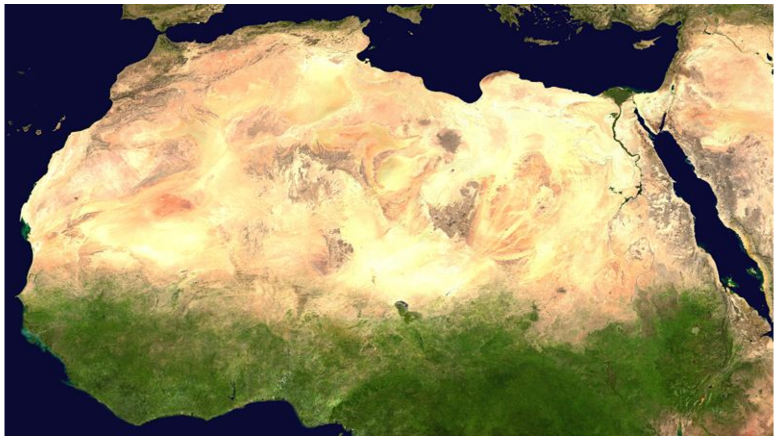

Figure 17.11: The Sahara desert takes up much of northern Africa. The green band below the sandy Sahara is the Congo. (10)

sun can be merciless and daytime temperatures are extremely hot. Temperatures often plunge when the Sun goes down and the daily temperature range may be 15° to 25°C (27° to 45°F). Annual rainfall is mostly less than 25 cm (10 inches). The Sonora desert gets much of its rain in the winter, when storms come in from the Pacific. Summer monsoon rains drop a great deal of rain in some areas. The existence of two wet seasons a year allows a unique group of plants and animals to survive in the southwestern deserts.

Vegetation is limited, since water is scarce. Desert plants are adapted to surviving long periods of drought. Cacti and shrubby plants have wide or deep roots to reach water after a rain. Many desert plants are able to store water. Some plants lie dormant as seeds, and bloom after rain falls.

Semi-arid or Steppe (Bs)

Deserts in continental interiors or in rain shadows are found at higher latitudes. Semi-arid deserts often receive more rain than the arid deserts, between 20 to 40 cm (8 to 16 inches) annually. Because land areas change temperature easily, these areas have lower annual average temperatures plus greater annual temperature ranges. In the winter, these climate zones get very cold under cold high pressure cells. In the summer, they heat up, allowing air to rise and rain to fall.

In the United States, the Great Plains, portions of the southern California coast and the Great Basin are semi-arid deserts. The biome is called **steppe**, which has short bunch grass, and scattered low bushes, or sagebrush (**Figure** 17.13). A steppe has few or no trees because there is not enough rain for trees to grow.

Figure 17.12: The Sonora desert is home to many well-adapted plants including cacti, scrubby bushes, and perennials. (14)

Figure 17.13: This photo of the Great Basin in Utah illustrates the steppe biome. (26)

Moist Subtropical Mid-latitude (Group C)

The *Moist Subtropical Mid-latitude* (Group C) climates are found along the coastal areas in the United States. Seasons are distinct, although winters are mild. The average temperature of the coldest month ranges from just below freezing to almost balmy, between -3°C and 18°C (27° to 64°F). Summers are often mild with average temperatures above 10°C (50°F). There is plentiful annual rainfall.

Dry Summer Subtropical or Mediterranean Climates (Cs)

The *Dry Summer Subtropical* climate is found on the western sides of continents between 30° and 45° latitude. Annual rainfall is 30 to 90 cm (14 to 35 inches), most of which comes in the winter. This climate is also called the *Mediterranean* climate because it is found around the Mediterranean Sea (**Figure** 17.14). The climate is also typical of coastal California, which sits beneath a summertime high pressure for about five months each year. Land and sea breezes make winters moderate and summers cool. The mild winters and foggy summers of San Francisco represent a coastal Mediterranean climate. Further inland in Sacramento, summer temperatures are much higher, representing an interior Mediterranean climate. Vegetation must survive long summer droughts. This vegetation type is called **chaparral**. Scrubby, woody plants and trees are common (**Figure** 17.15).

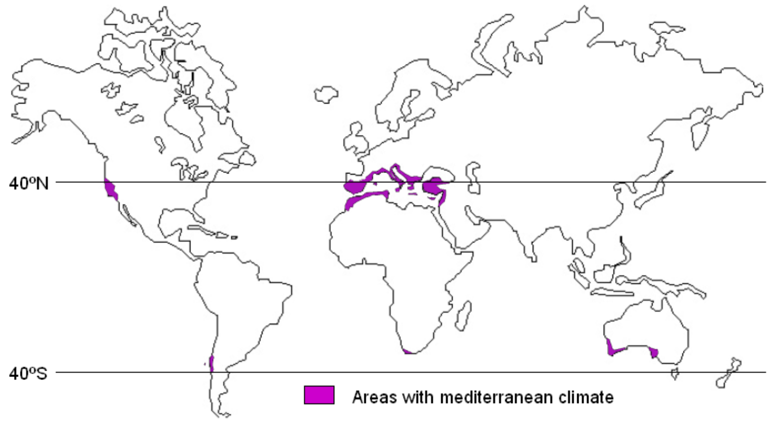

Figure 17.14: A map showing locations which have a Mediterranean climate. The areas around the Mediterranean Sea are the best representatives of this climate type. (25)

Figure 17.15: The scrubby plants that are typical of a Mediterranean climate. This photo is from southern France. (1)

Humid Subtropical (Cfa)

The *Humid Subtropical* climate zone is found mostly on the eastern sides of continents (**Figure** 17.16). Rain falls throughout the year with annual averages between 80 and 165 cm (31 and 65 inches). Summer days are humid and hot, from the lower 30's up to 40°C (mid-80's up to 104°F). Afternoon and evening thunderstorms are common. These conditions are due to warm tropical air passing over the hot continent. Winters are mild, but middle-latitude storms called cyclones may bring snow and rain. The southeastern United States, with its hot humid summers and mild, but frosty winters, is typical of this climate zone.

Figure 17.16: The humid subtropical climate zone is shown in green. (36)

Forests grow thickly in much of this region, due to the mild temperatures and high humidity. Pine forests are common in the lower latitudes, while oak are more common at higher latitudes (**Figure** 17.17).

Marine West Coast Climate (Cfb)

This climate lines western North America between 40° and 65° latitude, an area known as the Pacific Northwest (**Figure** 17.18). Ocean winds bring mild winters and cool summers. The temperature range between seasons and between day and night is fairly small. Rain falls year-round, although summers are drier as the jet stream moves northward. Low clouds, fog, and drizzle are typical. Snowfall is infrequent and short-lived. The mountain ranges that line the western U.S. keep this climate from extending far inland.

Dense forests of **Douglas fir** thrive in the heavy rain and mild temperatures (**Figure** 17.19). In Western Europe the climate covers a larger region since no high mountains are near the coast to block wind blowing off the Atlantic.

Continental Climates (Group D)

Continental (Group D) climates are found in most of the North American interior from about 40°N to 70°N. In this climate, summers are cool-to-warm and winters are very cold

Figure 17.17: Pine forests are common in the humid subtropical climate zone. (32)

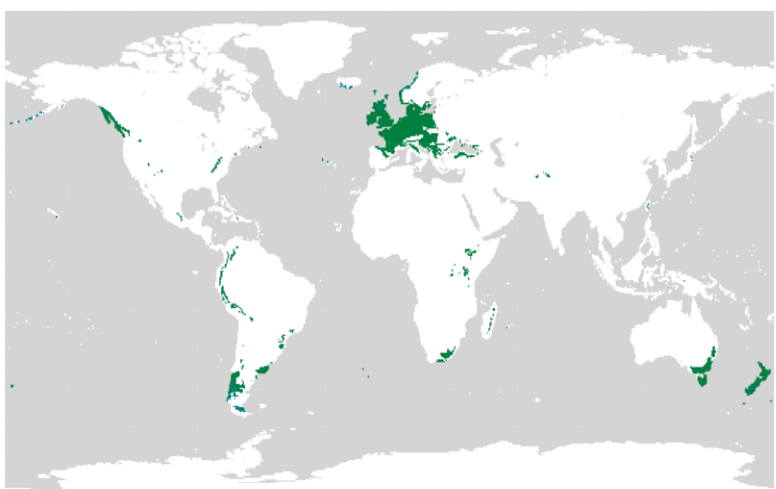

Figure 17.18: The west coast marine climate zone. (16)

Figure 17.19: A Douglas fir forest in the Pacific Northwest. (38)

and stormy. The average temperature of the warmest month is higher than 10°C (50°F) and the coldest month is below -3°C (-27°F). Snowfall is common and the cold temperatures mean that snow stays on the ground for long periods of time. Trees grow in continental climates, even though winters are extremely cold, because the average annual temperature is fairly mild. Continental climates are not found in the Southern Hemisphere due to the absence of a continent large enough to generate this effect.

Humid Continental (Dfa, Dfb)

Humid continental climates are found around the polar front at about 60°N latitude within continental North America and Europe (**Figure** 17.20). In the winter, middle-latitude cyclones bring chilly temperatures and snow. In the summer, westerly winds bring continental weather and warm temperatures. The average July temperature is often above 20°C (70°F). The region is typified by deciduous trees, which protect themselves in winter by losing their leaves.

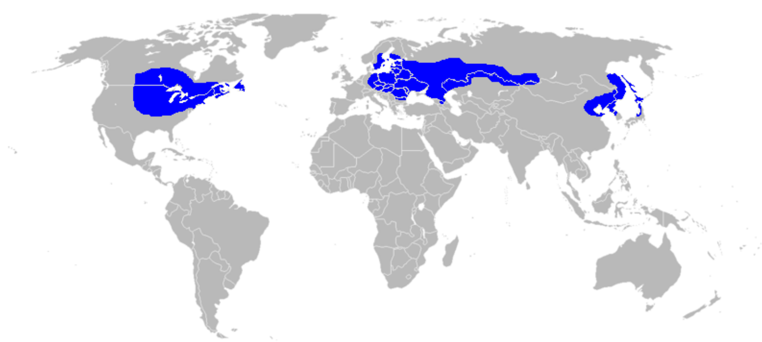

Figure 17.20: The humid continental climate zone covers much of the northeastern United States, southeastern Canada and middle Europe. (18)

The two variations of this climate are based on summer temperatures. In the humid continental climate with *long, hot summers* (Dfa), the long summers and high humidity foster plant growth (**Figure** 17.21). Summer days may be over 38°C (100°F), nights are warm and the temperature range is large, perhaps as great as 31°C (56°F)! In the humid continental climate with *long, cool summers* (Dfb), summertime temperatures and humidity are lower. Winter temperatures are below -18°C (0°F) for long periods. For example, Winnipeg, Canada has a 38°C (68°F) annual temperature range.

Subpolar (Dfc)

The *subpolar* climate is found between the humid continental and the polar tundra climates (**Figure** 17.22). This climate is dominated by long, very cold winters with very little precipitation. Continental polar air masses form when air stagnates in this zone. Snowfall is

Figure 17.21: Parts of South Korea lies in the humid continental climate zone. (28)

light, but temperatures are so cold that snowfall remains on the ground for months. Most of the approximately 50 cm (20 inches) of annual precipitation falls during summer cyclonic storms. The angle of the Sun's rays is low but the Sun is visible in the sky for most or all of the day, so temperatures may get warm, but are rarely hot. These continental regions have very high annual temperature ranges. The climate of Fairbanks, Alaska is a typical subarctic climate.

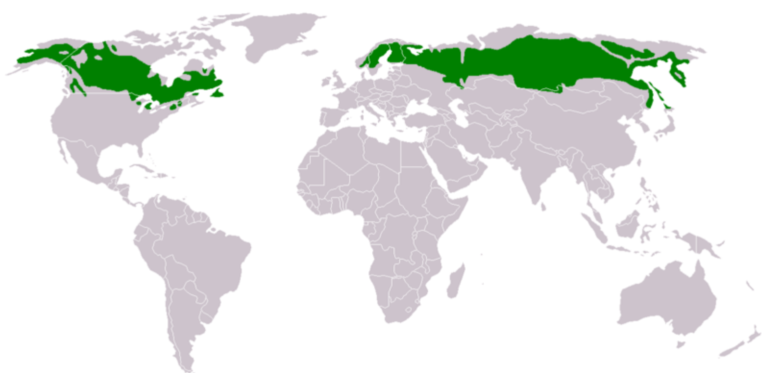

Figure 17.22: The location of the subpolar climate. (40)

The boreal coniferous forests of this climate are called **taiga** (**Figure** 17.23). These vast forests stretch across North America from western Alaska to Newfoundland, and across Eurasia from Norway to the Pacific coast.

Figure 17.23: The vast taiga is known for its small, hardy, and widely-spaced trees. This photo is of the Alaska Range in Alaska. (31)

Polar Climates (Group E)

In the polar regions, winters are entirely dark and bitterly cold. In the summer, days are long, but the sun is low on the horizon. Summers are cool with the average temperature of the warmest month at less than 10°C (50°F). Winters are extremely cold, so the annual temperature range is large. Polar climates receive less than 25 cm (10 inches) precipitation, mostly during the summer. This climate is found across the continents that border the Arctic Ocean, Greenland and Antarctica.

Polar Tundra (ET)

The *polar tundra* climate is continental, with severe winters (**Figure** 17.24). Temperatures are so cold that a layer of permanently frozen ground, called **permafrost** forms below the surface. This frozen layer can extend hundreds of meters deep. The average temperature of the warmest months is above freezing, so summer temperatures defrost the uppermost portion of the permafrost. In winter, the permafrost prevents water from draining downward. In summer, the ground is swampy. Although the precipitation is low enough in many places to qualify as a desert, evaporation rates are also low, so the landscape receives more usable water than a desert.

The only plants that can survive the harsh winters and soggy summers are small ground-hugging plants like mosses, lichens, small shrubs and scattered small trees that make up the **tundra** (**Figure** 17.25). Due to the lack of ice-free land near the South Pole, there is very little tundra in the Southern Hemisphere. The area surrounding the Arctic Ocean is the only part of the globe with much tundra.

Figure 17.24: Tundra loses its green in the fall, as mosses and leaves turn brown. (11)

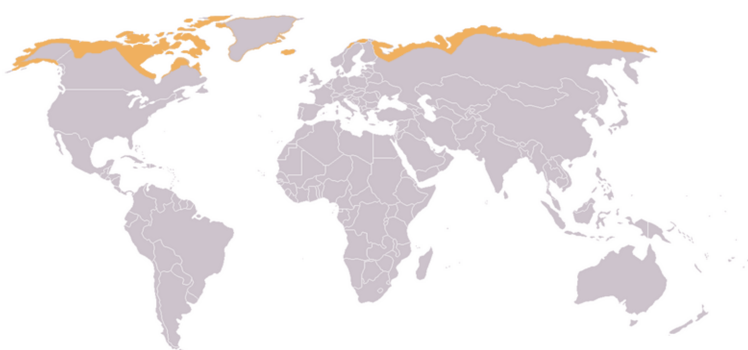

Figure 17.25: The tundra biome is shown in this map. (3)

Ice Cap

Ice caps are found mostly on Greenland and Antarctica, about 9% of the Earth's land area (**Figure** 17.26). Ice caps may be thousands of meters thick. Ice cap areas have extremely low average annual temperatures, e.g. -29°C (-20°F) at Eismitte, Greenland. Precipitation is low, since the air is too cold to hold much moisture. Snow occasionally falls in the summer.

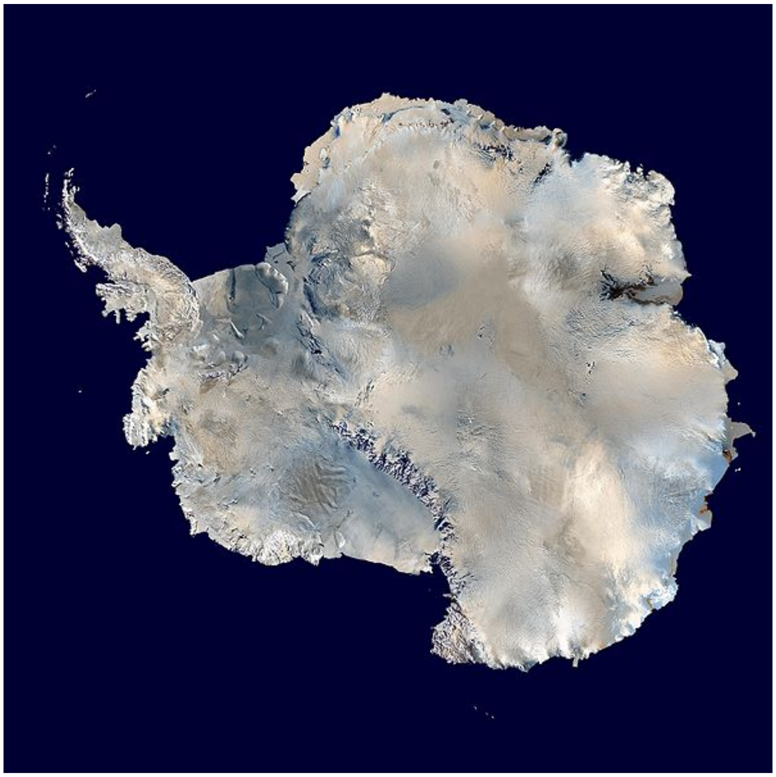

Figure 17.26: A composite satellite image of Antarctica. Almost all the continent is covered with an ice cap. (6)

Microclimates

When climate conditions in a small area are different from those of the surroundings, the climate of the small area is called a **microclimate.** The microclimate of a valley may be cool relative to its surroundings since cold air sinks. The ground surface may be hotter or colder than the air a few feet above it, since rock and soil gain and lose heat readily. Different sides of a mountain will have different microclimates. In the Northern Hemisphere, a south-facing slope receives more solar energy than a north-facing slope, and so each side supports different amounts and types of vegetation.

Altitude mimics latitude in climate zones. Climates and biomes typical of higher latitudes may be found in other areas of the world at high altitudes. Mt. Kilimanjaro in Africa lies near the equator in the tropics, but the top of the mountain is in the tundra biome and there is also a small glacier at the top.

Lesson Summary

- A climate zone depends on a region's latitude, continental position, and relationship to prevailing winds, large water bodies and mountains, among other factors.
- The temperature, rainfall, length of dry season, and other features of the climate zone determine which plants can grow.
- When living organisms develop in similar climates, they must adapt to that same environment. So the organisms in similar climate zones resemble each other, no matter how geographically distant they are. Because the organisms are so similar, a climate zone and its organisms make up a biome.

Review Questions

1. Why are most climate zones found in similar locations on continents within the Northern Hemisphere?
2. What are some reasons that climate zones differ between continents, even though locations are similar?
3. Why do organisms in the same biome often look the same even though they are not the same species? Think about desert plants, for example. Why are the plants that live in low latitude deserts on different continents so similar?
4. Why is the length of the dry season important in distinguishing different types of climate zones? Give an example.
5. Since the equator receives the most solar radiation over the course of a year, why are the hottest temperatures found in the low-latitude deserts? Why are low-latitude deserts often chilly at night, even in the summer?
6. What are the differences between arid and semi-arid deserts?
7. What conditions bring about the hot and humid summer days found in the American South?
8. What is the most important factor in determining the presence of a forest?
9. Look at **Figure 7** and see which major climate types are found in California (ignore the 3^{rd} letter on each symbol). Look at a geographic map at the same time if you need to. Which climate type is the most common and where is it found? Which other two types of climates are found and where? Why does California have so many major climate types?
10. Polar regions receive little precipitation. Why are they not considered deserts?
11. What is permafrost? Does it stay the same year-round?
12. Why are microclimates important to living things?

Vocabulary

biodiversity The number of species of plants, animals and other organisms within a particular habitat.

biome The living organisms that are found within a climate zone that make that zone distinct, such as rainforests, arid deserts, tundra, and ice caps.

chaparral Scrubby woody plants and widely scattered trees typical of the Mediterranean climate.

desert Areas receiving very little precipitation, less than 25 cm (10”) per year; found in arid climates; plants are infrequent.

Douglas fir A coniferous, evergreen tree found in enormous forests in western North America.

ice cap Permanent ice that is found mostly around Greenland and Antarctica.

permafrost Permanently frozen ground that is found in the polar regions, where temperatures do not rise above freezing most months.

rainforest The tropical wet biome where temperatures are warm and rain falls nearly every day.

savanna The tropical wet and dry biome, typified by grasses and widely scattered deciduous trees.

steppe The biome found in semi-arid deserts, typified by bunch grasses, scattered low bushes and sagebrush.

taiga Vast, boreal forests of small, more widely spaced trees that are typical of the subpolar climate.

tundra The treeless area of the arctic with very cold, harsh winters. The only polar climate that contains living organisms.

Points to Consider

- Why aren't biomes always determined by latitude? What geographic features or other factors affect the climate?
- Climate zones and biomes depend on many climate features. If climate changes, which of these features changes too?
- If global warming is increasing average global temperatures, how would you expect biomes to be affected?

17.3 Climate Change

Lesson Objectives

- Describe some ways that climate change has been an important part of Earth history.
- Discuss what factors can cause climate to change and which of these can be exacerbated by human activities.
- Discuss the consequences of rising greenhouse gas levels in the atmosphere, the impacts that are already being measured, and the impacts that are likely to occur in the future.

Introduction

For the past two centuries, climate has been relatively stable. People placed their farms and cities in locations that were in a favorable climate without thinking that the climate could change. But climate has changed throughout Earth history, and a stable climate is not the norm. In recent years, Earth's climate has begun to change again. Most of this change is warming due to human activities that release greenhouse gases into the atmosphere. The effects of warming are already being seen and will become more extreme as temperature rise.

Climate Change in Earth History

Climate has changed throughout Earth history. At times, the Earth's climate was hotter and more humid than it is today, but climate has also been colder than it is today, when glaciers covered much more of the planet. The most recent ice ages were in the Pleistocene Epoch, between 1.8 million and 10,000 years ago (**Figure** 17.27). Glaciers advanced and retreated in cycles, known as glacial and interglacial periods. With so much of the world's water bound into the ice, sea level was about 125 meters (395 feet) lower than it is today. We are currently in a warm, interglacial period that has lasted about 10,000 years.

It is likely that the average global temperature during glacial periods was only 5.5°C (10°F) less than Earth's current average temperature. Temperatures during the interglacial peri-

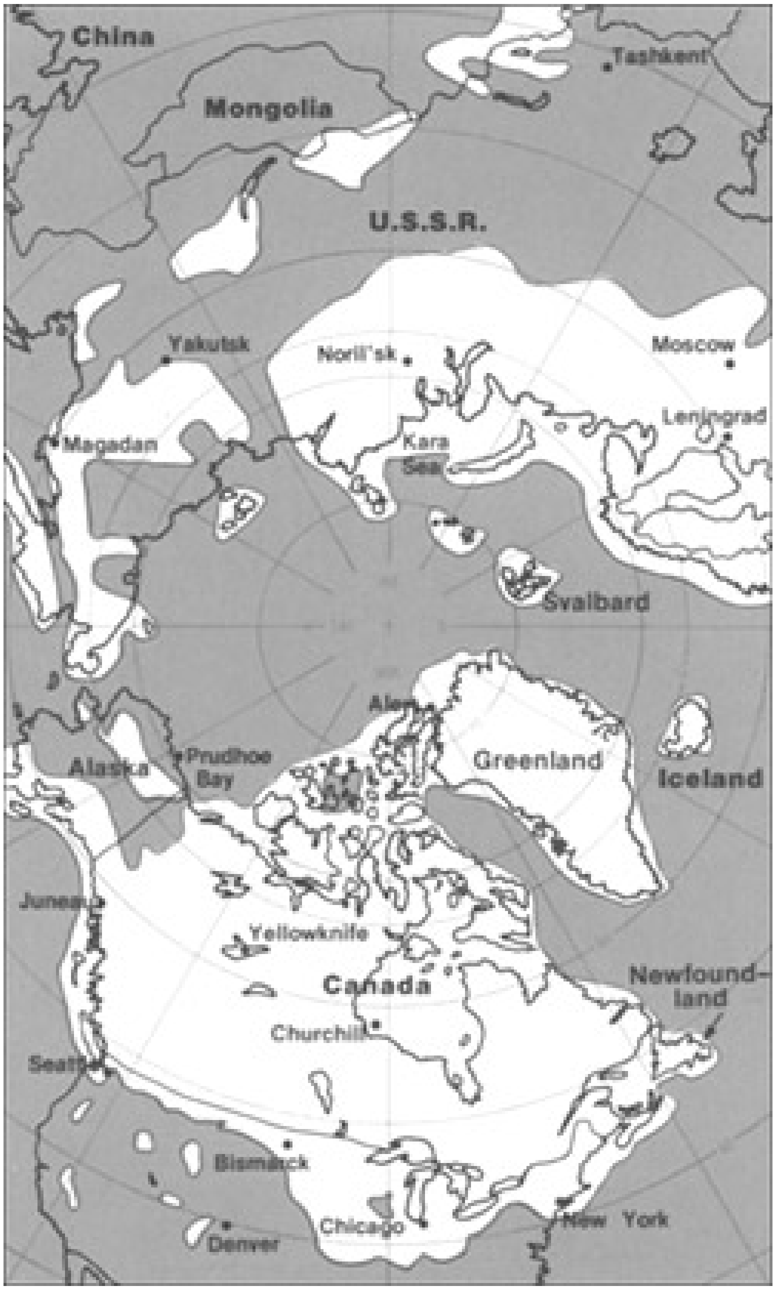

Figure 17.27: The maximum extent of glaciers in the Northern Hemisphere during the Pleistocene epoch. (39)

ods were about 1.1°C (2.0°F) higher than today (**Figure** 17.28). Notice that fairly small temperature changes can have major effects on global climate. Over the last 900,000 years, Earth's average temperature has varied less than 5 º C. Some scientists think that glaciers will advance again, but not for thousands of years.

Since the end of the Pleistocene, the global average temperature has risen about 4°C (7°F). Glaciers are retreating and sea level is rising. The climate has been relatively mild and stable when compared with much of Earth's history. Climate stability has been beneficial for human civilization. Stability has allowed the expansion of agriculture and the development of towns and cities. While climate is getting steadily warmer, there have been a few more extreme warm and cool times in the last 10,000 years. The Medieval Warm Period from 900 to 1300 A.D. allowed Vikings to colonize Greenland and Great Britain to grow wine grapes. When the climate cooled in the The Little Ice Age, from the 14th to 19th centuries, the Vikings were forced out of Greenland and humans had to plant crops further south.

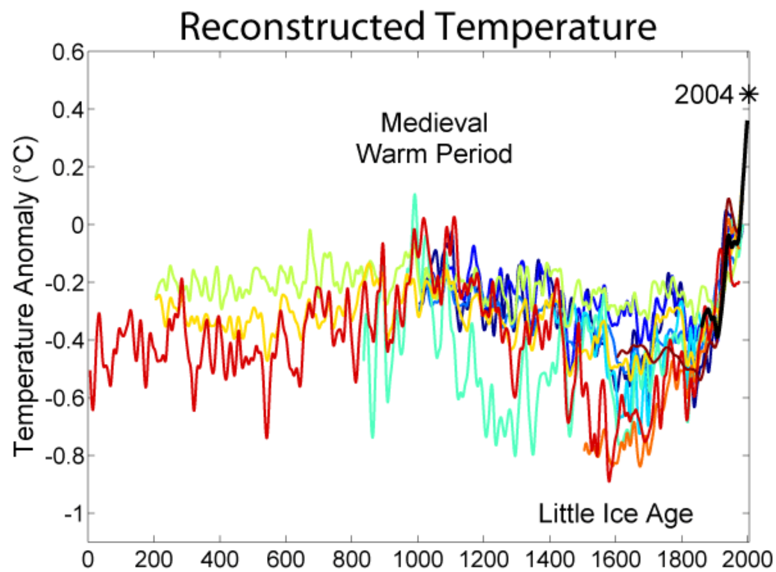

Figure 17.28: The graph is a compilation of 10 reconstructions (the colored lines) of mean temperature changes over the past 2,000 years, and one graph of instrumentally recorded data of mean temperature changes (black). This illustrates the high temperatures of the Medieval Warm Period, the lows of the Little Ice Age, and the very high (and climbing) temperature of this decade. (15)

Short-Term Climate Oscillations

Short-term changes in climate are common as conditions oscillate (or change) from one state to another (**Figure** 17.29). The largest and most important of these is the Southern Oscillation between **El Niño** and **La Niña** conditions. This oscillation drives changes in climate that are felt around the world about every two to seven years.

In a normal year, the trade winds blow across the Pacific Ocean near the equator from east to west (in the direction of Southeast Asia), piling up warm water in the western Pacific Ocean and actually raising sea levels there by half a meter. Meanwhile, along the western coast of South America, the Peru Current carries cold water northward, and cold, nutrient-rich waters upwell from the deep sea. When the Peru Current nears the equator, it flows westward across the Pacific Ocean with the trade winds.

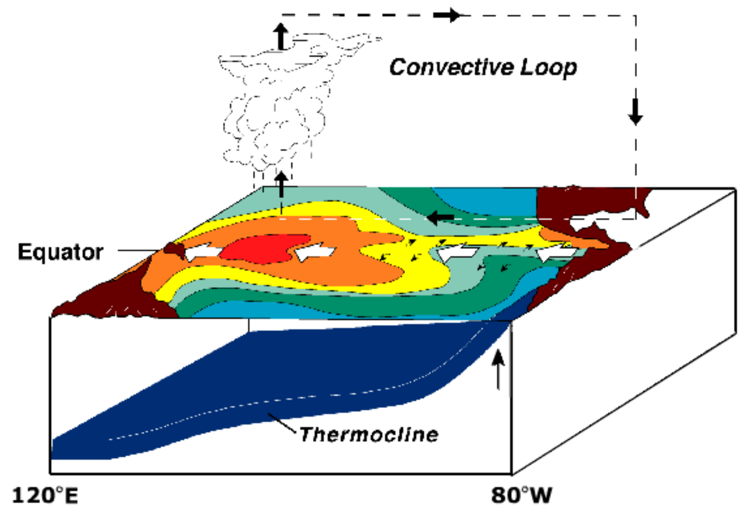

Figure 17.29: Normal conditions in the Southern Oscillation have a low pressure region in the western Pacific Ocean and warm water (shown in red) building up there as well. Notice that continents are shown in brown in the image. North and South America are on the right in this image. (2)

When water temperature reaches around 28°C (82°F), the trade winds weaken or reverse direction and blow east (towards South America). An El Niño cycle has begun (**Figure** 17.30). Warm water is dragged back across the Pacific Ocean, heating the central Pacific Ocean and the surface waters off the west coast of South America. With warm, low density water at the surface, no upwelling occurs along the coast of South America. Without upwelling, nutrients are scarce and plankton populations decline. Since plankton form the base of the food web, fish cannot find food, and fish numbers decrease as well. All the animals that eat fish, including birds and humans are affected by the decline in fish.

El Niño events change global climate when circulation patterns in the atmosphere and oceans change. Some regions receive more than average rainfall, including the west coast of North and South America; the southern United States; and Western Europe. Drought occurs in other parts of South America, the western Pacific, southern and northern Africa, and southern Europe.

An El Nino cycle lasts one to two years and ends when the warm mass of central Pacific water has moved eastward once more. Normal circulation patterns resume, but sometimes

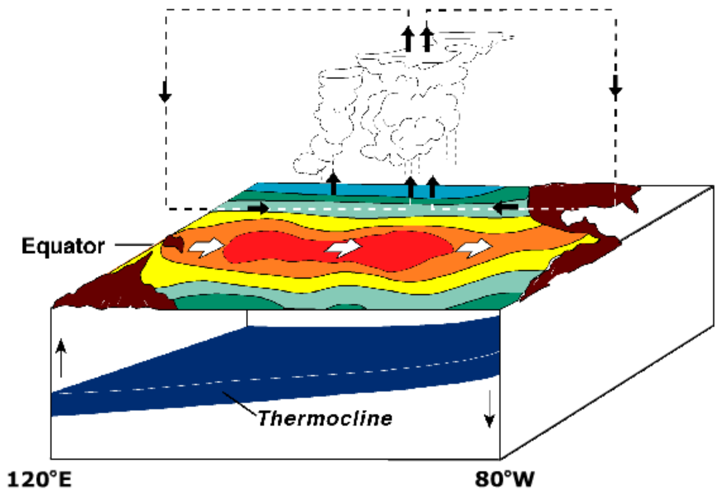

Figure 17.30: In El Niño conditions, the trade winds weaken or reverse directions. Warm water moves eastward across the Pacific Ocean and piles up against South America. (30)

they are quicker and more energetic. This pattern, with unusually cold water in the eastern Pacific Ocean, is called La Niña (**Figure** 17.31). El Niño events take place every three to seven years but vary in their strength.

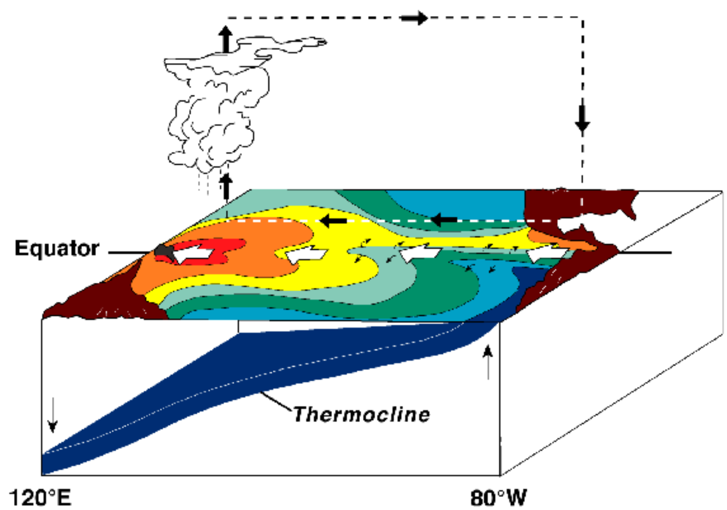

Figure 17.31: During a La Niña, ocean temperatures along the coast of South America are colder than normal (instead of warmer, as in El Niño) and cold water reaches farther into the western Pacific than normal. As in a normal year, trade winds moving from east to west and warm water piles up in the western Pacific Ocean. (20)

Other important oscillations are smaller and have a local, rather than global, effect. The

North Atlantic Oscillation mostly alters climate in Europe. The Mediterranean also goes through cycles, varying between being dry at some times, and warm and wet at others.

Causes of Climate Change

Many natural processes cause climate to change. There can be changes in the amount of energy the Sun produces. As Earth orbits the Sun, there are also changes over thousands of years in the tilt of Earth's axis and orbit. Over millions of years, the positions of our continents change, driven by plate tectonic motions. Random catastrophic events, like a large asteroid impact can cause sudden, dramatic changes in climate. Human activities have greatly increased the amount of greenhouse gases in the atmosphere, which impacts global climate by warming the Earth.

Solar Variation

The amount of energy the Sun radiates is variable. **Sunspots** are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle (**Figure** 17.32). When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is and there is no known 11-year cycle in climate variability. The Little Ice Age corresponded to a time when there were no sunspots on the Sun.

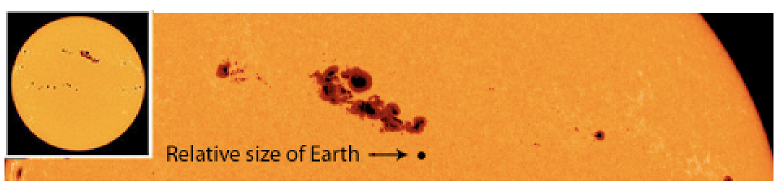

Figure 17.32: Sunspots on the face of the Sun. (33)

Plate Tectonics

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents are joined into one supercontinent (like Pangea), nearly all locations experience a continental climate. When the continents separate, heat is more evenly distributed. Plate tectonic movements may help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age.

Plate tectonics also triggers volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather. Ash from the 1991 eruption of Mount Pinatubo in the Philippines cooled global temperature by around 0.5°C (0.9°F) for a year. Massive eruptions of a fluid type of lava can flood the surface, releasing much more gas and dust, changing climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

Asteroid Impacts

If a large **asteroid** hits the Earth, it may trigger a **mass extinction**. This likely happened at the end of the Cretaceous period, around 65 million years ago. An asteroid 10 kilometers (6 miles) in diameter struck the Yucatan Peninsula in southeastern Mexico. About 85% of all species present on Earth at that time became extinct, including the dinosaurs. Dust that was kicked high into the atmosphere came together as rocks and fell to the ground. The organisms that survived had to endure extreme cold, as dust blocked the Sun for many years. Photosynthesis slowed down and the planet cooled to levels that were intolerable for many species.

Milankovitch Cycles

The most extreme climate of recent Earth history was the Pleistocene. Scientists attribute a series of ice ages to variation in the Earth's position relative to the Sun, known as **Milankovitch cycles.**

The Earth goes through regular variations in its position relative to the Sun:

1. The shape of the Earth's orbit changes slightly as it goes around the Sun. Our orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.
2. The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun, when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun. This results in chilly summers and warmer winters.
3. The planet's tilt on its axis varies between 22.1° and 24.5°. Seasons are caused by the tilt of Earth's axis of rotation, which is at a 23.5° angle now. When the tilt angle is smaller, summers and winters differ less in temperature. This cycle lasts 41,000 years.

When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can only form over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Rising Atmospheric Greenhouse Gases

Greenhouse gases in the atmosphere trap the heat that radiates off the planet's surfaces. Therefore, a decrease in greenhouse gas levels lowers the average air temperature. An increase in greenhouse gases raises air temperature. Greenhouse gas levels have varied throughout Earth history. For example, CO_2 been present in Earth's atmosphere at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for 650,000 years or more, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods. CO_2 levels are higher during interglacial than glacial periods (**Figure** 17.33).

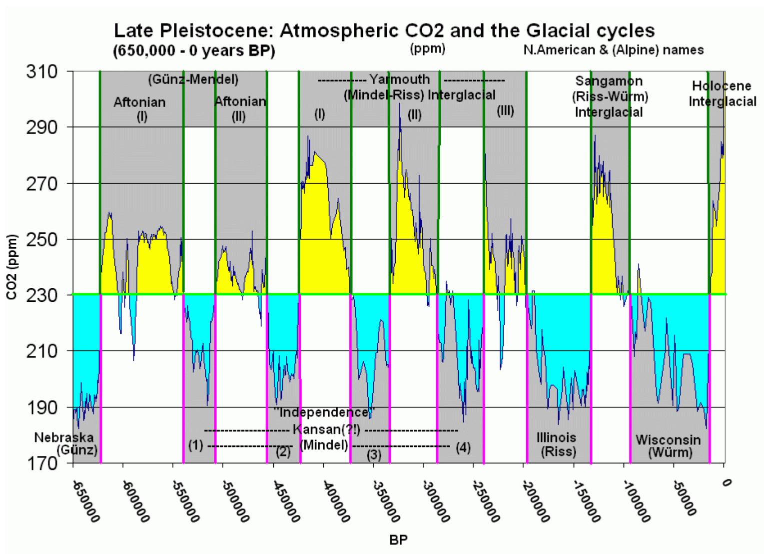

Figure 17.33: CO_2 is high during interglacial periods, when temperatures are high. CO_2 is low during glacial periods, when temperatures are low. BP means years before present. Glacial periods are shown in blue and interglacial periods are shown in yellow. Current carbon dioxide levels are at 387 ppm, the highest level for the last 650,000 years. (4)

Greenhouse gases are added to the atmosphere by natural processes, like volcanic eruptions, and the decay or burning of organic matter. Greenhouse gases are also removed from the atmosphere when CO_2 is absorbed by plant tissue. When plants die and are turned into fossil fuels - coal, oil, natural gas - deep in the Earth, the CO_2 they hold is stored with them. Storing CO_2 in the ground removes the greenhouse gas from the atmosphere, lowering Earth's average temperature.

Human activities are now releasing much of this stored CO_2 into the atmosphere. Although people have been burning wood and coal to meet their energy needs for hundreds of thousands of years, fossil fuel usage has increased dramatically in the past 200 years, since the Industrial Revolution. Fossil fuel use has skyrocketed in the past few decades as population has grown, and there are more and more cars, homes, and industries to power. Burning rainforests, to clear land for agriculture prevents the growing trees from removing CO_2 from the atmosphere and releases all the CO_2 stored in rainforest trees. With more people to feed, the destruction of rain forests has increased.

CO_2 is the most important greenhouse gas that human activities affect. And, after water vapor, CO_2 is the most abundant. But other greenhouse gases are increasing as well. Methane is released from raising livestock, rice production, and the incomplete burning of rainforest plants. Chlorofluorocarbons (CFC's) are human-made chemicals that were invented and used widely in the 20th century. Tropospheric ozone, mostly from vehicle exhaust, has more than doubled since 1976. All of these gases act as greenhouse gases as well as CO_2.

Global Warming

With more greenhouse gases trapping heat, average annual global temperatures are rising. This is known as **global warming.** There is now nearly 40% more CO_2 in the atmosphere than there was 200 years ago, before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii in 1958 (**Figure** 17.34).

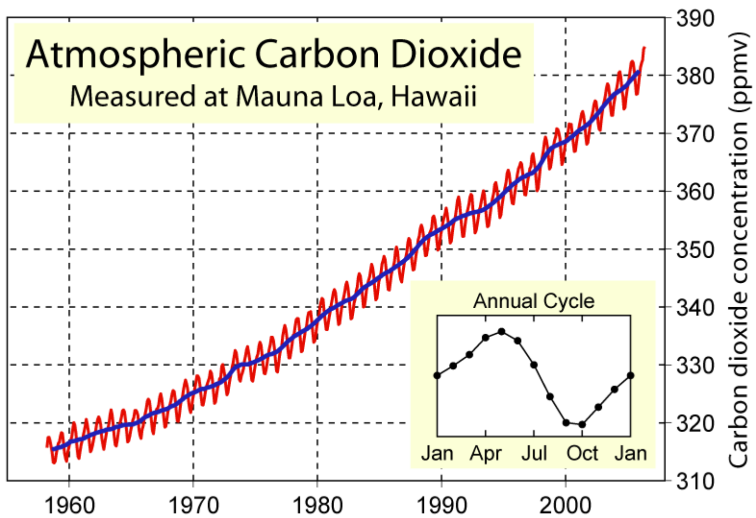

Figure 17.34: The Keeling Curve shows the upward trend in atmospheric CO_2 on Mauna Loa volcano since measurements began in 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2. (22)

The United States has been the largest emitter of greenhouse gases, with about 20% of total emissions in 2004 (**Figure** 17.35). China has been the second highest emitter (18.4%), followed by the European Union (11.4%). As a result of China's rapid economic growth, in early 2008 its CO_2 emissions probably surpassed those of the United States. However, it's also important to keep in mind that the US has only about 1/5 the population of China. Therefore, the average US citizen produces far more greenhouse gases than the average

Chinese person. 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.

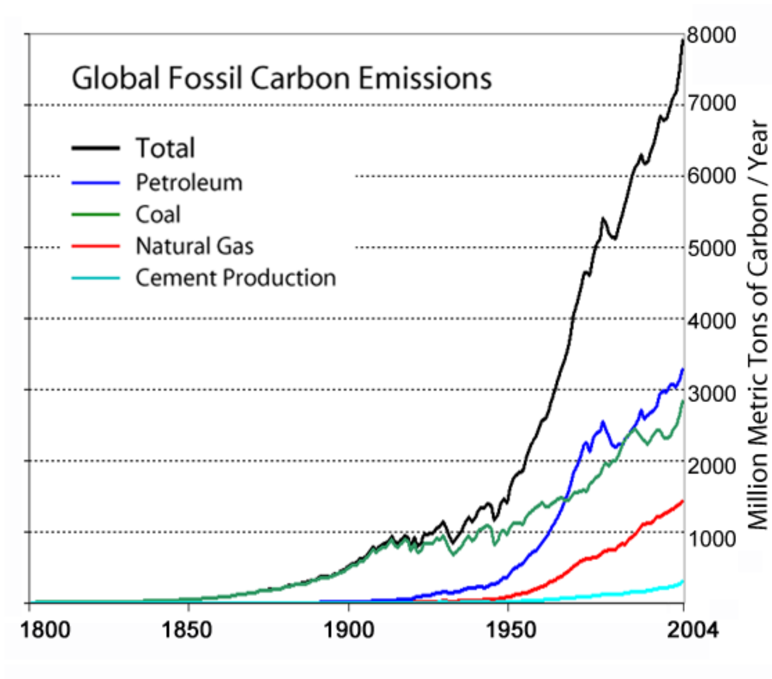

Figure 17.35: Global CO_2 emissions are rising rapidly. The industrial revolution began about 1850 and industrialization has been accelerating. (9)

How much CO_2 levels will rise in the next decades is unknown. It depends on how much CO_2emissions in developing nations increase. It also depends on how much technological advances or lifestyle changes increase or decrease emissions in developed nations. If nothing is done to control greenhouse gas emissions and they continue to increase at current rates, the surface temperature of the Earth can be expected to increase between 0.5°C and 2.0°C (0.9°F and 3.6°F) by 2050 and between 2° and 4.5°C (3.5° and 8°F) by 2100, with CO_2 levels over 800 parts per million (ppm)(**Figure** 17.36). On the other hand, if severe limits on CO_2 emissions begin soon, temperatures could rise less than 1.1°C (2°F) by 2100. Whatever the temperature increase, it will not be uniform around the globe. A rise of 2.8°C (5°F) would result in 0.6° to 1.2°C (1° to 2°F) at the equator, but up to 6.7°C (12°F) at the poles. So far, global warming has affected the North Pole more than the South Pole.

Changes in the Earth and organisms as a result of global warming are already being observed. While temperatures have risen since the end of the Pleistocene, 10,000 years ago, this rate of increase had been more rapid in the past century, and has even risen even faster since 1990. The eight warmest years on record have all occurred since 1998, and the 14 warmest years have occurred since 1990 (through 2007) (**Figure** 17.37).

As a result of these high temperatures, glaciers are melting and ice caps are breaking apart at

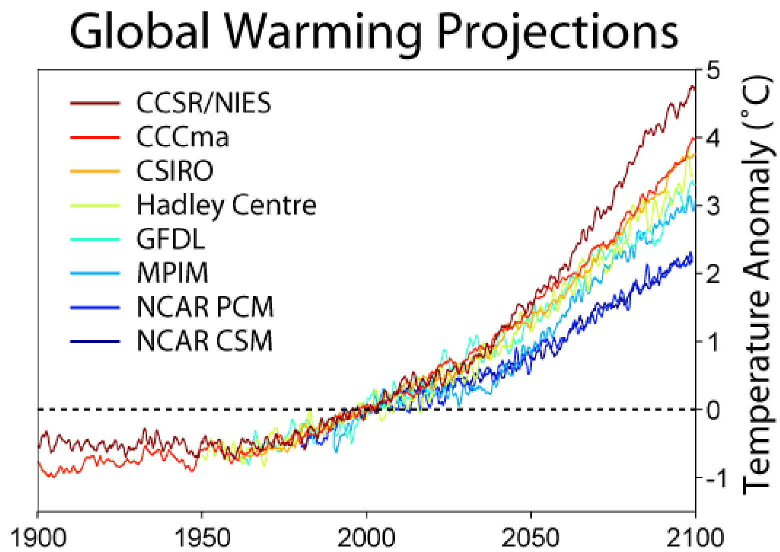

Figure 17.36: Various climate prediction models show how temperature is likely to rise by 2100. (24)

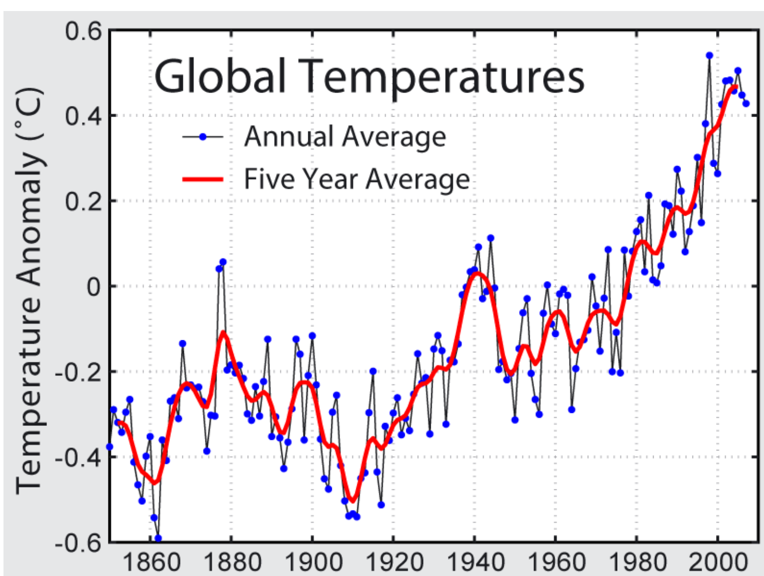

Figure 17.37: Recent temperature increases show how much temperature has risen since the Industrial Revolution began. (37)

the edges (**Figure** 17.38). Permafrost is melting, causing swamps in locations that were once frozen solid. Melting ice caps add water to the oceans, so sea level is rising (**Figure** 17.39). Also contributing to sea level rise is that water slightly expands as it warms — this expansion of water accounts for about one-quarter to one-half of the observed sea level change. Since warmer air can hold more moisture, storms are becoming more intense. Weather is therefore likely to be more severe with more heat waves and droughts. More rainfall sometimes results in increased flooding.

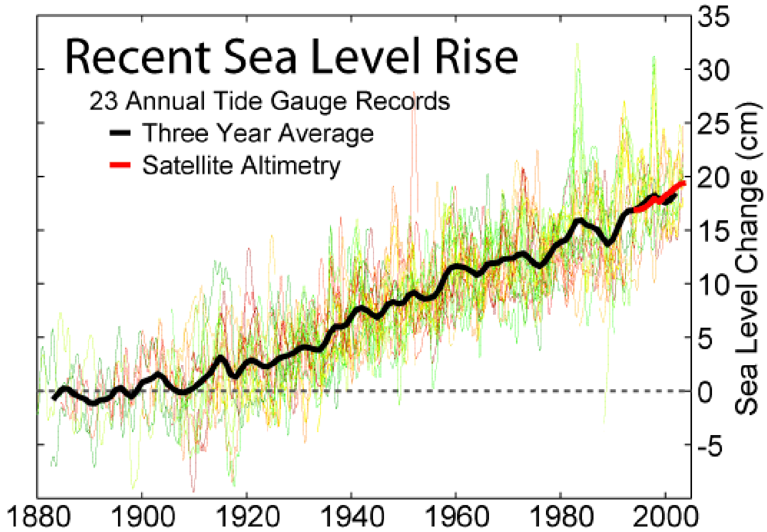

Figure 17.38: Sea level has been rising in recent decades. Twenty-three different geologically stable tide gauge sites with long-term records are represented here. (27)

Plants and animals are feeling the effects of the changing climate. Winters are shorter so some animals are changing their seasonal behaviors: migrating earlier in the spring, for example. Coral reefs are dying worldwide due in part to the increase in surface ocean temperatures. Forests are also dying in some places because warm weather has allowed insect pests to expand their ranges into areas that were once too cold. As surface seas warm, phytoplankton productivity has decreased. Some regions that were already marginal for agriculture are no longer farmable, because they have become too warm or dry.

As greenhouse gases increase, changes will be more extreme. Oceans will become slightly more acidic, making it more difficult for creatures with carbonate shells to grow, including coral reefs. A studying monitoring ocean acidity in the Pacific Northwest found ocean acidity increasing ten times faster than expected and 10 to 20 percent of shellfish (mussels) 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°C (8°F) rise in global temperature. There will be a tremendous loss of biodiversity because forest species can't migrate that rapidly. Even if they could, human development would block their spread

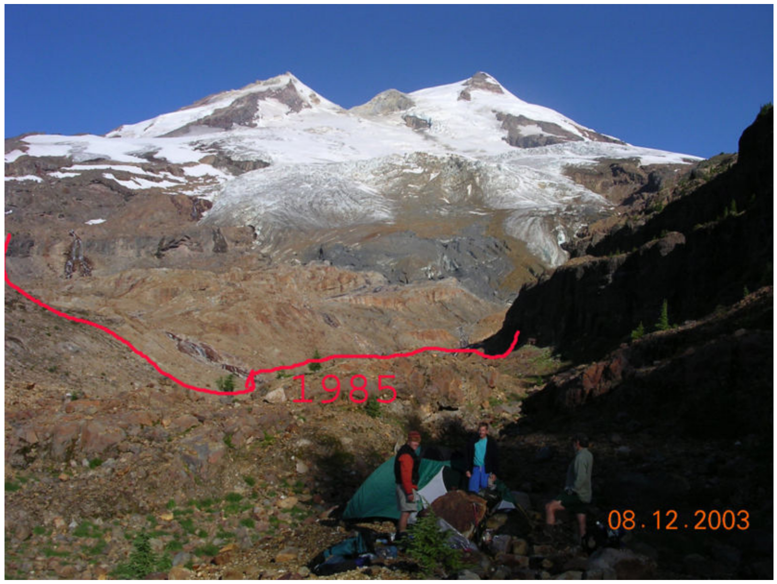

Figure 17.39: The Boulder Glacier has melted back tremendously since 1985. Other mountain glaciers around the world are also melting. (23)

and stop them from colonizing many new areas. Parks and wildlife refuges might be left protecting nothing. And biologists have already documented the extinction of high altitude species that have nowhere higher to go.

Decreased snowpacks, 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** 17.40). 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.

There will be more severe heat waves and heat-related illnesses and deaths. Drought could make many marginal regions uninhabitable. Some modelers predict that the Midwestern United States will become too dry to support agriculture and the areas that currently produce our best agriculture would move into Canada. 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. Hurricanes cause a tremendous loss of life in developing nations and a loss of property in developed ones. Tropical and subtropical insects will expand their ranges. This will result 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. This

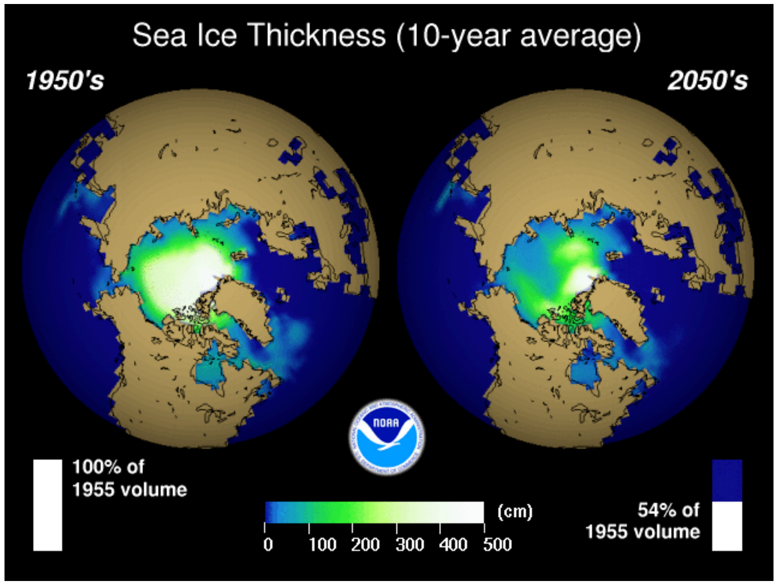

Figure 17.40: Sea ice thickness around the North Pole has been decreasing in recent decades and will continue to decrease in the coming decades. (13)

uncertainty 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.

Lesson Summary

- Climate has changed throughout Earth history. In general, when greenhouse gas levels are high, temperature is high.
- Greenhouse gases are now increasing due to human activities, especially fossil fuel use.
- We are already seeing the effects of these rising greenhouse gases in higher temperatures and changes to physical and biological systems.
- Society must choose to reduce greenhouse gas emissions or face more serious consequences.

Review Questions

1. Why is the climate currently warming?
2. Why does sea level rise and fall during interglacial and glacial periods?
3. How can the human history of Greenland be related to climate cycles?
4. Why did human civilization not develop significantly until the Pleistocene ended?
5. If climate has been much warmer in Earth history, why do we need to worry about global warming now?

6. When the weather along coastal California is especially rainy with many winter storms, what is likely to be happening in the equatorial Pacific in terms of the Southern Oscillation?
7. The Peruvian anchovy fishery collapsed in 1972. Using what you know about climate and food webs, can you devise an explanation for this event?
8. What two events must occur for there to be an ice age?
9. What human activities are responsible for increasing greenhouse gases in the atmosphere?
10. Why are CO_2 emissions projected to increase by so much during the next few decades?
11. What role do the developed nations play a role in increasing CO_2 emissions in the next few decades?
12. Why do storms increase in frequency and intensity as global temperatures increase?
13. Earth is undergoing some important changes, some of which are known about and monitored by satellites. Describe the sort of global change that satellites can monitor.
14. What will happen if sea level rises by 60 cm (2 feet0 by the end of this century? Which locations will be hardest hit?
15. What can be done to reduce greenhouse gas emissions?

Vocabulary

asteroid A chunk of rock or ice that moves through the solar system.

El Niño Part of the Southern Oscillation in which the trade winds weaken or reverse directions, and warm water accumulates on the ocean surface off of South America.

global warming The global increase in average global temperature that has been taking place due to human activities.

La Niña Part of the Southern Oscillation in which the trade winds are stronger than normal and surface water off of South America is cold

mass extinction An extinction in which 25% or more of the planet's species die out in a fairly short period of time.

Milankovitch cycles Cycles in Earth's position relative to the sun that affect global climate, resulting in a cycle of around 100,000 years.

Southern Oscillation A reversal of normal atmospheric low and high pressure conditions in the Pacific Ocean.

sunspot Sunspots are magnetic solar storms on the sun that cause solar radiation to decrease slightly. Sunspots come and go over an 11-year cycle.

Points to Consider

- Nearly all climate scientists agree that human activities are causing the accelerated warming of the planet that we see today. Why do you suppose that the media is still talking about the controversy in this idea when scientists are almost entirely in agreement?
- If greenhouse gas emissions must be lowered to avoid some of the more serious consequences of global warming, why have humans not done something to lower these emissions instead of letting them increase?
- In what ways can progress be made in reducing greenhouse gas emissions? Think about this on a variety of scales: for individuals, local communities, nations, and the global community.

Image Sources

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Chapter 18

Ecosystems and Human Populations

18.1 Ecosystems

Lesson Objectives

- Discuss the importance of chemical and physical factors to living organisms.
- Describe the role of different species in an ecosystem.
- Describe the function of an ecosystem, and how different species fill different roles in different ecosystems.
- Describe energy transfer from the lowest to the highest trophic level in a chain, including energy loss at every trophic level.
- Discuss how materials are cycled between trophic levels and how they can enter or leave a food web at any time.

Introduction

An ecosystem is made up of the living creatures and the nonliving things that those creatures need within an area. Energy moves through an ecosystem in one direction. Nutrients cycle through different parts of the ecosystem and can enter or leave the ecosystem at many points.

Biological Communities

A **population** consists of all individuals of a single species that occur together at a given place and time. A **species** is a single type of organisms that can interbreed and produce fertile offspring. All of the populations living together in the same area make up a **community.** An **ecosystem** is all of the living things in a community and the physical and chemical factors that they interact with. The living organisms within an ecosystem are its

biotic factors. Living things include bacteria, algae, fungi, plants (**Figure** 18.1) and animals, including **invertebrates** (**Figure** 18.2), animals without backbones and **vertebrates** (**Figure** 18.3), animals with backbones.

Figure 18.1: The horsetail *Equisetum* is a primitive plant. (16)

Physical and chemical features are **abiotic** factors. Abiotic factors include resources living organisms need like light, oxygen, water, carbon dioxide, good soil, and nitrogen, phosphorous and other nutrients. Abiotic factors also include environmental features that are not materials or living things, like living space and the right temperature range.

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 hopefully 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. This niche can be filled by a lion in a savanna, a wolf in the tundra, or a tuna in the oceans.

Figure 18.2: Insects are among the many different types of invertebrates. (25)

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

An organism's **habitat** is where it lives. The important characteristics of a habitat include climate, the availability of food, water and other resources, and other factors, such as weather. A habitat may be a hole in a cactus or the underside of a fern in a rainforest. It may be a large area of savanna.

Roles in Ecosystems

There are many different types of ecosystems (**Figure** 18.4). A few examples of some ecosystems are a rainforest, chaparral, tundra, and desert. These words are the same words used for biomes. This is because climate conditions determine which ecosystems are found in which location. A particular biome encompasses all of the ecosystems that have similar climate and organisms.

Different organisms live in each different type of ecosystems. Lizards thrive in deserts, but no reptiles can survive at all in polar ecosystems. Large animals generally do better in cold climates than in hot climates. Despite this, every ecosystem has the same general roles that living creatures fill. It's just the organisms that fill those niches that are different. For example, every ecosystem must have some organisms that produce food in the form of chemical energy. These organisms are primarily algae in the oceans, plants on land, and bacteria at deep sea hot springs.

The organisms that produce food are extremely important in every ecosystem. The most fundamental distinction between types of organisms is whether they are able to produce their own energy or not. Organisms that produce their own food are called **producers**. In contrast, organisms that use the food energy that was created by producers are named

Figure 18.3: A giraffe is an example of a vertebrate. (11)

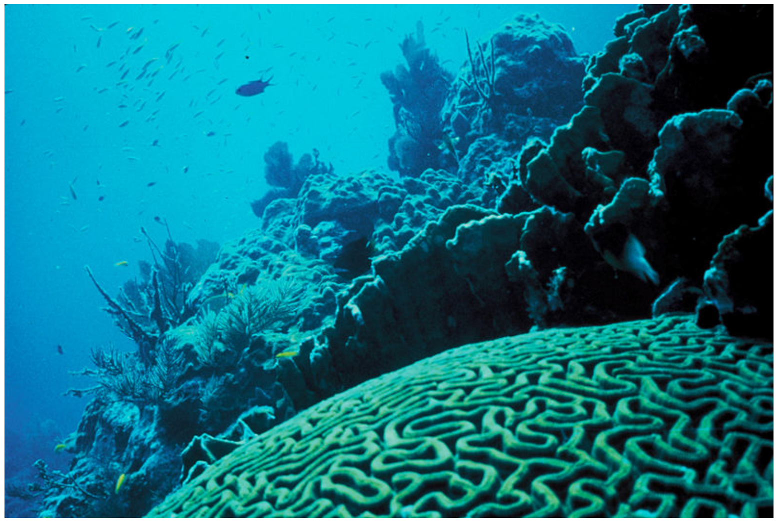


Figure 18.4: Coral reefs are complex and beautiful ecosystems. (6)

consumers.

There are two types of producers. Nearly all producers take energy from the Sun and make it into chemical energy (food) by the process of **photosynthesis**. Photosynthesizing organisms use carbon dioxide (CO_2) and water (H_2O) to produce sugar ($C_6H_{12}O_6$) and oxygen (O_2). This food can be used immediately or stored for future use.

A tiny group of producers create usable chemical energy from chemicals, without using any sunlight. At the bottom of the ocean, at deep-sea hot springs known as hydrothermal vents, a few types of bacteria break down chemicals to produce food energy. This process is called **chemosynthesis** (**Figure** 18.5).

There are many types of consumers. **Herbivores** eat producers directly (**Figure** 18.6). These animals break down the plant structures to get the materials and energy they need. Many other consumers eat animals. These are known as **carnivores**. Carnivores can eat herbivores or they can eat other carnivores. **Omnivores** eat plants and animals, as well as fungi, bacteria and organisms from the other kingdoms.

There are many types of feeding relationships between organisms. A **predator** is an animal that kills and eats another animal (**Figure** 18.7). The animal it kills is its **prey.**

Scavengers are animals that eat organisms that are already dead. Vultures and hyenas are just two types of scavengers. **Decomposers** break apart dead organisms or the waste material of living organisms, returning the nutrients to the ecosystem. Many decomposers are bacteria, but there are others as well, including fungi (**Figure** 18.8). Decomposers are recyclers; they make nutrients from dead organisms available for living organisms.

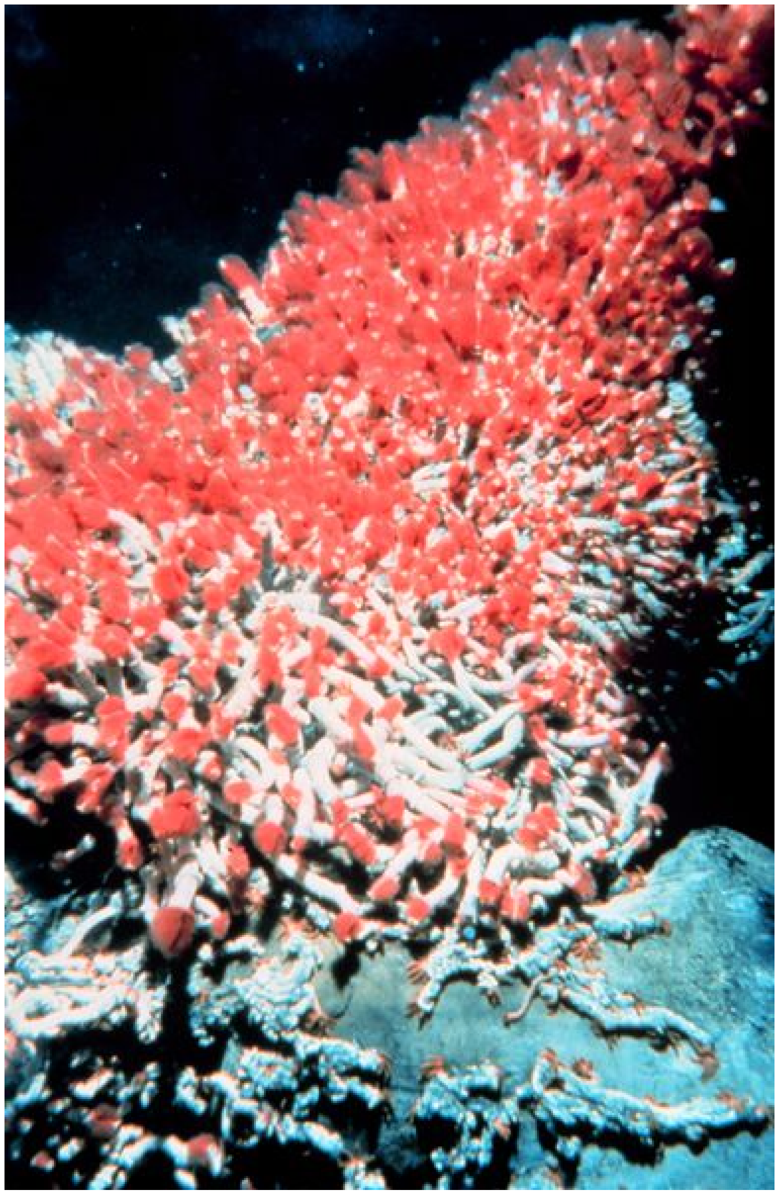


Figure 18.5: Tube worms have a symbiotic relationship with chemosynthetic bacteria. The bacteria provide the worms with food and the worm tubes provide the bacteria with shelter. (7)

Figure 18.6: Deer are herbivores. (19)

Figure 18.7: This South China Tiger is a predator. (22)

Figure 18.8: Fungi are decomposing this tree. (14)

Flow of Energy in Ecosystems

Energy cannot be created or destroyed. Energy can only be changed from one form to another. This is such a fundamental law in nature that it has its own name: **The Law of Conservation of Energy**. Plants do not create chemical energy from nothing. Instead, they create chemical energy from abiotic factors that include sunlight. So they transform solar energy into chemical energy. Organisms that use chemosynthesis start with chemical energy to create usable chemical energy. After the producers create the food energy, it is then passed on to consumers, scavengers, and decomposers.

Energy flows through an ecosystem in only one direction. Energy enters the ecosystem with the producers. In nearly all ecosystems, sunlight is the original energy source. This energy is passed from organisms at one **trophic level** or energy level, to organisms in the next trophic level. Producers are always the first trophic level, herbivores the second, the carnivores that eat herbivores the third, and so on.

An average of 90% of the energy that reaches a trophic level is used to power the organisms at that trophic level. They need it for locomotion, heating themselves, and reproduction. So animals at the second trophic level have only about 10% as much energy available to them as do organisms at the first trophic level. They use about 90% of what they receive, and so those at the third level have only 10% as much available to them as those at the second level. This 10% rule continues up the trophic levels, so much less energy is available at the next higher trophic level in an ecosystem.

The set of organisms that pass energy from one trophic level to the next is described as the **food chain** (**Figure** 18.9). In this simple depiction, all organisms eat at only one trophic level. Animals at the 3rd trophic level only eat from the 2nd trophic level and those at the 2nd eat only from the 1st. But many omnivores feed at more than one trophic level, with plants and animals in their diets.

Since only 10% of the energy is passed up the food chain, each level can support fewer organisms. A top predator, like a jaguar, must have a very large range in which to hunt so that it can get enough energy to live. Top carnivores are quite rare relative to herbivores for this reason. The result of this is that the number of organisms at each trophic level looks like a pyramid. There are many more organisms at the base of the pyramid, at the lower trophic levels than at the top of the pyramid, the higher trophic levels.

Food chains usually have only four or five trophic levels because 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. Organisms at higher trophic levels also tend to be larger than those at lower levels. The reason for this is simple: a whale must be able to eat a plankton, but the plankton does not have to be able to eat the whale. Sometimes multiple smaller predators will act together to take down a larger prey, so the organisms at the higher level are smaller than those at the lower level. This is true of a pack of wolves, which acts together as one to hunt a moose.

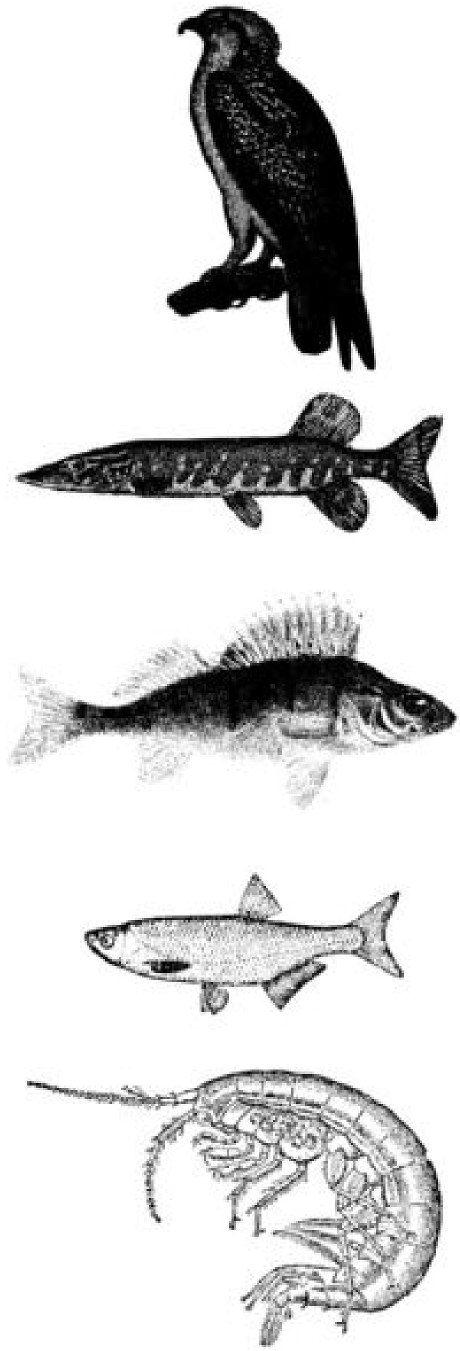


Figure 18.9: A simple food chain from a Swedish lake. Not pictured: algae eaten by the shrimp; Shrimp are eaten by a small fish, a bleak, which is eaten by a perch, which is eaten by a northern pike, which is eaten by an osprey. (17)

Since some organisms feed at more than one trophic level, the food chain does not adequately describe the passage of energy in an ecosystem. The more accurate representation is a **food web** (**Figure** 18.10). A food web recognizes that many organisms eat at multiple trophic levels. A food web includes the relationships between producers, consumers and decomposers.

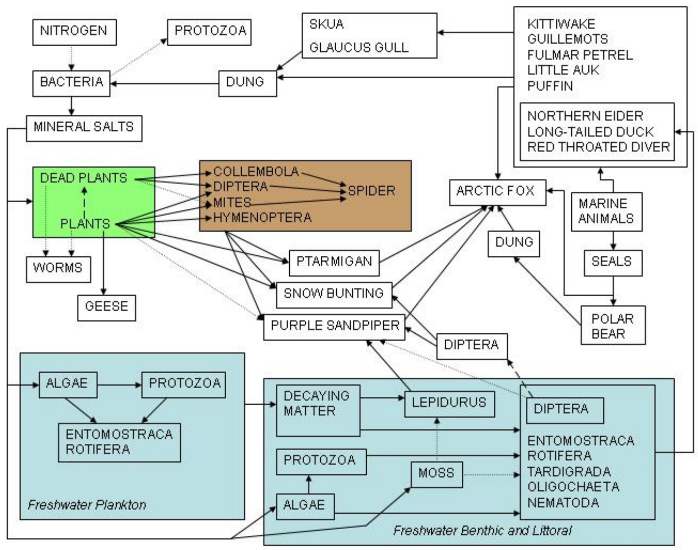


Figure 18.10: An arctic food web. Besides the living organisms, some abiotic components (nitrogen, mineral salts) and nonliving parts (dung) are included. (10)

All organisms depend on two global food webs that are interconnected. The base of one is phytoplankton, microscopic ocean producers. These tiny organisms are eaten by zooplankton. The zooplankton are tiny animals which in turn are eaten by small fish and then larger fish. Land plants form the base of the second food web. They are eaten by herbivores, that are eaten by carnivores and so on. Birds or bears that live on land may eat fish, which connects the two food webs. Humans are an important part of both of these food webs; we are at the top of a food web since nothing eats us. That means that we are top predators.

Flow of Matter in Ecosystems

The flow of matter in an ecosystem is not like energy flow. Matter can enter an ecosystem at any level and can leave at any level. It cycles freely between trophic levels and between the ecosystem and the physical environment. **Nutrients** are ions that are crucial to the growth of living organisms. Nutrients, like 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 like carbohydrates, lipids, proteins and nucleic acids.

Nutrients may enter an ecosystem from the breakdown of rocks and minerals. They enter the soil and are taken up by plants. Nutrients can be brought in from other regions, perhaps carried to a lake by a stream. 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. Nutrients can blow out of an ecosystem on the wind.

Decomposers play a key role in making nutrients available to organisms. After scavengers eat dead organisms, they almost always leave some parts of the dead animal or plant behind. Decomposers complete the process of breaking down dead organisms. They convert dead organisms into nutrients and carbon dioxide, which they respire into the air. These left over nutrients are then available for other organisms to use. Without decomposers, life on Earth would not be able to continue. Dead tissue would remain as it is and eventually nutrients would run out. Decomposers break apart tissue and return the nutrients to the ground. Without decomposers, life on earth would have died out long ago.

Relationships Between Species

Species have different types of relationships with each other. **Competition** occurs between species that are trying to use the same resources. When there is too much competition, one species may move or adapt so that it uses slightly different resources. It may live at the tops of trees and eat leaves that are somewhat higher on bushes, for example. If the competition does not end, one species will die out. Each niche can only be inhabited by one species.

Some relationships between species are beneficial to at least one of the two interacting species. These relationships are known as **symbiosis** and there are three types. In **mutualism**, the relationship benefits both species (**Figure** 18.11). Most plant-pollinator relationships are mutually beneficial. The pollinator, such as a hummingbird, gets food. The plant get its pollen caught in the bird's feathers, so that pollen is spread to far away flowers helping them reproduce.

In **commensalism**, the relationship is beneficial to one species, but does not harm or help the other (**Figure** 18.12). A bird may build a nest in a hole in a tree. This neither harms nor benefits the tree, but it provides the bird and its young with protection.

In **parasitism**, the parasite species benefits and the host is harmed (**Figure** 18.13). Parasites do not usually kill their hosts because a dead host is no longer useful to the parasite. A visible example of parasite and host is mistletoe on an oak tree. The mistletoe gains water and nutrients through a root that it sends into the tree's branch. The tree is then supporting the mistletoe, but the tree is not killed, even though its growth and reproduction are slightly harmed by the parasite. Humans can host parasites, like the flatworms that cause schistosomiasis.

Figure 18.11: This hummingbird and flower each benefit from the mutualism of their relationship. (8)

Figure 18.12: The relationship between these barnacles and the humpback whale is an example of commensalism. The barnacles receive protection and get to move to new locations and the whale is not harmed. (26)

Figure 18.13: These tiny mites are parasitic on a harvestman. (23)

Lesson Summary

- Each species fills a niche within an ecosystem. Each ecosystem has the same niches, although the same species doesn't always fill them.
- Each ecosystem has producers, consumers, and decomposers. Decomposers break down dead tissue to make nutrients available for living organisms.
- Energy is lost at each trophic level, so top predators are scarce. Feeding relationships are much more complicated than a food chain, since some organisms eat from multiple trophic levels.
- As a result, food webs are needed to show all the predator/prey interactions in an ecosystem.

Review Questions

1. What is the difference between a population, a community and an ecosystem?
2. What is the difference between a niche and a habitat?
3. Why are the roles in different ecosystems the same but the species that fill them often different?
4. Why are there no producers in the deep sea ecosystem? Without producers, where does the energy come from? What is the ultimate source of the energy?
5. Is a predator an herbivore, carnivore or omnivore? How about a prey?
6. Biologists have been known to say that bacteria are the most important living things on the planet. Why would this be true?
7. Why are you so much more likely to see a rabbit than a lion when you're out on a hike?
8. How much energy is available to organisms on the 5^{th} trophic level compared with those on the 1st? How does this determine how long a food chain can be?
9. Why is a food web a better representation of the feeding relationships of organisms than a food chain?
10. Why is energy only transferred in one way in an ecosystem, but nutrients cycle around?
11. Why does a predator kill its prey but a parasite rarely kills its host?

Vocabulary

abiotic Nonliving features of an ecosystem include space, nutrients, air, and water.

biotic Living features of an ecosystem include viruses, plants, animals, and bacteria.

carnivore Animals that only eat other animals for food.

chemosynthesis The creation of food energy by breaking down chemicals.

commensalism A relationship between two species in which one species benefits and the other species is not harmed.

community All of the living creatures of an ecosystem; all of the populations of all of the species that live together.

competition A rivalry between two species, or individuals of the same species, for the same resources.

consumer An organism that does not create its own chemical energy, but uses other organisms for food.

decomposer An organism that breaks down the tissues of a dead organism into its various components, including nutrients that can be used by other organisms.

ecosystem All of the living things in a region and the physical and chemical factors that they need to live.

food chain An energy pathway that includes all organisms that are linked as they pass along food energy, beginning with a producer and moving on to consumers.

food web Interwoven food chains that show each organism eating from different trophic levels, which more closely reflects reality.

habitat Where an organism lives; habitats have distinctive features like climate or resource availability.

herbivore An animal that only eats producers.

invertebrate Animals without backbones.

mutualism A symbiotic relationship between two species in which both species benefit.

niche An organism's "job" within its community.

omnivore An organism that consumes both plants (producers) and other consumers (animals) for food.

parasitism A symbiotic relationship between two species in which there is a parasite and a host. The parasite gains nutrition from the host. The host in a parasitic relationship is harmed but usually not killed.

photosynthesis The process in which plants use carbon dioxide and water to produce sugar and oxygen: $6CO_2 + 12H_2O$ + solar energy $C_6H_{12}O_6 + 6O_2 + 6H_2O$.

population All the individuals of a species that occur together in a given place and time.

predator An animal that kills and eats other animals.

prey An animal that could be killed and eaten by a predator.

producer An organism that creates chemical energy to be used as food. Most producers use photosynthesis but a very small number use chemosynthesis.

scavenger Animals that eat animals that are already dead.

species A classification of organisms that includes those that can or do interbreed and produce fertile offspring; members of a species share the same gene pool.

symbiosis Relationships between two species in which at least one species benefits.

trophic level Energy levels within a food chain or food web.

vertebrate Animals with backbones.

Points to Consider

- What happens if two species attempt to fill the same niche?
- There is at least one exception to the rule that each ecosystem has producers, consumers and decomposers. Excluding hydrothermal vent, what does the deep sea ecosystem lack?
- Where do humans fit into a food web?
- Most humans are omnivores, but a lot of what we eat is at a high trophic level. Since ecosystems typically can support only a few top predators relative to the number or lower organisms, why are there so many people?

18.2 The Carbon Cycle and the Nitrogen Cycle

Lesson Objectives

- Describe the short term cycling of carbon through the processes of photosynthesis and respiration.
- Identify carbon sinks and carbon sources.
- Describe short term and long term storage of carbon.
- Describe how human actions interfere with the natural carbon cycle.
- Describe the nitrogen cycle.

Introduction

Carbon is a very important element. It is not the most abundant element in the universe or even on the Earth, but it is the second most common element in the human body. You could not live without carbon. If something you eat has protein or **carbohydrates** or fats, then it contains carbon. When your body breaks down that food to produce energy, you breathe out carbon dioxide. Carbon is also a very important element on Earth. Carbon is provided by the environment, moves through organisms and then returns to the environment again. When all this happens in balance, the ecosystem remains in balance too. In this section, let's follow the path of a carbon atom over many years and see what happens.

Nitrogen is also a very important element. Nitrogen must be converted to a useful form so that plants can grow. Without "fixed" nitrogen, plants and therefore animals could not exist as we know them.

Short Term Cycling of Carbon

The short term cycling of carbon begins with carbon dioxide and the process of **photosynthesis**. Our atmosphere is mostly made of nitrogen and oxygen, but there is a small amount of carbon dioxide in the air too. Plants and **algae** use this carbon dioxide, along with water and energy from sunlight to produce their own food. This is a little miracle that is happening everywhere around you each and every day. Plants and algae have the ability to take the inorganic carbon in carbon dioxide and make it into organic carbon, which is food. That is something that we cannot do at all! Imagine the difference between what would happen if you tried to eat a piece of coral or a shell and what happens when we eat sugar. We can't get energy from the bits of rock at all, but you know how quickly sugar can be used for energy in our bodies.

Through photosynthesis, carbon dioxide plus water and energy from sunlight is transformed into food with oxygen given off as a waste product. Chemists write shorthand equations for different types of chemical reactions. The equation for photosynthesis looks like this (**Figure**

18.14):

$$6\,CO_2 + 6\,H_2O + \text{Energy from sunlight} \rightarrow C_6H_{12}O_6 + 6\,O_2$$

carbon dioxide water glucose (sugar) oxygen

Figure 18.14: (3)

The amazing transformation that has happened here is changing energy from sunlight into chemical energy that plants and animals can use as food (**Figure** 18.15).

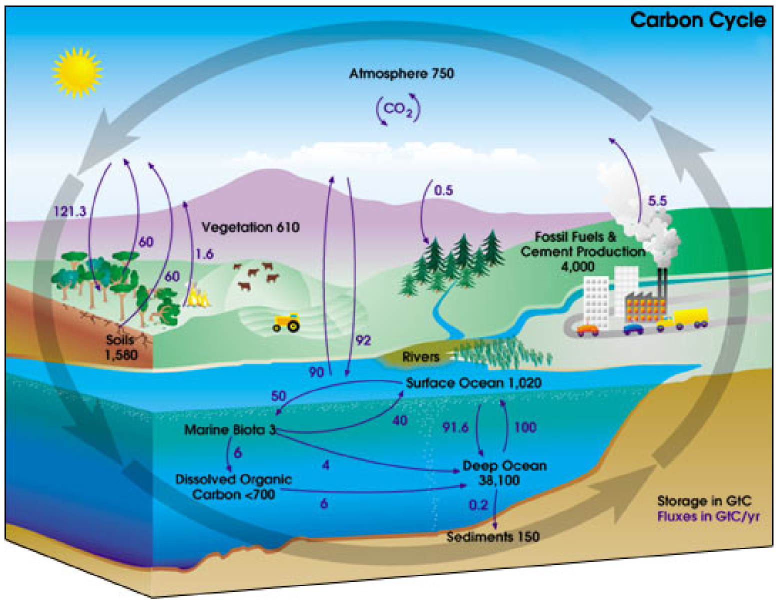


Figure 18.15: This diagram of the carbon cycle shows some of the places a carbon atom might be found. The black numbers indicate how much carbon is stored in various reservoirs, in billions of tons ("GtC" stands for gigatons of carbon; figures are circa 2004). The purple numbers indicate how much carbon moves between reservoirs each year. The sediments, as defined in this diagram, do not include the ˜70 million GtC of carbonate rock and kerogen. (18)

Carbon Can Also Cycle in the Long Term

As described above, an individual carbon atom could cycle very quickly if the plant takes in carbon dioxide to make food and then is eaten by an animal, which in turn breathes out carbon dioxide. Carbon might also be stored as chemical energy in the cells of the plant or the animal. If this happens, the carbon will stay stored as part of the organic material that makes up the plant or animal until it dies. Some of the time, when a plant or animal dies, it decomposes and the carbon is released back into the environment. Other times, the organic material of the organism is buried and transformed over millions of years into coal, oil, or natural gas. When this happens, it can take millions of years before the carbon becomes available again.

Another way that carbon is stored for long periods of time happens when carbon is used by ocean organisms. Many ocean creatures use calcium carbonate ($CaCO_3$) to make their shells or to make the reef material where coral animals live. When algae die, their organic material becomes part of the ocean sediments, which may stay at the bottom of the ocean for many, many years. Over millions of years, those same ocean sediments can be forced down into the mantle when oceanic crust is consumed in deep ocean trenches. As the ocean sediments melt and form magma, carbon dioxide is eventually released when volcanoes erupt.

Carbon Sinks and Carbon Sources

We can think of different areas of the ecosystem that use and give back carbon as **carbon sources** and **carbon sinks**. Carbon sources are places where carbon enters into the environment and is available to be used by organisms. One source of available carbon in the environment happens when an animal breathes out carbon dioxide. So carbon dioxide added to our atmosphere through the process of respiration is a carbon source. Carbon sinks are places where carbon is stored because more carbon dioxide is absorbed than is emitted. Healthy living forests and our oceans act as carbon sinks.

In the natural situation, the amount of carbon dioxide in the atmosphere is very low. This means that we can quickly change the amount of carbon dioxide in our atmosphere. Scientists can use data from air bubbles trapped in the ice of glaciers to determine what the natural level of carbon dioxide was before the Industrial Revolution, when humans began to use lots of fossil fuels. Measurements of the different gases in the air bubbles tell us that the natural level of carbon dioxide was about 280 parts per million. Today the amount of carbon dioxide in our atmosphere is 388 parts per million and that amount continues to rise every year. Scientists have been making measurements in the middle of the Pacific Ocean, far from any large land areas for fifty years. The graph (**Figure** 18.16) of this data shows that the amount of carbon dioxide has been steadily increasing every year.

Human Actions Impact the Carbon Cycle

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Remember that in the natural cycle, the carbon that makes up coal, oil, and natural gas would be stored for millions of years. When we burn coal, oil, or natural gas, we release the stored carbon in the process of combustion. That means that combustion of fossil fuels is also a carbon source.

The equation for combustion of propane, which is a simple **hydrocarbon** looks like this (**Figure** 18.17):

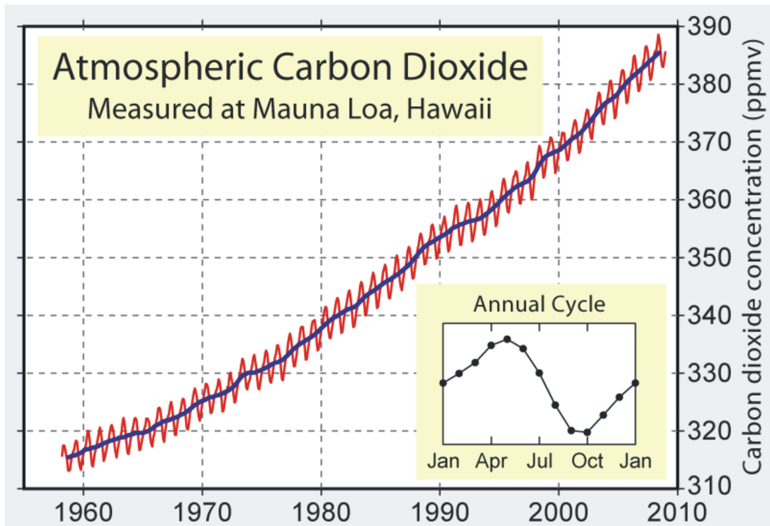


Figure 18.16: The Keeling curve of atmospheric CO_2 concentrations measured at Mauna Loa Observatory. (4)

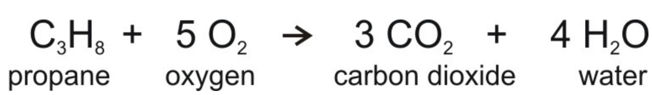


Figure 18.17: (20)

The equation shows that when propane burns, it uses oxygen and the result is carbon dioxide and water. So each time we burn a fossil fuel, we increase the amount of carbon dioxide in the atmosphere. Another way that carbon dioxide is being added to our atmosphere is through the cutting down of trees, called **deforestation** (**Figure** 18.18). Trees are very large plants, which naturally use carbon dioxide while they are alive. When we cut down trees, we lose their ability to absorb carbon dioxide and we also add the carbon that was stored in the tree into the environment. Healthy living forests act as a carbon sink, but when we cut them down, they are a carbon source.

Figure 18.18: This forest in Mexico has been cut down and burned to clear forested land for agriculture. (21)

Coal, oil, and natural gas as well as calcium carbonate rocks and ocean sediments are long term carbon sinks for the natural cycling of carbon. When humans extract and use these resources, combustion makes them into carbon sources.

Why Do We Need to Know About the Carbon Cycle?

You may wonder why scientists study the carbon cycle or why we would be concerned about such small amounts of carbon dioxide in our atmosphere. Carbon dioxide is a **greenhouse gas** (**Figure** 18.19). Different gases in our atmosphere absorb infrared energy, the longer wavelengths of the Sun's reflected rays. These gases hold onto heat energy that would otherwise radiate out into space. As the heat is held in our atmosphere, it warms the Earth. This is just like what happens in a greenhouse. The glass that makes up the greenhouse holds in heat that would otherwise radiate out.

When our atmosphere holds onto more heat than it would in the natural situation, it produces

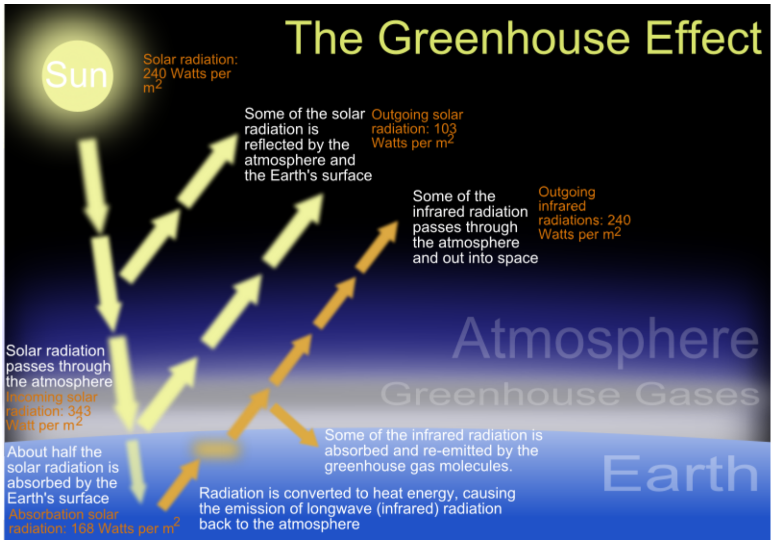


Figure 18.19: This diagram explains the role of greenhouse gases in our atmosphere. (24)

global warming. As our Earth continues to warm, there are many potential consequences. One possibility is that the current weather patterns will change. With rain falling in different areas, we won't be able to grow crops in the same regions which will impact our ability to grow food. Another possibility is that our polar ice caps will melt. We can already see this happening today. Glaciers all over the world are retreating as they melt away. Another possible consequence is that some species of plants and animals could become extinct. Polar bears have recently been added to the endangered species list as threatened because they need sea ice in order to hunt (**Figure** 18.20).

Figure 18.20: Polar bears depend on sea ice for hunting. (13)

As continental glacial ice melts, this will cause sea levels to rise, which will cause flooding of low lying coastal areas. That would be a big problem because many of our biggest cities are along coastlines.

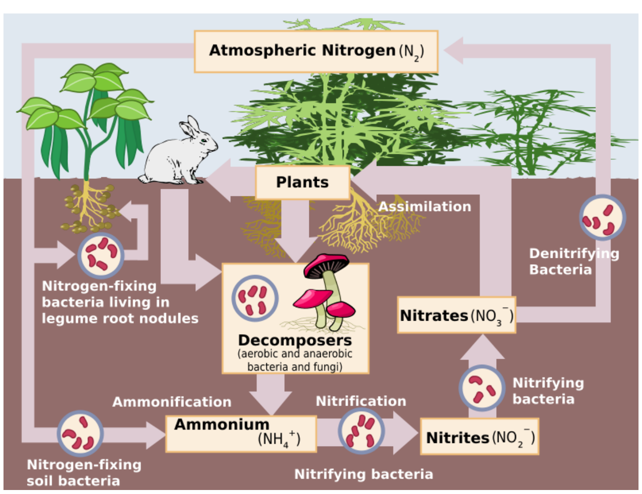
The Nitrogen Cycle

Nitrogen (N2) is also vital for life on Earth as an essential component of organic materials. Nitrogen is found in all amino acids, proteins, and nucleic acids such as DNA and RNA. Chlorophyll molecules in plants, which are used to create food by photosynthesis forming the basis of the food web, contain nitrogen.

Although nitrogen is the most abundant gas in the atmosphere, it is not in a form that plants can use. To be useful, nitrogen must be "fixed," or converted into a more useful form. Although some nitrogen is fixed by lightning or blue-green algae, much is modified by bacteria in the soil. These bacteria combine the nitrogen with oxygen or hydrogen to create nitrates or ammonia.

Nitrogen fixing bacteria either live free or in a symbiotic relationship with leguminous plants (peas, beans, peanuts). The symbiotic bacteria use carbohydrates from the plant to produce ammonia that is useful to the plant. Plants use this fixed nitrogen to build amino acids, nucleic acids (DNA, RNA) and chlorophyll. When these legumes die, the fixed nitrogen they contain fertilizes the soil.

Animals eat plant tissue and create animal tissue. After a plant or animal dies or an animal excretes waste, bacteria and some fungi in the soil fix the organic nitrogen and return it to the soil as ammonia. Nitrifying bacteria oxidize the ammonia to nitrites, other bacteria oxide the nitrites to nitrates, which can be used by the next generation of plants. In this way, nitrogen does not need to return to a gas. Under conditions when there is not oxygen, some bacteria can reduce nitrates to molecular nitrogen.



Usable nitrogen is sometimes the factor that limits how many organisms can grow in an ecosystem. Modern agricultural practices increase plant productivity adding nitrogen fertilizers to the soil. This can have unintended consequences as excess fertilizers run off the land, end up in water, and then cause nitrification of ponds, lakes and nearshore oceanic areas. Also, nitrogen from fertilizers may return to the atmosphere as nitrous oxide or ammonia, both of which have deleterious effects. Nitrous oxide contributes to the breakdown of the ozone layer and ammonia contributes to smog and acid rain.

Lesson Summary

- The carbon cycle begins with the process of photosynthesis, which transforms inorganic carbon into organic carbon.
- Our forested areas and our oceans are carbon sinks. When carbon is trapped in ocean sediments, or fossil fuels, it is stored for millions of years.
- Humans have changed the natural carbon cycle by burning fossil fuels, which releases carbon dioxide to the atmosphere. Burning of fossil fuels and deforestation are carbon sources.
- One potential consequence of increased carbon dioxide in the atmosphere is global warming.
- The nitrogen cycle begins with nitrogen gas in the atmosphere then goes through nitrogen-fixing micro organisms to plants, animals, decomposers and into the soil.

Review Questions

1. Describe the process of photosynthesis.
2. How can carbon cycle very quickly back into the environment?
3. Name two ways that carbon is stored for a very long time in the natural cycle.
4. Describe what makes a carbon sink and what makes a carbon source and give an example of each.
5. Name two ways that humans interfere with the natural carbon cycle.
6. Do we need carbon dioxide in our atmosphere?
7. Is global warming something that could impact you in your lifetime?

Vocabulary

algae Photosynthetic organisms in the ocean; includes one celled organisms and seaweeds.

carbohydrates An organic compound that supplies energy to the body; includes sugars, starches and cellulose.

carbon sink An area of an ecosystem that absorbs more carbon dioxide than it produces.

carbon source An area of an ecosystem that emits more carbon dioxide than it absorbs.

deforestation Cutting down and/or burning trees in a forested area.

greenhouse gas Gases like carbon dioxide that absorb and hold heat from the sun's infrared radiation.

global warming Warming of the Earth brought about by adding additional greenhouse gases to the atmosphere.

hydrocarbon An organic compound that contains only hydrogen and carbon.

photosynthesis The process using carbon dioxide, water, and energy from sunlight by which plants and algae produce their own food.

18.3 Human Populations

Lesson Objectives

- Describe how changes in a limiting factor can alter the carrying capacity of a habitat.
- Discuss how humans have increased the carrying capacity of Earth for our species and how we may have exceeded it.
- Discuss how human activities like agriculture and urbanization have impacted the planet.
- Describe what sustainable development is.

Introduction

Improvements in agriculture, sanitation, and medical care have enabled the human population to grow enormously in the last few 100 years. As the population grows, consumption, waste, and the overuse of resources also grow. People are beginning to discuss and carry out sustainable development that decreases the impact humans have on the planet.

Populations

The population size of a species depends on the biotic and abiotic factors present in that ecosystem. Biotic factors include the amount of food that is available to that species and the number of organisms that use that species as food. For life to thrive, a specific amount of abiotic factors are necessary. For example, too little water may cause land plants or animals to become dehydrated. Too much water, however, may cause drowning.

A population grows when the number of births is greater than the number of deaths. It shrinks, if deaths exceed births. For a population to grow, there must be ample resources and no major problems. 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.

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.

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: a nutrient, space, and water availability are examples. The size of a population is tied to its limiting factor. If the limiting factor decreases, the population decreases. If the limiting factor increases, the population increases. 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, and enough other ingredients but only two pounds of butter. You can make four batches of cookies, with butter as the limiting factor. If you get more butter, something else will be limiting.

Species ordinarily produce more offspring than their habitat can support. 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.

Human Population Growth

Human population growth over the past 10,000 years has been tremendous (**Figure** 18.21). The human population was about 5 million in 8000 B.C., 300 million in A.D. 1, 1 billion in

1802, 3 billion in 1961, and 6.7 billion in 2008. As the human population continues to grow, different factors may emerge limiting human population in different parts of the world. Space may be a limiting factor or having enough clean air, clean water or food to feed everyone are concerns we are already facing.

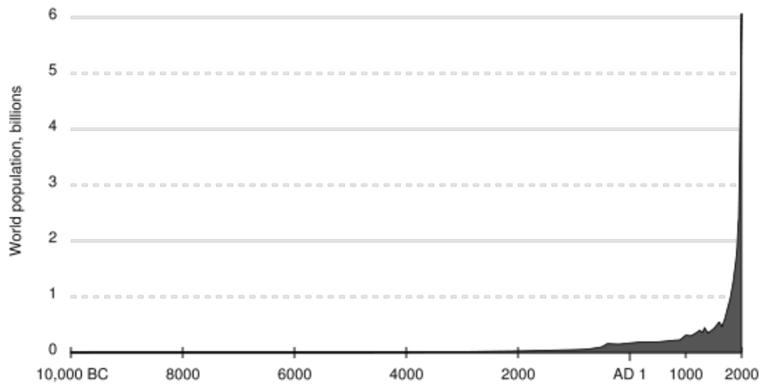


Figure 18.21: Human population from 10,000 BC through 2000 AD showing the exponential increase in human population that has occurred in the last few centuries. (5)

Not only has the population increased, but the rate of growth has also increased (**Figure** 18.22). It took all of human history for the population to reach the first 1 billion people, in around 1802. The second billion was added 125 years later, in 1927. It took 33 years for there to be 3 billion people in 1960, and only 15 years for there to be 4 billion people in 1975. Another billion was added by 1987, just twelve years later, and it took only another twelve years for the population to reach 6 billion people in 1999. Estimates are that the population will reach 7 billion in 2012, 13 years after reaching 6 billion.

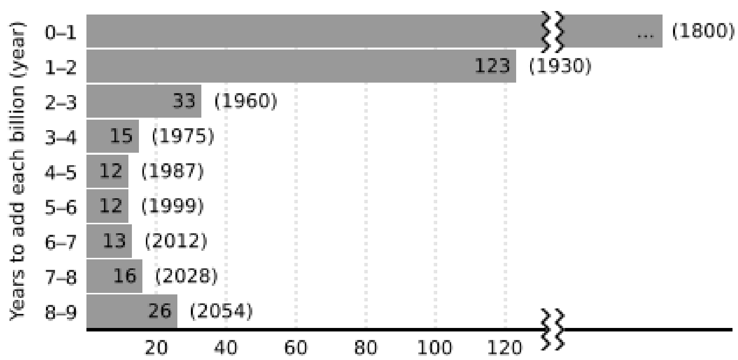


Figure 18.22: The amount of time between the addition of each one billion people to the planet's population including speculation about the future. (9)

Although population continues to grow rapidly, the rate of growth has declined. Still, it is likely that there will be between 9 and 10 billion people sharing this planet by the middle of the century. The total added will be about 2.5 billion people, which is more than were even in existence as recently as 1950.

With so many more people on the planet than ever before, we must ask whether humans now are 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. This population was reached about 10,000 years ago. At the time, people lived together in small bands of hunters and gatherers. Commonly women gathered nuts and vegetables and men hunted animals and fished. People within a band shared their resources. Although they had trading networks with outside groups, trading was limited by what could reasonably be carried. For the most part, people relied on the resources that they could find where they lived.

As you can see, human populations have blown past this hypothetical carrying capacity. By using our brains, our erect posture, and our hands, we have been able to do things that no other species has ever done. About 10,000 years ago, we developed the ability to grow our own food. Farming allowed us to grow the plants we wanted to eat and to have food available year-round. We domesticated animals to have meat when we wanted. With agriculture, people could settle down, so that they no longer needed to carry all their possessions. 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. Early farmers could grow only enough food for their families, with perhaps a bit extra to sell, barter, or trade. More advanced farming practices allowed a single farmer to grow food for many more people. Being freed from having to gather or grow food allowed people to do other types of work.

The next major stage in the growth of the human population was the Industrial Revolution, which started in the late 1700's. Increased efficiency in farming freed up large numbers of people available to work in factories. This major historical event marks when products were first mass produced and when fossil fuels were first widely used for power.

Every major advance in agriculture allowed global population to increase. 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. Currently about 70% of the world's fresh water is used for agriculture.

The biggest advance in agriculture in recent decades is called the **Green Revolution**. It is this advance that has allowed the population to grow so rapidly. The first focus of the Green Revolution was to improve crops. A tremendous increase in the use of artificial fertilizers, nutrients that help plants to grow and chemical pesticides, chemicals that kill pests followed. About 23 times more fertilizer and 50 times more pesticides are used around the world than just 50 years ago. Most agricultural work is now done by machines: plowing, tilling, fertilizing, picking, and transporting (**Figure** 18.23). About 17% of the energy used each year in the US is for agriculture.

The Green Revolution has increased the productivity of farms immensely. A century ago,

Figure 18.23: Rows of a single crop and heavy machinery are normal sights for modern day farms. (15)

a single farmer produced enough food for 2.5 people, but now a farmer can feed more than 130 people. Due to this increased productivity, the Green Revolution is credited for feeding 1 billion people that would not otherwise have been able to live.

The flip side of this is that for the population to continue to grow, more advances in agriculture 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, like groundwater. The question is, even though we have increased the carrying capacity of the planet, have we now exceeded it? Are humans on Earth experiencing **overpopulation**?

There are many different opinions about human population growth. 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. Some scientists think that the carrying capacity of the planet is around 1 billion people, not the almost 7 billion people we have today. How did we get to where we are today? Many of our limiting factors have changed as we have used our intelligence and technology to expand our resources. Can we continue to do this into the future? Do we now have more people and more impacts on our environment than the Earth can handle?

Humans and the Environment

Along with the increases in food that have come from the Green Revolution have come enormous impacts on the planet. More food has allowed the human population to explode. 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.

Modern agricultural practices produce a lot of pollution (**Figure** 18.24). Some pesticides are toxic. Fertilizers drain off farmland and introduce nutrients into lakes and coastal areas, causing fish to die. 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 moves between air, water, and land. As a result, no location or organism—not even polar bears in the remote Arctic—is free from pollution.

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** 18.25).

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 need resources to produce and fossil fuels to power. Their production, use and disposal all produce wastes. Many people refer to the abundance of luxury items in these people's lives as **overconsumption**. People in developed nations use 32 times more resources than people in the developing countries of the world.

There are many problems worldwide that result from overpopulation and over-consumption. One such problem is the advance of farms and cities into wild lands, which diminishes the habitat of many organisms. In addition, water also must be transported for irrigation and domestic uses. This means building dams on rivers or drilling wells to pump groundwater. Large numbers of people living together need effective sanitation systems. Many developing countries do not have the resources to provide all of their citizens with clean water. It is not uncommon for some of these children to die of diseases related to poor sanitation. Improving sanitation in many different areas—sewers, landfills, and safe food handling—are important to prevent disease from spreading.

Figure 18.24: Pesticides are hazardous in large quantities and some are toxic in small quantities. (1)

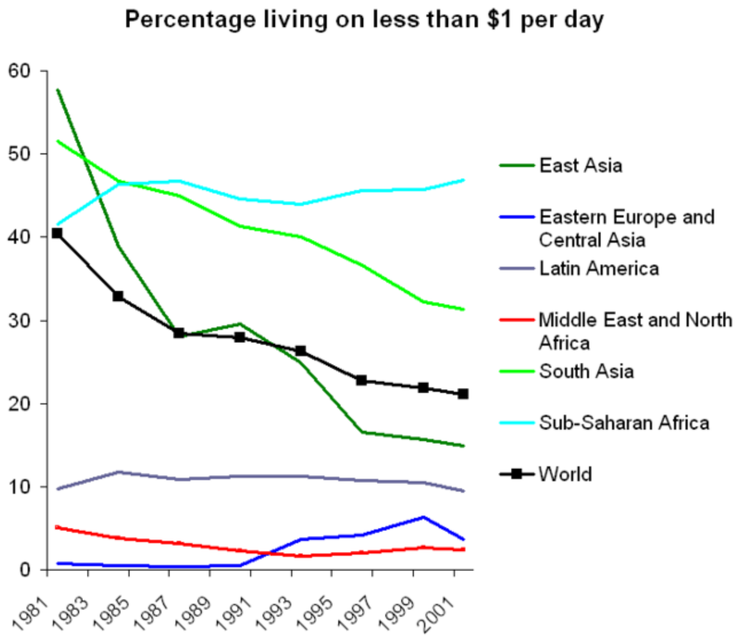


Figure 18.25: The percentage of people in the world that live in abject poverty is decreasing somewhat globally, but increasing in some regions, like Sub-Saharan Africa. (12)

Wildlife is threatened by fishing, hunting and trading as population increases. Besides losing their habitat as land is transformed, organisms are threatened by hunting and fishing as human population grows. Hunting is highly regulated in developed nations, but many developing nations are losing many native animals due to hunting. Wild fish are being caught at too high a rate and many ocean fish stocks are in peril.

Humans also cause problems with ecosystems when they introduce species that do not belong in a habitat. **Invasive species** are sometimes introduced purposefully, but often they arrive by accident like rats on a ship. Invasive species often have major impacts in their new environments. A sad example is the Australian Brown Tree Snake that has wiped out 9 of the 13 native species on the island of Guam (**Figure** 18.26).

Pollution is a by-product of agriculture, urbanization, and the production and consumption of goods. Global warming is the result of fossil fuel burning.

Let's return to the question of whether humans have exceeded Earth's carrying capacity for our species. Carrying capacity is exceeded if resources are being used faster than they are being replenished. It is also exceeded if the environment is being damaged.

The answer to our original question therefore appears to be yes. Many resources are being used far in excess of the rate at which they are being replaced. The best farmland is already in use and more marginal lands are being developed. Most rivers in the developed nations

Figure 18.26: An Australian Brown Tree Snake perched on a post in Guam. (2)

and many in developing nations are already dammed. Groundwater is being used far more rapidly than it is being replaced. The same is true for fossil fuels and many mineral resources. Forests are being chopped down; and wild fish are being overharvested. Human have caused the rate of extinction of wild species to increase to about at least 100 times the normal extinction rate.

In addition, the stability of the environment decreases as landscapes are transformed, organisms die out and the planet becomes polluted. Although many more people are alive in the world than ever before, many of these people do not have secure lives. Many people in the world live in poverty, with barely enough to eat. They often do not have safe water for drinking and bathing. Diseases kill many of the world's children before they reach five years of age.

Sustainable Development

A topic generating a great deal of discussion these days is **sustainable development**. This is development that attempts to help people out of poverty, while protecting the environment, without using natural resources faster than they can be replaced. It is development that allows people to use resources no faster than the rate at which they are regenerated.

One of the most important steps to achieving a more sustainable future is to reduce human population growth. This has been happening in recent years. Studies have shown that the birth rate decreases as women become educated. Educated women tend to have fewer and healthier children.

Science can be an important part of sustainable development. When scientists understand how Earth's natural systems work, they can recognize how people are impacting them. Scientists can work to develop technologies that can be used to solve problems wisely. An example of a practice that can aid sustainable development is fish farming, as long as it is done in environmentally sound ways. Engineers can develop cleaner energy sources to reduce pollution and greenhouse gas emissions.

Citizens can change their behavior to reduce the impact they have on the planet by demanding products that are produced sustainably. When forests are logged, new trees should be planted. Mining should be done so that the landscape is not destroyed. People can consume less and think more about the impacts of what they do consume.

Lesson Summary

- Populations of organisms are kept to a habitat's carrying capacity by factors that limit their growth.
- By developing agriculture and other technologies, the human population has grown well past any natural population limits.
- Many people on Earth live in poverty, without enough food or clean water or shelter.
- Overpopulation and over-consumption are causing resources to be overused and much pollution to be generated.
- Society must choose development that is more sustainable, in order to secure a long term future for our species and the other species that we share the planet with.

Review Questions

1. If phosphorous is limiting to a species in an ecosystem and the amount of phosphorous is increased, what will happen to the population of that species? What will happen to the carrying capacity?
2. Name some factors that could cause a population to increase. Try to include as many types of factors as possible.
3. In terms of numbers of births and deaths, explain in detail why you think human population is growing so tremendously?
4. If all people on Earth were allowed only to replace themselves (that is, each person could only have one child or each couple two children), what would happen to the planet's population in the next decade? Would it decrease, increase, or remain exactly the same as it is now?
5. What role has agriculture played in human population and why?
6. Discuss the good and bad points about the Green Revolution.
7. In the United States, 17% of energy is used for agriculture? How is this possible, if plants photosynthesize with sunlight?
8. What is more threatening to the future of the planet: overpopulation or overconsump-

tion? How does an increase in the standard of living for people living in poverty affect the planet?
9. What evidence is there that humans are exceeding Earth's carrying capacity for our species?
10. What is sustainable development?

Vocabulary

carrying capacity The number of individuals of a given species a particular environment can support.

Green Revolution Changes in the way food is produced since World War II that have resulted in enormous increases in production.

invasive species A species of organism that spreads in an area where it is not native, and negatively impacts the native vegetation. People often introduce invasive species either purposefully or by accident.

limiting factor The one factor that limits the population of a region. The limiting factor can be a nutrient, water, space, or any other biotic or abiotic factor that species need.

over-consumption Resource use that is unsustainable in the long term; obtaining many more products than people need.

overpopulation When the population of an area exceeds its carrying capacity or when long-term harm is done to resource availability or the environment.

pesticide A chemical that kills a certain pest that would otherwise eat or harm plants that humans want to grow.

sustainable development Economic development that helps people out of poverty, use resources at a rate at which they can be replaced, and protects the environment.

Points to Consider

- How much impact on the planet does an infant born in the United States have during its lifetime, compared with one born in Senegal?
- How does consuming less impact global warming?
- Can ordinary people really make a difference in changing society toward more sustainable living?

Image Sources

(1) USDA.
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(2) http://en.wikipedia.org/wiki/Image:Snake_browntree.jpg. GNU-FDL.

(3) .

(4) http://en.wikipedia.org/wiki/File:Mauna_Loa_Carbon_Dioxide.png. GNU-FDL.

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Chapter 19

Human Actions and the Land

19.1 Loss of Soils

Lesson Objectives

- Explain how human actions accelerate soil erosion.
- Describe ways that we can prevent soil erosion.

Introduction

Have you ever seen muddy rain or snow falling from the sky? Can you imagine what it might be like if the water that came down as rain and snow was muddy and brown? In May 1934, a huge wind storm picked up and blew away massive amounts of **topsoil** from the Central United States (**Figure** 19.1). The wind carried the soil eastward to Chicago. Some of the soil then fell down to the ground like a snowstorm made of mud. The rest of it continued blowing eastward, and reached all the way to New York and Washington, D.C. That winter, states like New York and Vermont actually had red snow because of all the dusty soil in the air.

A little less than one year later, in April 1935, another such storm happened (**Figure** 19.2). It was called a Black Blizzard. It made the day turn dark as night; people could not see right in front of them because of all the soil blown up by the wind storm. The storm caused tremendous damage and led to many people leaving the central United States to find other places to live. Many people became sick from breathing the soil in the air.

These storms are sometimes called the Dust Bowl storms. They continued on and off until about 1940. They are extreme examples of soil erosion, which is the process of moving soil from one place to another. Soil erosion is a serious problem because it takes away a valuable

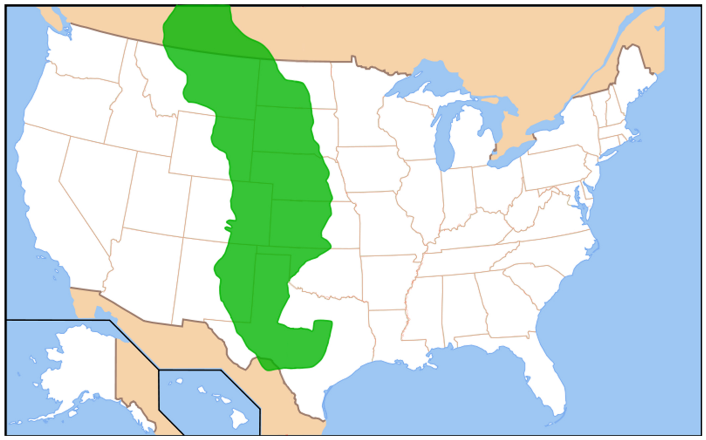

Figure 19.1: Soil loss from the dust storms of 1934 and 1935 came mostly from the states shown here in green in the Central United States. The soil blew all the way to the east coast of the United States. (10)

Figure 19.2: This wind storm blew huge amounts of soil into the air in Texas on April 14, 1935. (8)

resource that we need to grow food. Several factors contributed to the Dust Bowl storms. First, farmers in the Central United States had plowed grasslands there to grow food crops. They left the crop fields bare in the winter months. This left the soil exposed to wind. Secondly, a long drought in the 1930's left the exposed soil especially dry. When the spring winds began blowing, the dry exposed soil was easily picked up and blown away.

We learned many lessons from the Dust Bowl storms. Today, we encourage farming practices that keep the soil covered even during the winter, so that it is not exposed and vulnerable to erosion. We have also learned of ways to prevent erosion in cities and towns as well as on farmlands. In this lesson, you will learn about some human activities that lead to erosion. You will then learn some of the specific ways we can prevent soil erosion.

Causes of Soil Erosion

Soil erosion occurs when water, wind, ice or gravity moves soil from one place to another. Running water is the leading cause of erosion, since it can easily take soil with it as the water flows downhill or moves across the land. Wind is the next leading cause of erosion. Just as in the Dust Bowl storms of the 1930's, wind can blow soil many hundreds of kilometers away. Soil is especially vulnerable to erosion if it is bare or exposed. Plants therefore serve a tremendous role in preventing soil erosion. If the soil is covered with plants, erosion is slowed down. But when soil is bare, the rate of erosion speeds up tremendously. What are some human activities that leave the soil exposed and speed up erosion? We speed up erosion through the following actions:

- Agriculture
- Grazing animals
- Logging and mining
- Construction
- Recreational activities, like driving vehicles off-road or hiking

Agriculture, is probably the most significant human action that accelerates, or speeds up, erosion (**Figure** 19.3). We first plow the land to plant fields of crops. This takes away the natural vegetative cover of an area and replaces it with rows of crop plants mixed with bare areas. It also creates an area where there may not be anything growing in the winter, because in most areas, food crops only grow in the spring and summer. The bare areas of a field are very susceptible to erosion. Without anything growing on them, the soil is easily picked up and carried away. The fields also experience more erosion in the winter if no plants are growing on them and they are just left as bare soil. In addition, farmers sometimes make deep grooves in the land with their tractor tires. These grooves act like small channels that give running water a path. This speeds up erosion from water.

Some parts of the world use an agricultural practice called slash and burn. This involves cutting and burning forests to create fields and **pastures**. It is one of the worldwide leading

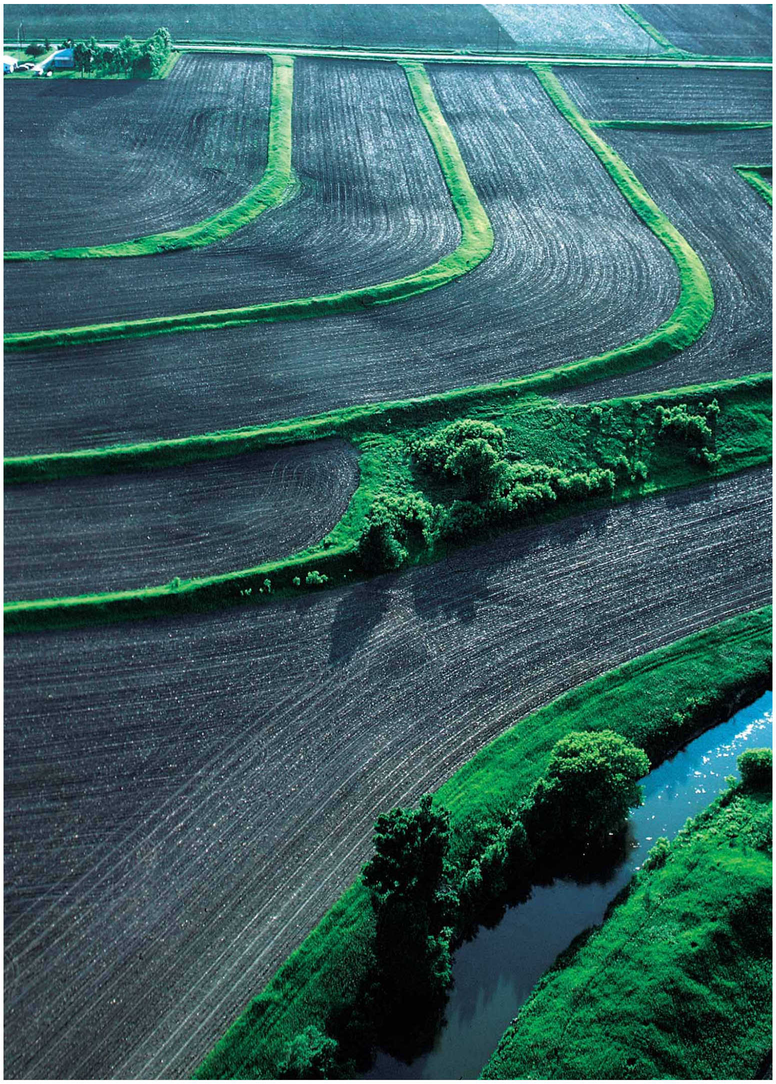

Figure 19.3: The bare areas of farmland are especially vulnerable to erosion. (12)

causes of excessive soil erosion. It is most commonly practiced in developing countries in tropical areas of the world, as people create more land for agriculture.

Grazing animals are animals that live on large areas of grassland (**Figure** 19.4). They wander over the area and eat grasses and shrubs. They can remove large amounts of the plant cover for an area. If too many animals graze the same land area, once the tips of grasses and shrubs have been eaten, they will use their hooves to pull plants out by their roots.

Figure 19.4: Grazing animals can cause erosion if they are allowed to overgraze and remove too much or all of the vegetation in a pasture. (11)

When an area is logged, large areas of trees are cut down and removed for human use (**Figure** 19.5). When the trees are taken away, the land is left exposed to erosion. Even more importantly, logging results in the loss of **leaf litter**, or dead leaves, bark, and branches on the forest floor. Leaf litter decreases because no trees are left to drop leaves or other plant parts to the ground. The leaf litter plays an important role in protecting forest soils from erosion.

Mining is another activity that speeds up erosion (**Figure** 19.6). When we mine we are digging in the Earth for mineral resources, like copper or silver. The huge holes dug by mining operations leave large amounts of ground exposed. In addition, most of the rock removed when mining is not actually the precious mineral, but **tailings**, or unwanted rock that is left next to the mine after the valuable minerals are removed. These tailings are usually piled up next to a mine, and are easily eroded downhill.

Constructing human buildings and roads also causes much soil erosion. This **development** involves changing forest and grassland into cities, buildings, roads, neighborhoods, and other human-made features. Any time we remove natural vegetation, we make the soil more susceptible to erosion. In addition, features like roads, sidewalks, and parking lots do not let

Figure 19.5: Logging exposes large areas of land to erosion. (9)

Figure 19.6: This large coal mining pit in Germany, and other mines like it, are major causes of erosion. (4)

water run through them into the ground because they are hard and **impermeable** (**Figure** 19.7). Since the water cannot enter the ground, it then runs over the ground faster than usual. This can speed up water erosion.

Figure 19.7: Urban areas and parking lots result in less water entering the ground. Therefore, more water runs over the land and quickly forms channels that can speed up erosion. (6)

Humans also cause erosion through recreational activities, like hiking and riding off-road vehicles. An even greater amount of erosion occurs when people drive off-road vehicles over an area. The area eventually develops bare spots where no plants can grow. Erosion becomes a serious problem in these areas.

Human-caused Erosion

Some erosion is a natural process and has always happened on Earth. However, human activities like those discussed above, have accelerated soil erosion, which may occur about 10 times faster than its natural rate. As the human population grows, we increase our impact on soil erosion. In order to support Earth's human population, we need to create more and more farmland, we develop more areas and build more cities, and we use much more of the land for recreation. Human population growth can lead to degradation of the natural environment.

Human impact on erosion differs throughout the world. In developed countries like the United States, we have learned good agricultural practices that greatly slow down agriculture's impact on erosion. However, we still experience much erosion from the development of urban areas and construction of new cities. In developing countries, many people are very poor and just want to be able to grow food and make a simple living. They carry out slash and burn agriculture because it quickly gives them land to grow food crops on. Poverty is a big contributing factor to environmental problems like soil erosion in developing countries.

Preventing Soil Erosion

Soil is a renewable, natural resource necessary for growing food. However, it renews itself slowly: it can take hundreds or thousands of years to replenish lost soil. When we lose valuable soil, we also lose an important natural resource. Many of the farmers affected by the Dust Bowl storms of the 1930's lost their homes because they could no longer grow crops and earn money to live, once their topsoil had all blown away. While agriculture can cause erosion, it is also necessary for human life. We have learned many good agricultural practices that reduce erosion, instead of speeding it up.

Table 19.1 shows some seps that we can take to prevent erosion. Which of these things can you do in your own personal life? Can you think of any other steps we can take to slow down erosion? Notice that many of the things listed here involve ways that we use the land. Land use always requires humans to make choices.

Table 19.1:

Source of Erosion	Strategies for Prevention
Agriculture	• Leave leaf litter on the ground in the winter • Grow **cover crops**, special crops grown in the winter to cover the soil • Plant tall trees around fields to buffer the effects of wind • Drive tractors as little as possible • Use drip irrigation that puts small amounts of water in the ground frequently • Avoid watering crops with sprinklers that make big water drops on the ground • Keep fields as flat as possible to avoid soil eroding down hill

Table 19.1: (continued)

Source of Erosion	Strategies for Prevention
Grazing Animals	• Move animals throughout the year, so they don't consume all the vegetation in one spot • Keep animals away from stream banks, where hills are especially prone to erosion
Logging and Mining	• Reduce the amount of land that we log and mine • 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 that we turn into cities, urban areas, parking lots, etc. • Keep as much "green space" in cities as possible, such as strips of trees 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 19.1: (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

Lesson Summary

- Soil erosion is a natural process, but human activities have greatly accelerated soil erosion.
- We accelerate erosion through agriculture, grazing, logging and mining, development, and recreation.
- Soil is an important natural resource necessary for plant growth and should be kept safe from erosion as much as possible.
- There are many ways that we can slow down or prevent erosion, but practicing these involves making decisions about how we use land resources. It also requires striking a balance between economic needs and the needs of the environment.

Review Questions

1. Many farmers harvest their crops in the fall and then let the leftover plant material stay on the ground over winter. How does this help prevent erosion?
2. List five ways human activity has accelerated soil erosion.
3. How do urban areas contribute to soil erosion?
4. What is the connection between poverty and soil erosion in developing countries?
5. What is one way you can prevent soil erosion when you are hiking?
6. You often see stone barriers or cage-like materials set up along coastal shores and river banks. How do you think these serve to prevent erosion? Why are areas like this prone to erosion?
7. How can your own activities affect the environment, especially soil erosion?
8. What can we do to help solve environmental problems in developing countries? What responsibility do you have to help solve this problem?

Further Reading / Supplemental Links

- People who lived during the Dust Bowl talk about their experiences, the Ganzel Group http://www.livinghistoryfarm.org/farminginthe30s/water_02.html
- Video of the Dust Bowl http://www.weru.ksu.edu/vids/dust002.mpg

Vocabulary

cover crop A special crop grown by a farmer in the wintertime to reduce soil erosion. Cover crops often also add nitrogen to the soil.

development The construction of new buildings, roads, and other human-made features in a previously natural place.

impermeable Not allowing water to flow through it.

leaf litter Dead leaves, branches, bark, and other plant parts that accumulate on the floor of a forest.

pasture Land that is used for grazing animals.

topsoil The very important top few inches of soil, where much of the nutrients are found necessary for plant growth; Part of the A horizon

Points to Consider

- Is soil a renewable resource or a nonrenewable resource? Explain the ways it could be either.
- Could humans live without soil?
- What could you do to help to conserve soil?

19.2 Pollution of the Land

Lesson Objectives

- Define hazardous waste and describe its sources.
- Describe some of the impacts of hazardous waste on human health and on the environment.
- Detail some ways that we can control hazardous wastes.

Introduction

Sometimes human activities lower the quality or **degrade** the land by putting hazardous substance in the soil and water. A well-known example of this is the story of Love Canal in New York. The story began in the 1950's, when a local chemical company put dangerous chemicals in steel drum containers. They buried the containers in Love Canal, an abandoned waterway near Niagara Falls, New York (**Figure** 19.8). They then covered the containers with soil and sold the land to the local school system.

Figure 19.8: Steel barrels like these were used to contain the hazardous chemicals at Love Canal. After several years, they began to leak the chemicals into the soil and groundwater, which caused many people to become sick. (7)

The school system built a school on the land. The city of Niagara Falls also built more than 800 homes near Love Canal. Several years later, people who lived there began to notice bad chemical smells in their homes. Children developed burns after playing in the soil, and they were often sick. A woman living in the area, named Lois Gibbs, organized a group of citizens called the 'Love Canal Homeowners Association' to try to find out why their children kept getting sick (**Figure** 19.9). They discovered that their homes and school were sitting on top of the site where the dangerous chemicals had been buried. They believed that the old steel drums used to contain the dangerous chemicals were leaking and making them and their children sick. They demanded that the government take action to clean up the area and remove the chemicals.

By 1979, the United States government fully realized that the old drums were indeed leaking dangerous chemicals into the soil and water where the people lived and went to school. The government gave money to many of the people to move somewhere safer and began

Figure 19.9: A resident of Love Canal protests the hazardous waste contamination in her neighborhood. (2)

cleaning up the site. The work of Lois Gibbs was important in bringing the problem of hazardous chemical pollution to peoples' attention. After the Love Canal problem, the U. S. government created a law called the **Superfund Act**. This law requires companies to be responsible for hazardous chemicals that they put into the environment. It also requires them to pay the money needed to clean up polluted sites, which can often be hundreds of millions of dollars. As a result, companies today are more careful about how they deal with hazardous substances.

This lesson describes some of the sources of hazardous wastes throughout the world. It then discusses the effects these wastes have on human health and the environment. Finally, this lesson covers ways that we can control hazardous wastes.

What is Hazardous Waste?

Hazardous waste is any waste material that is dangerous to human health or that degrades the environment. Hazardous waste materials include substances that are:

1. Toxic: something that causes serious harm, death or is poisonous.
2. Chemically active: something that causes dangerous or unwanted chemical reactions, like dangerous explosions.
3. Corrosive: something that destroys other things by chemical reactions.
4. Flammable: something that easily catches fire and may send dangerous smoke into the air.

Hazardous waste may be solid or liquid. It comes from many sources, and you may be surprised to learn that you probably have some sources of hazardous waste right in your own home. 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. When we use, store, and dispose of them, we have to be careful. We have to protect our bodies from exposure to them and make sure they do not enter the environment (**Figure** 19.10). If they are thrown away or disposed of improperly, they become hazardous to the environment. Others sources of hazardous waste are shown in **Table** 19.2.

Table 19.2:

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

Table 19.2: (continued)

Type of Hazardous Waste	Example	Why it is Hazardous
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

Impacts of Hazardous Waste

Many hazardous waste materials have serious impacts on human health. They often cause cancer and can also cause birth defects. They can make people sick for very long times. Breathing the air or drinking the water that is contaminated with hazardous waste is a major health threat.

Two chemicals that are especially toxic in the environment are lead and mercury. Lead harms people by damaging their brain and nervous system. Lead is especially harmful in children under the age of six; about 200 children die every year from lead poisoning. Lead was once a common ingredient in gasoline and paint (**Figure** 19.11). In the 1970's and 1980's, the United States government passed laws completely banning lead in gasoline and paint. This has prevented the lead poisoning of millions of children in the United States. However, several other countries still use gasoline with lead in it. Also, homes built before the 1970's may contain paint that has lead in it. These still pose a threat to human health.

Mercury is a pollutant affecting the whole world (**Figure** 19.12). Mercury enters the environment from volcanic eruptions, burning coal and from waste products like old batteries and electronic switches. It is also found in old discarded electronic appliances like television sets. Like lead, mercury also damages the brain and impairs nervous system function. Mercury often accumulates in fish, so people and other animals that eat the fish then are in danger of getting the mercury in their own bodies.

Preventing Hazardous Waste Pollution

The United States is currently the world's largest producer of hazardous wastes. However, as China becomes more industrialized, it may take over the number one spot. Countries with

Figure 19.10: This farm worker wears special clothes for protection from the hazardous pesticide in the container. (1)

Figure 19.11: In the United States, automotive gasoline must now be unleaded, or free from lead. (3)

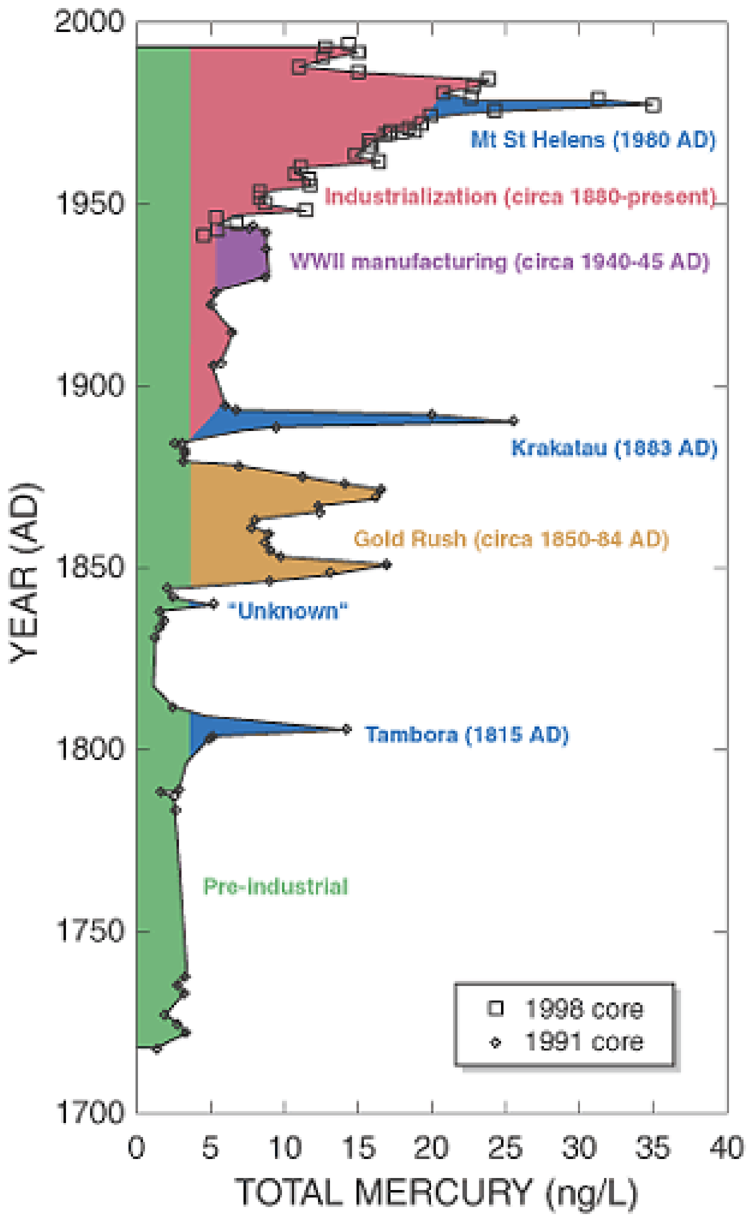

Figure 19.12: This graph shows historic increases of mercury in the atmosphere. Events in blue are volcanic eruptions. Events in brown, purple and pink are human-caused. Notice the effect of industrialization on mercury levels in the atmosphere (the red region of the graph). (5)

more industry produce more hazardous waste than those with little industry. Hazardous wastes can enter the air when we burn things like batteries containing mercury or old tires. Hazardous waste can enter the water when chemicals are dumped on the ground, or are buried and then leak. Substances buried in the ground often leak from their containers after a number of years. The chemicals then move through the soil until they reach groundwater. Hazardous chemicals are especially dangerous once they reach our groundwater resources. Sites like the one at Love Canal are now referred to as **Superfund sites**. They are found throughout the country. Many of them have been identified and cleaned up. We now have strict laws to prevent new sites like the Love Canal site from ever forming in the first place.

In the United States, we have several laws that help control hazardous waste. The Resource Conservation and Recovery Act requires any company that produces hazardous materials to keep careful track of what happens to it. The government has passed special rules for how these materials can be disposed of. Companies must ensure that hazardous waste is not allowed to enter the environment in dangerous amounts. They have to protect their workers from the hazards of the materials. They must keep a record of how they dispose of hazardous wastes, and show the government that they did so in a safe way.

Individual people can also do much to control hazardous wastes. We can choose to use materials that are not hazardous in the first place. We can make sure that we dispose of materials properly. We can control the amount of pesticides that we use. We can make sure to not pour toxic chemicals over the land, or down the drain or toilet, or even into the trashcan. We can also use hazardous materials less often. We can find safer alternatives for many of the chemicals we use. For example, we can use vinegar and water to clean windows instead of the usual glass-cleaning chemicals.

Lesson Summary

- Hazardous wastes are dangerous to human health and the environment. They come from many sources, such as household chemicals, gasoline, paints, old batteries, discarded appliances, and industrial chemicals.
- Once in the air or buried on land, they can cause human health problems or even death and degrade the environment for other organisms.
- Developed countries like the United States produce most of the world's hazardous waste.
- We have passed laws that require careful disposal of hazardous materials and that make their producers financially responsible for them if they pollute the environment.

Review Questions

1. How does the United States Superfund Act help control hazardous wastes?
2. What is the difference between corrosive and flammable?

3. Organic farming is a method of growing food crops with natural alternatives to chemical pesticides. How does organic farming help control hazardous wastes?
4. What is one disadvantage of storing hazardous wastes in barrels buried deep in the ground?
5. Scientists who work with hazardous wastes often wear special clothing like gloves and masks. Why do you think they wear these items?
6. Which do you think is easiest and hardest to keep track of: hazardous waste that is present as a gas, liquid, or solid? Why?

Further Information / Supplemental Links

- Love Canal Pathfinder, Nathan Tallman http://www.nathantallman.org/pathfinders/lovecanal.html

- Superfund Sites Where You Live http://www.epa.gov/superfund/sites/index.htm

Vocabulary

degrade To lower the quality of something.

pesticides Chemicals used to kill or harm unwanted pests such as insects that damage food crops.

superfund act A law passed by the US Congress in 1980 that held companies responsible for any hazardous chemicals that they might create.

superfund site A site where hazardous waste has been spilled. Under the Superfund act, the company that created the hazardous waste is responsible for cleaning up the waste.

Points to Consider

- What are the best ways to either prevent or safely dispose of hazardous materials?
- If humans are the ones who mostly create hazardous materials, whose responsibility is it to clean them up?
- Is it important for each generation to leave the world a safe place? If one generation doesn't do this, who pays the price?

Image Sources

(1) USDA. http://commons.wikimedia.org/wiki/Image:Hazardous-pesticide.jpg. Public Domain.

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Chapter 20

Human Actions and Earth's Resources

20.1 Use and Conservation of Resources

Lesson Objectives

- Discuss some natural resources used to make common objects.
- Describe some ways to conserve natural resources.

Figure 20.1: The Monongahela National Forest in West Virginia supplies us with many natural resources, including, timber, wildlife, coal, gas, recreation, and fishing. (5)

Introduction

In the Monongahela National Forest of West Virginia (**Figure** 20.1), scientists have a mystery to solve: the mystery of the missing plant **nutrients**, which are substances in the soil that plants need to grow. For several years, the trees there have not grown as well as they should. Soil scientists believe that the soil is missing many of the important nutrients that the trees and other plants there need to grow. They have conducted many years of research to determine why the nutrients are disappearing and why the trees are not growing like they should.

Mary Lusk was one of the soil scientists who worked to solve the mystery of the missing nutrients in the forest. She gathered samples of the soil and tested it for important nutrients. She saw that the soil has very low levels of plant nutrients, such as magnesium and calcium. If these nutrients are not in the soil, the trees cannot grow well. She wondered why the soil had such low levels of these nutrients. After a little more research, she developed the hypothesis that air pollution from nearby factories has been putting chemicals in the environment that are removing the nutrients from the soil. In a sense, the pollution is "snatching" the nutrients and carrying them out of the soil.

Scientists in the Monongahela National Forest are still researching the missing plant nutrients. They are trying to learn what they can do to help keep the nutrients in the soil, so the trees will grow better. The forest is an important natural resource. A natural resource is something from nature that we depend on. We depend on the Monongahela National Forest for many reasons, including:

- Recreation, such as hiking, camping, and picnics.
- The forest is vital habitat for many animals, including 9 endangered species and 50 different species of rare plants.
- The forest contains 207 kilometers (129 miles) of streams for fishing, particularly trout fishing.
- Hunters use the forest for hunting deer, squirrels, turkeys, rabbits, mink, and foxes.
- The forest contains materials that we use, such as coal, gas, limestone, and gravel.
- The forest has abundant hardwood trees used for **timber**, which is sold for over 7 million dollars a year.

Like the Monongahela National Forest, we use many parts of the Earth for many reasons (**Figure** 20.2). We depend on materials from the Earth for food, water, building materials, timber, recreation, and energy. However, human activities can degrade these natural resources, just like air pollution from factories is speeding up the loss of soil nutrients in West Virginia (**Figure** 20.3). We need to **conserve** our natural resources so they will always be around. When we practice conservation, we make sure resources will be available in the future, both for ourselves and for other organisms.

Figure 20.2: We use Earth's resources for many purposes, including recreation and natural beauty. (8)

Figure 20.3: Severe pollution can lead to drastic environmental damage and loss of natural resources. This forest in Europe was damaged by air pollution. (3)

Renewable versus Non-Renewable Resources

Natural resources may be classified as renewable or non-renewable. Renewable resources are those that can be regenerated, which means new materials can be made or grown again at the same rate as they are being used. For example, trees are a renewable resource because new trees can be grown to replace trees that are cut down for use. Other examples of renewable resources include soil, wildlife, and water. However, some resources, like soil, have very slow rates of renewal, so we still need to conserve them. It is also important to realize that while these resources are in most cases renewable, we can still pollute them, damage them or over-use them to the point that they are not fit for use anymore. Fish are considered a renewable resource because we can take some fish but leave others to reproduce and create new fish for later use. Imagine, however, what can happen if we over-fish, or take too many fish at one time. If we over-harvest our trees or wildlife resources, we may not leave enough to let the resource renew itself.

Non-renewable resources are resources that renew themselves at such slow rates that, practically, they cannot be regenerated. Once we use them up, they are gone for good - or at least for a very, very long time. Coal, oil, natural gas and minerals are non-renewable resources. It takes millions of years for these materials to form, so if we use them to the point of depletion, new resources will not be made for millions more years. We can run out of these resources.

Common Materials We Use From the Earth

What do a CD, a car, a book, a soda can, a bowl of cereal, and the electricity in your home all have in common? They are all made using natural resources. For example, a CD and a soda can are made of metals that we mine from the Earth. A bowl of cereal comes from wheat, corn, or rice that we grow in the soil. The milk on the cereal comes from cows that graze on fields of grass. We depend on natural resources for just about everything that we eat and use to keep us alive, as well as the things that we use for recreation and luxury. In the United States, every person uses about 20,000 kilograms (40,000 pounds) of minerals every year for a wide range of products such as cell phones, TV's, jewelry, and cars. **Table** 20.1 shows some common objects, the materials they are made from and whether they are renewable or non-renewable.

Table 20.1:

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 20.1: (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

Human Population and Resource Use

As the human population grows, so does the use of our natural resources. A growing population creates a demand for more food, more clothing, more houses and cars, etc. Population growth puts a strain on natural resources. For example, nearly 500 people move into the

Tampa, Florida area every week (**Figure** 20.4). Tampa's population is growing quickly. The Tampa area may have over 3 million people by 2010. One of Tampa's rivers, the Hillsborough River, is pumped for drinking water to support all the people. Too much water is being taken from the river. The river is becoming salty, as water from the near-by Gulf of Mexico starts to take the place of the **freshwater** being pumped out. This hurts wildlife and may eventually make the river water unsuitable for human use. Many other examples like this are taking place worldwide.

Figure 20.4: Downtown Tampa, Florida is growing at an enormous rate. The growing human population puts a strain on natural resources, like rivers and other bodies of water. (1)

Resource Availability

You can see from the table above that many of the resources we depend on are non-renewable. We will not be able to keep taking them from the Earth forever. Also, non-renewable resources vary in their availability. Some are very abundant and others are rare. Precious gems, like diamonds and rubies, are valuable in part because they are so rare. They are found only in small areas of the world. Other materials, like gravel or sand are easily located and used. Whether a resource is rare or abundant, what really determines its value is how easy it is to get to it and take it from the Earth. If a resource is buried too deep in the Earth or is somehow too difficult to get, then we don't use it as much. For example, the oceans are filled with an abundant supply of water, but it is too salty for drinking and it is difficult to get the salt out, so we do not use it for most of our water needs.

Resource availability also varies greatly among different countries of the world. For example, 11 countries (Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela) have nearly 80% of all the world's oil (**Figure** 20.5). However, none of these is the world's biggest user of oil. In fact, the biggest users of oil, the United States, China, and Japan, are all located outside this oil-rich region. This difference in availability and use of resources can be a source of economic and political trouble throughout the world. Nations that have abundant resources often **export** them to other countries, while countries that lack a resource must **import** it from somewhere else.

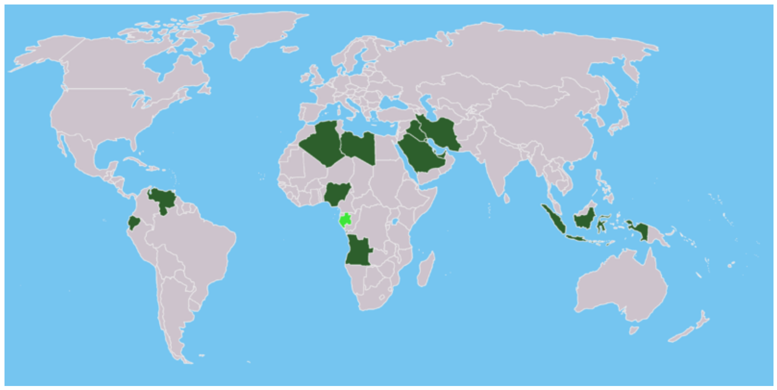

Figure 20.5: The nations in green are the 11 biggest producers of worldwide oil. They have almost 80% of the world's current oil supply, even though the United States, China, and Japan are the world's biggest users of oil. (7)

In developed countries like the United States and most of Europe, we often use many more natural resources than we need just to live. We have many luxury and recreational materials made from resources. We also tend to throw things away quickly because we can afford to replace them. Discarding materials not only leads to more resource use, but it also leads to more waste that has to be disposed of in some way. Pollution from discarded materials degrades the land, air, and water (**Figure** 20.6). As our cities and neighborhoods grow, we use more and more resources and produce more and more waste. Natural resource use is generally lower in developing countries because people cannot afford to use as much. Still, developing countries need to actively protect their resources by adopting sustainable practices as they develop.

Conserving Natural Resources

We need to conserve natural resources so that we can continue to use them in the future, and so that they will be safe for use. While renewable resources will not run out, they can become degraded or polluted. For example, water is a renewable resource, but we can pollute it to the point that it is not safe for use. Reducing use and recycling materials is a great way to conserve resources (**Figure** 20.7). Many people are also researching ways to find renewable alternatives to non-renewable resources. Here is a checklist of some things we can do to conserve resources:

Figure 20.6: Pollution from discarded materials degrades the environment and reduces the availability of natural resources. (6)

Figure 20.7: Recycling can help conserve natural resources. (2)

- Purchase less stuff (use items as long as you can, ask yourself if you really need something new.)
- Reduce excess packaging (for example, drink water from the tap instead of buying it in plastic bottles).
- Recycle materials like metal cans, old cell phones, and plastic bottles.
- Purchase products made from recycled materials.
- Keep air and water clean by not polluting in the environment.
- Prevent soil erosion.
- Plant new trees to replace ones that we cut down.
- Drive cars less, take public transportation, bicycle, or walk.
- Conserve energy at home (for example, by turning out lights when they are not needed).

Lesson Summary

- We use natural resources for many things. Natural resources give us food, water, recreation, energy, building materials, and luxury items.
- Many resources vary in their availability throughout the world. Some are rare, difficult to get or in short supply.
- We need to conserve our natural resources, protecting them from pollution and overuse.
- We can use materials less or recycle to conserve resources.
- We can also make efforts to reduce pollution and soil erosion in order to conserve resources.

Review Questions

1. List five general things we get from natural resources.
2. We depend on forests as habitat for wildlife. How does this make a forest an important resource for people?
3. How could human life be affected if a large amount of soil erosion affected our soil resources?
4. How does discarding products lead to more resource use?
5. How does choosing to walk or ride a bicycle instead of riding in a car help conserve resources?

Further Reading / Supplemental Links

- Maps of Renewable Resources in the United States http://www.nrel.gov/gis/maps.html
- What to Recycle [* Maps of Renewable Resources in the United States http://www.nrel.gov/gis/maps.html

Vocabulary

conserve To keep things safe and ensure that they will always be around.

export To send out to another country.

import To receive from another country.

macronutrients Nutrients that are needed by an organism in a large amount.

non-renewable A resource that cannot be regenerated; once it is used up, it cannot be replaced within a human lifetime.

timber Trees that are cut for wood to be used for building or some other purpose.

nutrients Substances that a living thing needs to grow.

renewable A resource that can be regenerated, new ones can be made or grown to replace ones that get used.

Points to Consider

- Could a renewable resource ever become nonrenewable?
- How many resources do you use every day?
- Which is more sustainable: using renewable resources or nonrenewable resources? Why?

20.2 Energy Conservation

Lesson Objectives

- Discuss why it takes energy to get energy and why some forms of energy are more useful than others.
- Describe some ways to conserve energy or to use energy more efficiently.

Introduction

Imagine that someone offers you a \$100 bill that you can use for whatever you want. That would be a pretty good deal, wouldn't it? Now imagine that the person attaches a condition to their offer: in order to get the \$100 bill you have to pay them \$75. You would still come out ahead, but this time you would only be getting \$25. Does it make sense to spend money to get money? That depends on how much you get back for what you spend.

Getting and using natural energy sources is a lot like spending money to get money. We use a lot of energy just to get energy (**Figure** 20.8). We have to find an energy source, extract it from the Earth, transport it to the places where it will be used, and often process or convert it into a different form of energy. All of these steps of getting energy require energy use themselves. For example, we use petroleum to make gasoline for our cars. To get the petroleum, we often have to build huge drilling facilities and drill down hundreds of meters into the Earth. It takes energy to do this. We then use trucks or ships to transport the oil all over the world, which also takes energy. We then have to heat the petroleum to its boiling point to make different products from it, like gasoline and automotive oil and this takes even more energy.

In this lesson, you will learn that different sources of energy all require adding some other energy before they can be made useful. You will be able to compare various sources of energy in terms of their usefulness. You will also learn some ways that we can conserve energy or use it more efficiently.

Obtaining Energy

It takes energy to get energy. Net energy is the amount of useable energy available from a resource after subtracting the energy used to extract it from the Earth and make it useable by humans. We just discussed someone giving you \$100 but requiring you to pay them back \$75. In this case, your net pay would be \$25, or \$100 minus \$75. Net energy is calculated the same way. For example, for every 5 barrels of oil that we take from the Earth, we have to use 1 barrel for the extraction and refining process. This leaves us a net supply of only 4 barrels (5 barrels minus 1 barrel).

Remember that oil is a non-renewable resource. Imagine what would happen if the energy needed to extract and refine oil increased. What might happen if it took 4 barrels of oil being used to get 5 barrels of new oil? Then our net supply would only be 1 barrel. Our supply of oil would begin to dwindle away even faster than the current rate.

We sometimes use the expression **net energy ratio** to demonstrate the difference between the amount of energy available in a resource and the amount of energy used to get it. If we get 10 units of energy from a certain amount of oil, but use 8 units of energy to extract, transport, and refine the oil, then the net energy ratio is 10/8 or 1.25. A net energy ratio larger than 1 means that we are still getting some usable energy. A net energy ratio smaller

Figure 20.8: It takes energy to get energy. This is an oil platform used for drilling oil from deep underground. It took lots of energy to build the platform and to run it. (9)

than one means there is an overall energy loss. **Table** 20.2 shows several energy sources commonly used for heating our homes and schools. It shows their net energy ratios. Higher ratios mean that the source provides more useable energy than those with lower ratios.

Table 20.2:

Energy Source	Net Energy Ratio
Solar Energy	5.8
Natural Gas	4.9
Petroleum	4.5
Coal-fired Electricity	0.4

Notice from the table that renewable solar energy gives you much more net energy than other sources and that coal-fired electricity actually consumes more energy than it produces. Why do you think this is so? Burning coal for electricity requires a large input of energy to get energy. We have to find the coal, mine the coal, transport the coal, and build power plants to burn the coal (**Figure** 20.9). All of these take energy and reduce the net energy available for us to use. Solar energy, however, requires very little energy to get in the first place. We don't have to mine it or transport it in trucks. Sunshine is abundant globally and can be used in the same place where it is collected.

Figure 20.9: Transporting coal requires a large input of energy. It takes energy to run the train that transports the coal. (4)

Energy Efficiency

The discussion above on net energy shows you that it takes energy to get energy and that some sources of energy require more input than others to get usable energy. After we get the energy, we then use it for some purpose. Energy efficiency is a term that describes how much usable energy we have available to do work from every unit of energy that we use. Higher energy efficiency is desirable because it means we are wasting less energy and getting more use out of the energy sources that we take from the Earth. Higher energy efficiency also lets us extend our non-renewable sources and make them last longer.

Nearly 85% of the energy used in the United States comes from non-renewable fossil fuels. Since these exist in limited supplies, we need to be especially concerned about using them efficiently. Sometimes our choices affect energy efficiency. For example, transportation needs require huge amounts of energy. Forms of transportation such as cars and airplanes are less efficient than transportation by boats and trains. Fluorescent light bulbs are more efficient than regular, incandescent light bulbs. Hydroelectric power plants are more efficient than nuclear fission reactors.

Energy Conservation

Energy conservation involves reducing or eliminating the unnecessary use of energy. This improves energy efficiency. Energy conservation saves us money and it also ensures that our energy supplies will last longer. There are two main ways to conserve energy: use less energy and use energy more efficiently. The pie chart (**Figure** 20.10) shows how energy is used in the United States.

Almost one-half of the energy used in the United States is for transportation and home use. This means that individual people can do much to conserve energy on a national basis. **Table** 20.3 shows some ways that we can decrease energy use and use energy more efficiently in transportation, residences, industries, and office settings.

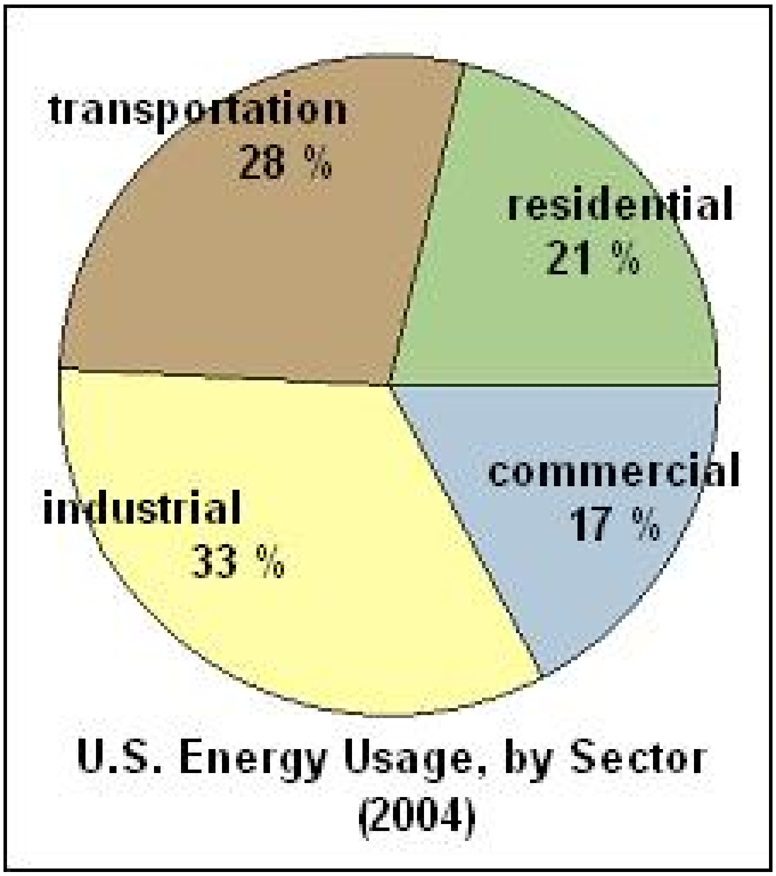

Figure 20.10: This pie chart shows how energy is used in the United States. (10)

Table 20.3:

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 • Read a book or play outside instead of watch TV • 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 20.3: (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.

Lesson Summary

- It takes energy to get energy. We use the term 'net energy' to refer to the amount of energy left for use after we expend energy to get, transport and refine other forms of energy.
- Once the energy is available, we use it for some purpose, but sometimes do so inefficiently.
- We can conserve energy resources by reducing energy use.
- We can also use energy more efficiently by getting more work out of the energy that we use.
- Examples of this include driving smaller cars and using fluorescent light bulbs.

Review Questions

1. Define net energy?
2. Why does solar power have a higher net energy ratio than coal-fired electricity?
3. Coal-fired electricity has a net energy ratio of 0.40. Explain why this means that getting electricity from burning coal is an undesirable option for energy use.
4. What are two ways you can use less energy in your home?
5. Why is it especially important to not waste energy from fossil fuels?
6. Trains are much more efficient than trucks in transporting items around. Why do you think this might be so?

Vocabulary

energy The ability to do work which we can get from a fuel.

extraction The process of taking oil out of the Earth.

fluorescent A type of lighting that uses less energy than regular light bulbs.

net energy ratio The ratio between the useful energy present in a type of fuel, and the energy used to extract and process the fuel.

refining The process of removing impurities from oil and to make it usable.

Points to Consider

- If it takes energy to get energy, then what are the best choices for types of energy?
- Put each of these actions in order from most important to least: choosing a sustainable form of energy, increasing energy efficiency, conserving energy use. Explain the order you chose.
- Could everyone in the world use as much energy as a person in the United States does each day? Why or why not?

Image Sources

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Chapter 21

Human Actions and Earth's Waters

21.1 Humans and the Water Supply

Learning Objectives

- Learn how humans use water.
- Discuss how much water is taken up by each water use.
- Explain the difference between consumptive and non-consumptive water uses.
- Discuss three of the most serious issues humans face today, including shortages of fresh water, lack of safe drinking water and water pollution.

- Discuss why humans are facing water shortages.
- Discuss how water shortages can lead to disputes and even battles between states and countries bordering on the same water source.
- Explain why one fifth of the human population does not have access to safe drinking water.
- Describe the relationship between disease and exposure to unsafe drinking water.
- What is the origin of California's fresh water supply?

Human Uses of Water

All forms of life need water to survive. As humans, we need water to drink or we need to get it from the foods we eat. We also use water for agriculture, industry, household uses, and recreation. Water is continually cycled and recycled through the environment.

Some ways that we use water consume a lot of water that then is lost to the ecosystem and some ways we use water put less demand on our water supplies. Understanding how water cycles and is replaced is important, especially when we look for ways to use less water.

Currently, agricultural uses the most water. Considering different methods of irrigation and times of day to water crops can improve this situation. Farming, growing crops and raising livestock uses more than two thirds of the water used by humans globally.

When water is used but not recycled, the water use is called consumptive. That water is lost to the ecosystem. When excess water is captured or recycled, it is called non-consumptive. As we move to a more sustainable future, we want to be sure as much of our water use is non-consumptive as possible.

What is the most important thing for all life on Earth? Not gold or diamonds. It is water! From the smallest bacteria to the largest trees, all forms of life on Earth depend on water for survival. As humans, we could not survive for more than a few days without drinking water or getting water from the foods we eat.

In addition to our basic survival need for water to drink, people also use freshwater for agriculture, industry and household needs. Across the world, different communities also use water for many kinds of recreational and environmental activities.

Which human activity uses the most water? Not showers, baths, washing dishes or other household uses. On average, agriculture uses more than two thirds of the water that humans use across the world. Industry and household uses average 15% each. Recreational use and environmental uses average 1% each. (See **Figure** 21.1)

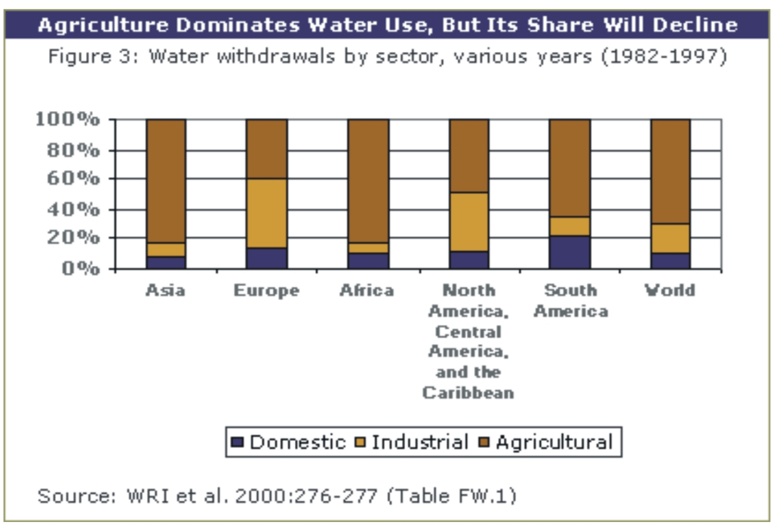


Figure 21.1: Proportion of water used for home, industrial, and agricultural purposes across the world. (3)

Some ways that people use water do not use up the water. When you swim in a lake, you do not use up the water. The water is still in the lake when you climb out. In some cases, water can be recycled for reuse. For example, the water you use to brush your teeth or take a bath can be collected through your household pipes and the sewer system, purified and then redistributed for reuse. These are examples of **non-consumptive water use.** By recycling water, we ultimately reduce our overall water consumption.

Unlike the previous examples, water sprinklers are called **consumptive,** because much of the water is lost to the air as evaporation. None of the lost water can be captured and reused.

Agricultural Water Uses

Have you ever watched huge sprinklers watering large fields of crops (**Figure** 21.2)? If you have, try to imagine how much water it takes to water a field compared to taking a shower or bath. You may be surprised to learn that agriculture uses more than two thirds (69%) of the water humans use, globally. http://authors.ck12.org/wiki/index.php/File:Ear-2101-02.jpg

Figure 21.2: Agricultural Water Use: Overhead sprinklers need to use large quantities of water on crops because much of the water is lost to evaporation and runoff. (25)

Two of the most popular irrigation methods are overhead sprinklers and trench irrigation. Trench irrigation systems are just that: trench canals that carry water from a water source to the fields. Farmers often chose these methods because they relatively inexpensive. Unfortunately, they are also wasteful of water. Roughly fifteen to thirty-six percent of the water never reaches the crops, because it evaporates into the air or is lost as runoff. When rain or irrigation water is not absorbed by the soil, often it washes valuable soil away.

Giving up irrigation is not a choice for most farmers. A farmer living in a dry region, such as a desert, needs irrigation, just to grow crops. A farmer living in a wetter place would use irrigation to produce more crops or to grow more profitable crops. In some cases, farmers can choose to grow crops that match the amount of rain that falls in that region naturally.

Figure 21.3: Drip Irrigation uses a series of pipes and tubes to deliver water to the base of each plant. Because little water is lost to evaporation and runoff, this method uses less water than sprinklers and trenches. (2)

Instead of giving up irrigation, farmers can use less water by choosing more efficient irrigation methods, such as **drip irrigation** (**Figure** 21.3). This irrigation system uses pipes and tubes to deliver small amounts of water directly to the soil at the roots of each plant or tree. It wastes less water than sprinklers and trenches, because almost all of the water goes directly to the soil and plant roots.

You might wonder why any farmer would not switch to efficient irrigation methods, since they would save so much water. There are two reasons. First, drip irrigation and other efficient irrigation methods cost more than trenches and sprinklers. Second, in some countries, such as the United States, the government pays for much of the cost of the water that is used for agriculture. Because, farmers do not have to pay the full price of the water they use, they do not have any financial reason or **incentive** to use less water.

Aquaculture

Aquaculture is the name for the type of farming you might do if you were raising fish, shellfish, algae or aquatic plants (**Figure** 21.4). This is a farming practice where plants and animals that live in water are raised. As the supplies of fish from lakes, rivers, and the oceans dwindle, people are getting more fish from aquaculture. Raising fish instead of hunting for them is a different way of increasing our food resources. The next time you pass the fish display in the grocery store, look for labels for "farm raised" fish. These fish would have been raised in an aquaculture setting.

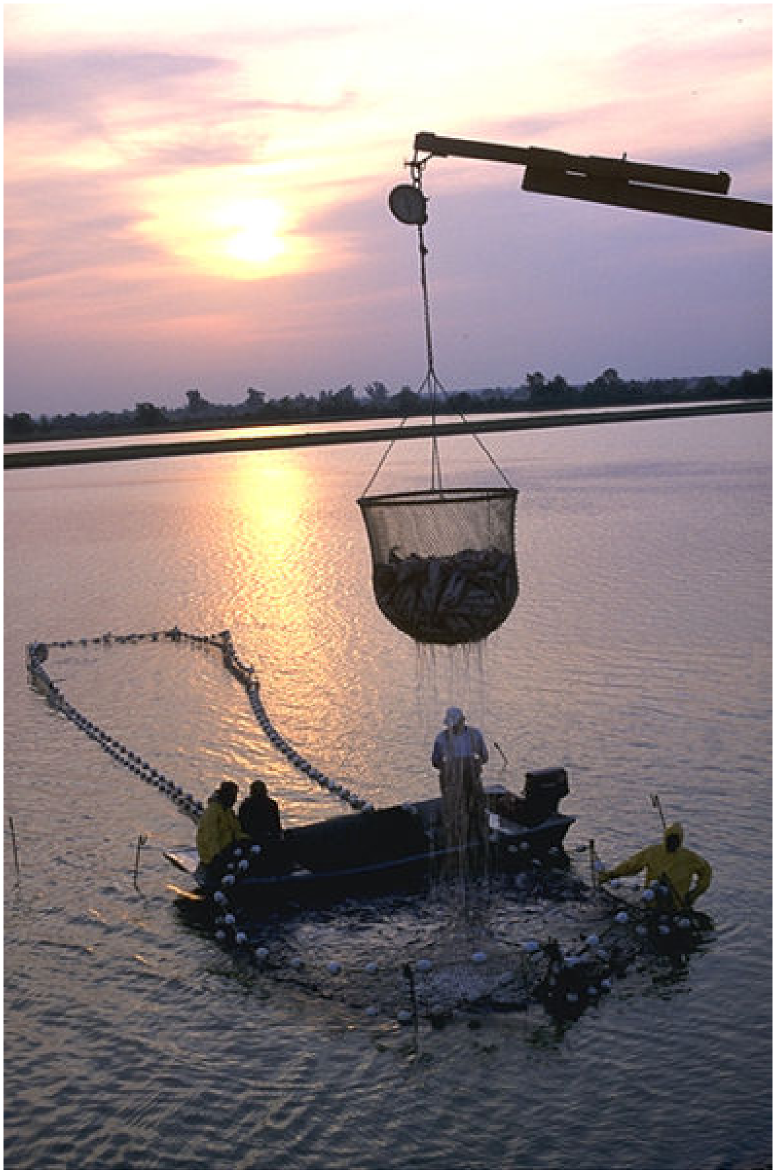


Figure 21.4: Aquaculture: Workers at a fish farm harvest fish they will sell to stores. (24)

Some of the most productive aquaculture farming takes place in wetland areas along coastlines. Rivers and streams carry nutrient-rich water into these wetlands, so fish and other animal life thrives. A good supply of nutrients is important when raising a large community of plants or animals. We need to be careful about the wastes that are added to our coastal waters when we increase plant and animal populations in these areas. Aquaculture can be considered a non-consumptive use of water, as long as we keep our coastal waters in good condition.

Industrial Water Use

Figure 21.5: Industrial water use: A power plant in Poland sits on the edge of a lake with easy access to water for cooling and other purposes. (8)

However, industrial water use accounts for an estimated fifteen percent of worldwide water use. Industries include power plants that use water to cool their equipment, and oil refineries that use water for chemical processes (**Figure** 21.5). Industry also uses water in many manufacturing processes. Looking at water use in a completely different way, hydroelectric power plants are built along rivers and streams to generate energy. This is a very efficient way to use water that is also non-consumptive.

Household Use

Starting from when you wake up in the morning, count the ways you use water at home (**Figure** 21.6). You will need to count the water you drink, water used in cooking, bathing, flushing toilets, and even gardening. You will be surprised to notice how many times a day you use water. Have you ever had to go without water? The United States is a developed country. In developed countries, people use a lot of water each day. People living in lesser

Figure 21.6: Domestic water use. (20)

developed countries use far less water than people in the United States. Globally, household or personal water use is estimated to account for fifteen percent of world-wide water use.

Some household water uses are considered non-consumptive, because water is recaptured in sewer systems, treated and returned to surface water supplies for reuse. Watering lawns with sprinklers is an exception. Just like sprinkler irrigation on farms, yard sprinklers are consumptive and use large amounts of water.

We all have many ways to lower the amount of water we use at home. Hardware stores sell water-efficient home products, such as drip irrigation to water lawns and gardens, low flow shower heads and low flow toilets. What other ways can you use less water at home?

Recreational Use

Figure 21.7: Recreational Water: Many recreational activities, such as swimming and fishing, are non-consumptive water activities; which won't deplete the water supply. (22)

Which sports use water? Swimming, fishing, and boating are easy examples to think about (**Figure** 21.7). Do you think playing golf requires water? Actually it does, because we irrigate the golf course in order to keep it nice and green! The amount of water that most recreational activities use is low: less than one percent of all the water we use.

Most recreational water uses are non-consumptive. That would include swimming, fishing, and boating. We can swim, fish, and boat without reducing the water supply. The same is not true for playing golf, which is the biggest recreational water consumer. Golf courses require large amounts of water. Water used for golf courses is generally consumptive, since most of it is lost to evaporation, soil, and runoff.

Environmental Use

Figure 21.8: Environmental Water Use: Wetlands and other environments depend on clean water to survive. Water shortages are a leading cause of global biodiversity loss. (14)

Environmental uses include activities to create habitat for wildlife, such as building lakes and fish ladders to help fish spawn (**Figure** 21.9). Most environmental uses are non-consumptive; they account for even less water use than recreation.

California Water Resources

California has a rich water supply from many sources. The winter snow pack in the Sierra Nevada and other mountain ranges feeds rivers that crisscross the state. Many of these streams feed into the Sacramento River in the northern part of the Central Valley, and the San Joaquin River in the southern portion (**Figure** 21.9). Virtually all of these rivers are dammed, some more than once, to supply power and water to the cities and farmland of the state.

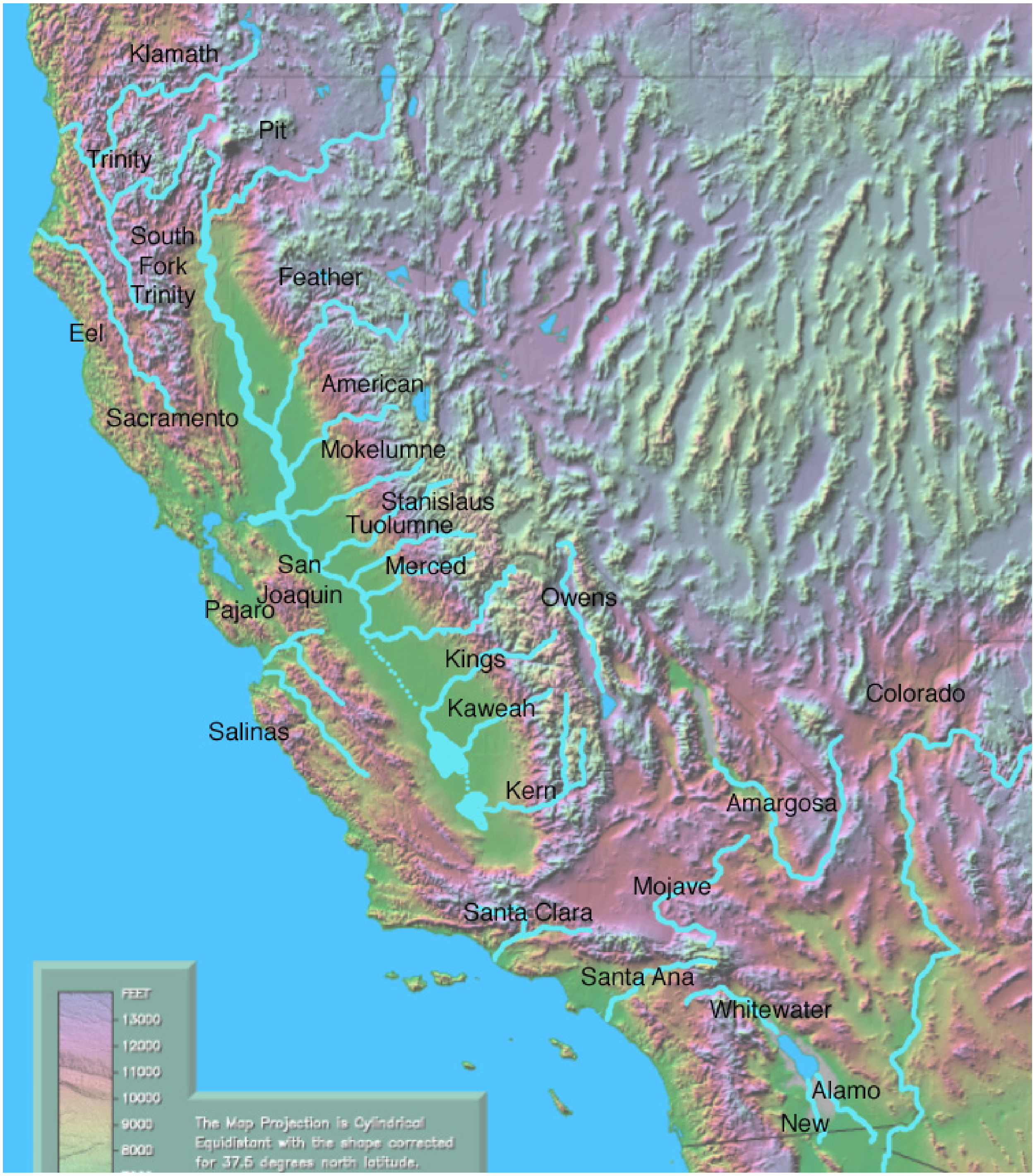


Figure 21.9: California rivers. (6)

Groundwater is also an important source of water in California. In a normal year about 40% of the state's water supply comes from groundwater. In a drought year, the number can rise to 60% or more. The largest groundwater reservoirs are found in the Central Valley where thousands of years of snow melt has fed the aquifers. In many locations, much more groundwater is used each year than is available to recharge the aquifer. Subsidence of the land is common in these regions.

Despite these vast water sources, the states large population and enormous agricultural landscape put a strain on the water supply. Water rights in California are complex and controversial. Although about 75% of the water resources are in the northern one-third of the state, the largest usage, about 80%, is in the southern two-thirds. Besides projects that exist to distribute water within the state, a large source of water is the Colorado River, which California must share with five other states and Mexico. The distribution of water resources in the Western United States will be a topic of much discussion in the coming decades.

Lesson Summary

- Human water use can be lumped into five categories. The uses are arranged in order of greatest to the least amounts of total water use on Earth:

- Agriculture (sixty-nine percent)
- Industry uses (fifteen percent of global water use)
- Home and Personal use (fifteen percent)
- Recreation uses (less than one percent)
- Environmental use (less than one percent)

- Despite California's abundant water supply from surface streams and groundwater, the state has a number of water rights issues that will be important long into the future.

Review Questions

1. Describe the three water uses that consume the most fresh water.
2. Explain why humans are limited to using less than one percent of all the water on Earth for our needs.
3. List two reasons why human water use has increased tremendously during the past century.
4. Describe four consequences of water shortages.
5. What does the phrase 'water is more valuable than gold' mean?
6. Describe why some water uses are called consumptive.
7. Describe drip irrigation and why it wastes less water than irrigating with sprinklers.
8. Describe why droughts are more serious in arid regions of the world than in wetter regions.

9. What is the origin of California's fresh water sources?

Vocabulary

consumptive Water use where water is 'lost' to evaporation.

drip irrigation Pipes & tubes that deliver small amounts of water directly to the soil at the roots.

incentive A financial benefit for taking a particular action.

non-consumptive Water use that does not 'use up' the water supply.

Points to Consider

- How could fresh water be more valuable than gold or a diamond?
- Which human activity uses more water than all other activities combined?
- Why don't all farmers use drip irrigation and other water efficient irrigation methods?

21.2 Problems with Water Distribution

Learning Objectives

- Explain why water shortages are increasingly frequent throughout the world.
- Discuss why 1.1 billion people (one fifth of the people on Earth) do not have access to safe drinking water.
- Explain why humans can use less than one percent of all water on Earth.
- Discuss the ways in which human water demands are unsustainable.

Introduction

Humans are facing a worldwide water crisis according to the United Nations. The crisis includes worldwide shortages of fresh water that humans can access, scarcity of safe drinking water supplies and water pollution.

World Water Supply and Distribution

Water is everywhere. More than 70% of the Earth's surface is covered by water. The Earth has a limited supply of water that we can use. There are supplies of freshwater in lakes, rivers, streams, swamps, reservoirs, and even underground water rich regions of soil and rock, called **aquifers.** Almost anywhere you stand, there is water somewhere beneath you. Sometimes that water is just several meters below you, sometimes it is deeper within the Earth.

Still, this supply of freshwater is less than 1% of all of the water on Earth. Why is so little water available for human use? Two reasons:

- For most of our needs, humans cannot use saltwater, which makes up 97-98% of all water on Earth.
- Humans cannot use most of the freshwater on Earth, because is frozen in glaciers and icebergs, mainly in Greenland and Antarctica (**Figure** 21.10).

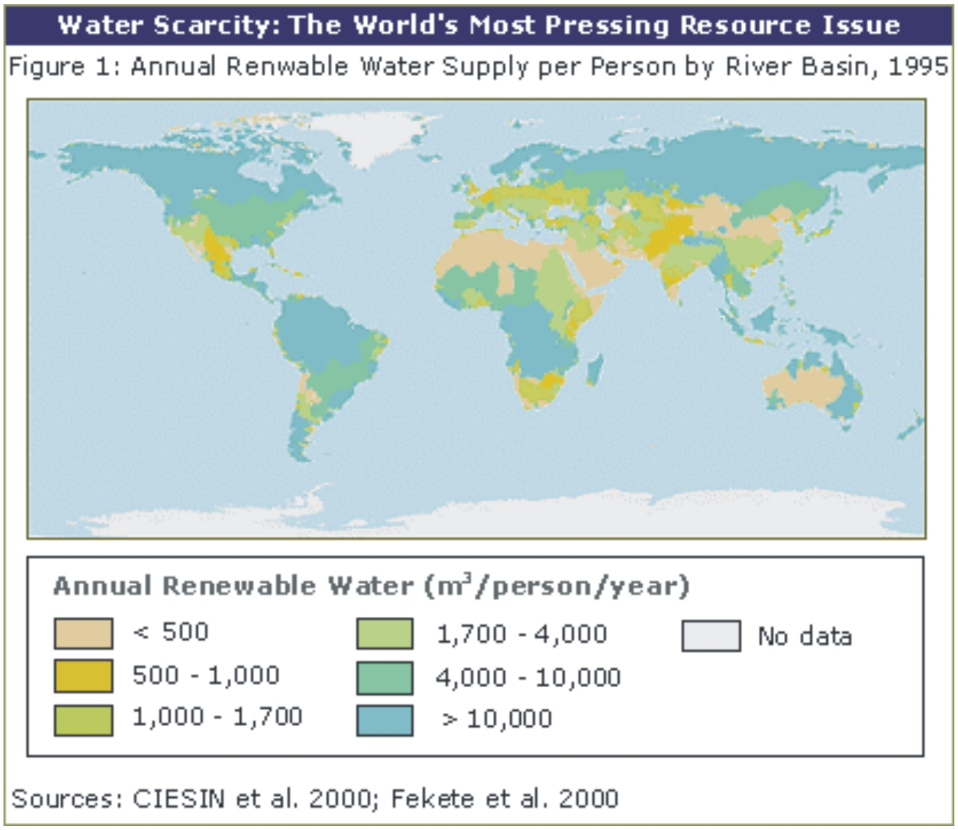
Figure 21.10: Most fresh water on Earth is in the form of frozen icebergs and glaciers. (11)

A common misconception is that water shortages can be solved by desalination, removing salt from seawater. This is because the desalination process requires so much energy and is so costly, that it is not an economical way to increase freshwater resources.

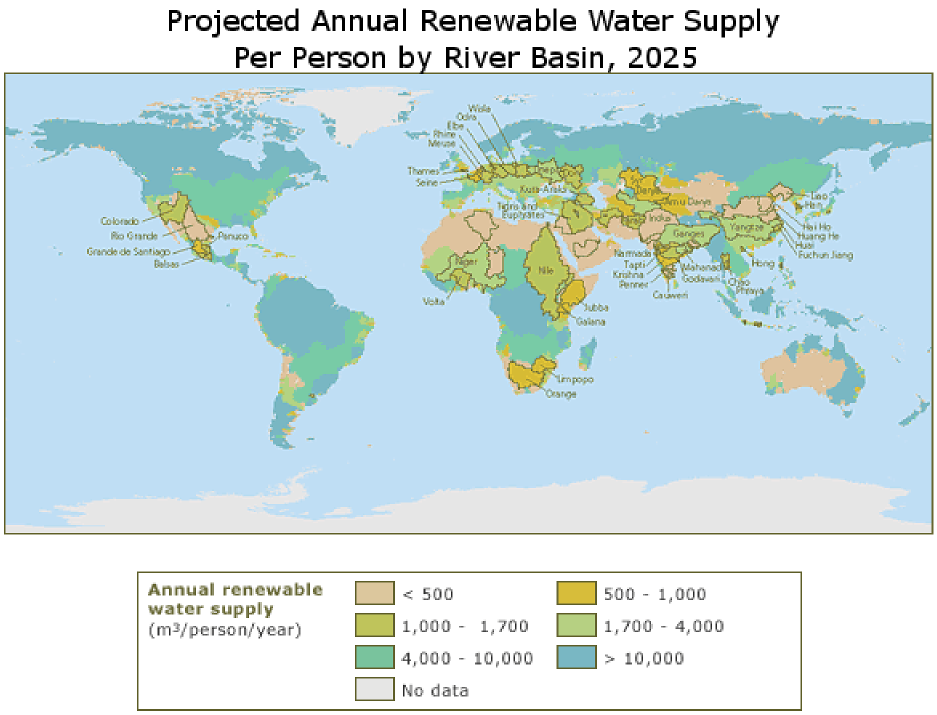
Water Distribution

Look closely at the climates of different regions around the Earth. Some places have water rich climates, while many others do not. Roughly 40% of the land on Earth is arid or semiarid, which means it receives little or almost no rainfall.

Water Distribution: Water is unevenly distributed across the world. The blue areas are the most water rich regions of the world. The salmon pink areas are desert areas. (Source: `http://earthtrends.wri.org/maps_spatial/maps_detail_static.php?map_select=264&theme=2.` CC-BY-SA)



Projected Water Distribution in 2025: The blue areas are the most water rich regions of the world. The salmon pink areas are desert areas. (Source: http://earthtrends.wri.org/maps_spatial/maps_detail_static.php?map_select=265&theme=2. CC-BY-SA)



Global warming affects patterns of rainfall and water distribution. As the Earth warms, regions that currently receive an adequate supply of rain may shift. Regions of Earth that normally are low pressure areas may become areas where high pressure dominates. That would completely change the types of plants and animals that can live successfully in that region.

In 1995, about 40% of the world's population faced water scarcity (**Figure** 21.11). Scientists believe 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 people in the world will have less than 500 m^3 of water per person to use in an entire year. A cubic meter of water equals 1,000 liters. That means in certain areas of the world, many people will have less water available in a year than some people in the United States use in one day.

Water Shortages

Water Shortages Projections for 2025

As we continue to use our precious freshwater supplies, scientists expect that we will encounter several different types of problems. We currently irrigate our crops using supplies of groundwater in aquifers underground. When we have used up these groundwater supplies, we will not be able to grow as many different types of crops or we will have lower yields of the crops we grow. Using our freshwater often adds many different types of dissolved

Nearly Half the World Will Live With Water Scarcity by 2025

Figure 2: Global Renewable Water Supply per Person, 1995 and 2025 (projected)

Water Supply (m3/person /year)	1995 Population (millions)	1995 Percent of Total	2025 Population (millions)	2025 Percent of Total
<500	1,077	19.0	1,783	24.5
500-1,000	587	10.4	624	8.6
1,000-1,700	669	11.8	1,077	14.8
Subtotal	2,333	41.2	3,484	47.9
>1,700	3,091	54.6	3,494	48.0
Unallocated	241	4.2	296	4.0
Total	5,665	100.0	7,274	100.0

Source: WRI. The 2025 estimates are considered conservative because they are based on the United Nations' low-range projections for population growth, which has population peaking at 7.3 billion in 2025 (UNDP 1999:3). In addition, a slight mismatch between the water runoff and population data sets leaves 4 percent of the global population unaccounted in this analysis.

Figure 21.11: Water Supply Compared to Population. (4)

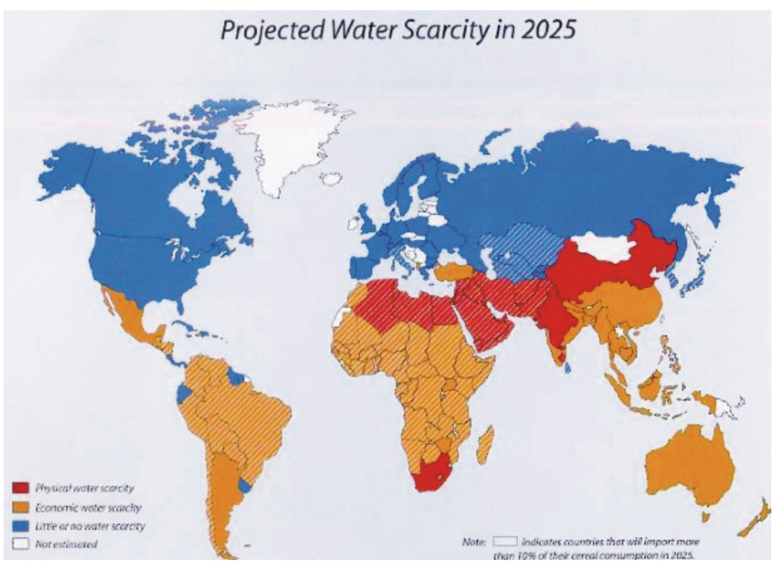


Figure 21.12: Water Scarcity Projections: If world-wide water use and population growth continues to grow at the current rate many people in the world will face serious water shortages. (23)

materials to the freshwater supply. This use may lead to pollution of our water resources and cause harm not only to humans but to many life forms, reducing our biodiversity. Most importantly, as our water supplies become scarce, there will be conflicts between individuals who have enough clean water and those who do not (**Figure** 21.12). As with any limited resource, this conflict could produce warfare.

Two of the most serious problems facing humans today are shortages of fresh water and the lack of safe drinking water.

Humans use six times as much water today as we did a hundred years ago. As the number of people on Earth continues to rise, our demand for water grows. Also, people living in developed countries use more water per person than individuals in lesser developed countries. This is because most of our activities today, such as farming, industry, building, and lawn care, are all water-intense practices, practices that require large amounts of water.

Droughts occur when for months or years, a region experiences unusually low rainfall (**Figure** 21.13). Periods of drought naturally make water shortages worse. Human activities, such as deforestation, can contribute to how often droughts occur. Trees and other land plants add water back into the atmosphere through transpiration. When trees are cut down, we break this part of the water cycle. Some dry periods are normal and can happen anywhere in the world. Droughts are a longer term event and can have serious consequences for a region. 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.

Water shortages hurt human health, agriculture and the environment. What happens when water supplies run out? In undeveloped regions in the world, people are often forced to move to a place where there is water. This can result in serious conflicts, even wars, between groups of people competing for water.

Water disputes happen in developed countries as well. Water-thirsty regions may build aqueducts, large canals or pathways to import water from other locations. For example, several cities in **arid** regions of the United States import water from the Colorado River. So much water is taken from the river that it can end as just a trickle when it reaches Mexico. Years ago, Mexico could depend on the river supplying water for irrigation and other uses. Today that water resource is gone from importing water upstream.

Some of the biggest legal battles in the United States have been over water rights, including access to the Colorado River. Water disputes may have lead to some of the earliest wars known.

Figure 21.13: Extended periods with lower than normal rainfall cause droughts. (21)

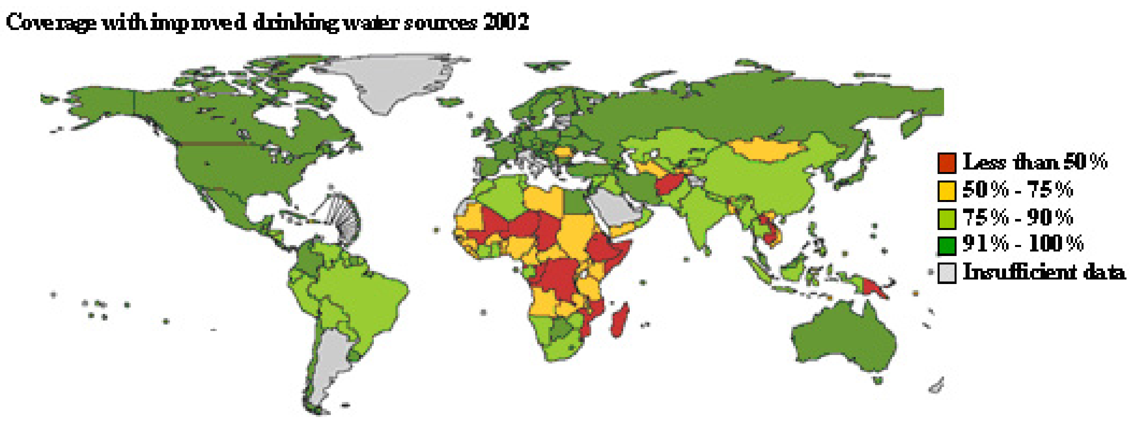


Figure 21.14: Access to improved drinking water and progress towards achieving the internationally agreed goals on water and sanitation. (1)

Problems with Water Quality

Scarcity of Safe Drinking Water

The next time you get water from your faucet, imagine life in a country that cannot afford the technology to treat and purify water. What would it be like if your only water came from a polluted river where sewage was dumped? Your only choice would be to drink polluted water. One fifth of all people in the world, more than 1.1 billion people, do not have access to safe water for drinking, personal cleanliness and domestic use. Unsafe drinking water can carry many disease-causing agents, such as infectious bacteria, toxic chemicals, radiological hazards, and parasites.

One of the leading causes of death worldwide is waterborne disease, disease caused by unsafe drinking water. It is also the leading cause of death for children under the age of five. Many children die when they only have unsafe drinking water and lack of clean water for personal hygiene. About eighty-eight percent of all diseases are caused by drinking unsafe water. At any given time, half of the world's hospital beds are occupied by patients suffering from a waterborne disease. The water you get from a faucet is safe because it has gone through a series of treatment and purification processes to remove contaminants.

Economic Considerations

A glass of water may be free in a restaurant, but this does not reflect its value as a resource. Water is often regarded as more valuable than gold, because human survival depends on having steady access to it.

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.
- Industrial, construction and economic development is halted.
- The risk of regional conflicts over scarce water resources rises.
- Ultimately some people die from lack of water.

Finding safe drinking water poses further challenges. What does it take for a country to provide its people with access to safe drinking water? It takes sophisticated technology to purify water, which removes harmful substances and **pathogens,** disease-causing organisms. Most developing countries lack the finances and the technology needed to supply their people with purified drinking water.

Water resources are so valuable, that wars have been fought over water rights throughout history. In many cases, water disputes add to tensions between countries where differing national interests and withdrawal rights have been in conflict (**Figure** 21.15).

Figure 21.15: The states and Canadian Provinces surrounding the Great Lakes have created a pact to control water in the lakes, preventing other states from over-draining the lakes. (9)

Some of today's greatest tensions are happening in places where water is scarce. Water disputes are happening along 260 different river systems that cross national boundaries including water disputes between:

- Iraq, Iran, and Syria
- Hungary and Czechoslovakia
- North and South Korea
- Iran and Syria
- Israel and Jordan
- Egypt and Ethiopia

International water laws, such as the Helsinki Rules, help interpret water rights among countries.

Lesson Summary

- Water is a renewable resource, but it is not unlimited. Humans are limited to less than one percent of the water on Earth. Also, water is not evenly distributed across the globe.

- Water is so valuable that countries have fought each other over water rights throughout history. Water shortages and water pollution have become so serious across the world, that some organizations call our water status a "water crisis." The crisis is blamed on overpopulation, overuse of water, pollution, and global warming.

- Undeveloped countries are rarely able to afford water treatment and purification facilities, unless other countries and international organizations help.

Review Questions

1. If most of the Earth is covered with water, how can there be water shortages?
2. Why are waterborne diseases more common in less developed countries than developed countries?
3. Why does the United Nations describe the current water status today as a crisis?
4. How do droughts affect water supplies?
5. Why do water disputes happen?
6. Give two reasons why water shortages are happening around the world today?

Vocabulary

aquifer Regions of soil or rock that are saturated with water.

arid Regions without enough water for things to grow.

drought A long period of lower than normal rainfall for a particular region.

pathogen Disease causing organisms.

Points to Consider

- What can we do to help the one fifth of the people on Earth who do not have access to safe drinking water?
- How can we reduce water shortages due to overuse, overpopulation, and drought?
- Water is so valuable that wars have been fought over it throughout history. Could conserving freshwater now help avoid future wars?

21.3 Water Pollution

Learning Objectives

- Discuss the risks that water pollution poses to human and environmental health.
- Explain where fresh and saltwater pollution come from.
- Discuss how pathogen born diseases are caused by water pollution.
- Describe why conserving water and protecting water quality is important to human health and the environment.
- Describe how water pollution reduces the amount of safe drinking water available.
- Discuss who is responsible for preventing and cleaning up water pollution.

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 undeveloped countries every year.

Sources of Water Pollution

Water pollution can make our current water shortages even worse than they already are. Imagine that all of your drinking water came from a river polluted by industrial waste and sewage. In undeveloped countries throughout the world, raw sewage is dumped into the same water that undeveloped people drink and bathe in. Without the technology to collect, treat and distribute water, people do not have access to safe drinking water. Throughout the world, more than 14,000 people die every day from waterborne diseases, like cholera which is spread through polluted water.

Even in developed countries that can afford the technology to treat water, 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 undeveloped countries is raw sewage dumped into lakes, rivers and streams. In developed countries, the three main sources of water pollution are:

- Agriculture, including fertilizers, animal waste and other waste, pesticides, etc.
- Industry, including toxic and nontoxic chemicals
- Municipal uses, including yard and human waste

Figure 21.16: Municipal and agricultural pollution. (15)

Types of Water Pollution

Municipal Pollution

Wastewater usually contains many different contaminants. This makes it difficult for the Environmental Protection Agency (EPA) to identify the main source when toxic chemicals are found in wastewater. The pollution coming from homes, stores and other businesses is called municipal pollution (**Figure** 21.16). 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 (See agriculture discussion of fertilizer waste)

Industrial Pollution

Many kinds of pollutants from factories and hospitals end up in our air and waterways (**Figure** 21.17). Some of the most hazardous industrial pollutants include:

- Radioactive substances from nuclear power plants, as well as medical and scientific

Figure 21.17: 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. (17)

uses.

- Other chemicals in industrial waste, such as heavy metals, organic toxins, oils, and solids.
- Chemical waste from burning high sulfur fossil fuels that cause acid rain.
- Inadequately treated or untreated sewage and solid wastes from inappropriate waste disposal.
- Oil and other petroleum products from supertanker spills and offshore drilling accidents.
- Heated water from industrial processes such as power stations.

Agricultural Pollution

Agriculture includes crops, livestock and poultry farming. Most agricultural contaminants are carried by runoff that carries fertilizers, pesticides, and animal waste into nearby waterways (**Figure** 21.18). Soil and silt erosion also contribute to surface water contamination.

Animal wastes expose humans and the environment to some of the most harmful disease causing organisms or pathogens. These include bacteria, viruses, protozoa, and parasites. Pathogens are especially harmful to humans, because they can cause many illnesses including typhoid and dysentery as well as minor respiratory and skin diseases.

You may be surprised to learn that even the fertilizers we use on our lawns and farm fields are extremely harmful to the environment. Fertilizers from lawns and farm fields wash into

Figure 21.18: Many types of agriculture add pollutants to groundwater. (12)

nearby rivers, lakes and the oceans. Fertilizers contain nitrates that promote tremendous plant growth in the water. Consequences of this accelerated plant growth include:

- Lakes, rivers and bays become clogged with a carpet of aquatic plants that block light from entering the water.
- Without light reaching plants in the water below, these organisms die.
- As the plants die, their decomposition uses up all the oxygen in the water. Without enough dissolved oxygen in the water, large numbers of plants, fish and bottom-dwelling animals die.

Every year you can see **dead zones**, hundreds of kilometers of ocean without fish or plant life (**Figure** 21.19). These dead zones occur in the Gulf of Mexico and other river delta areas due to water polluted with fertilizers. In 1999, a dead zone in the Gulf of Mexico reached over 7,700 square miles.

Ocean Water Pollution

Most (80 %) of ocean pollution comes as runoff from agriculture, industry, and domestic uses (**Figure** 21.20). These same kinds of runoff also pollute freshwater. The remaining 20% of water pollution comes from oil spills and people dumping sewage directly into the water.

Coastal pollution can make coastal water unsafe for humans and wildlife. After rainfall, there can be enough runoff pollution that beaches are closed to prevent the spread of disease from pollutants.

A large proportion of the fish stocks we rely on for food live in the coastal wetlands. Coastal runoff from farm waste often carries water-borne organisms that cause lesions that kill fish. Humans who come in contact with polluted waters and affected fish can also experience

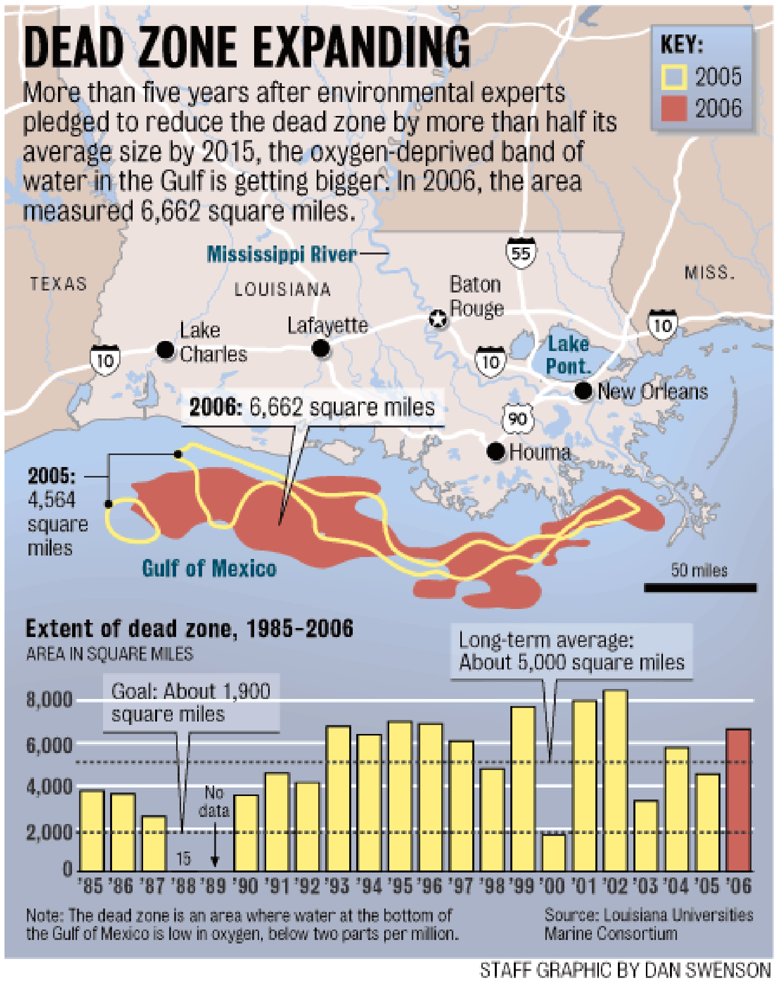


Figure 21.19: Agricultural Waste Water: A Dead Zone is a large area of water where fertilizer runoff pollutes farms and yards, ultimately killing off aquatic life. The size of the dead zone in the Gulf of Mexico varies at different times of the year. (13)

Figure 21.20: In some areas of the world, ocean pollution is all too obvious. (5)

harmful symptoms. More than one-third of the shellfish-growing waters of the United States are adversely affected by coastal pollution.

Thermal Water Pollution

Thermal pollution is anything that causes water temperatures to rise or fall (**Figure** 21.21). For example, power plants and other industries often use water to cool equipment. Once the water absorbs heat from a power plant or industry, the heated water is returned to the natural environment at a higher temperature. Cold water pollution can be observed when very cold water is released from reservoirs.

Figure 21.21: The Macquarie perch is now extinct in most of its upland river habitats partially due to thermal pollution by dams. (7)

Why would changing water temperature harm the environment? Fish and other aquatic organisms are often vulnerable to even small temperature changes. Heated water kills fish and other organisms by decreasing oxygen supply in the water. Frigid water has a severe effect on fish (particularly eggs and larvae), macro invertebrates and river productivity.

Lesson Summary

- Industrial, agricultural, and municipal sources produce harmful water pollutants such as toxic chemicals, radiological agents, and animal wastes. Thousands of people die from waterborne diseases every year.

Review Questions

1. What do the initials 'EPA' stand for?
2. What is runoff and why is it a problem?

3. Who is responsible for reducing water pollution?
4. Explain what a dead zone is and where you might find one?
5. What is the leading cause of death for children around the world?

Vocabulary

dead zone A region hundreds of kilometers wide without fish or plant life due to lack of oxygen in the water.

thermal pollution Water pollution created by added heat to water.

Points to Consider

- Water pollution not only harms human health and the environment. Consider how this reduces the amount of water available to humans.
- Fifty percent of all infectious diseases are caused by water pollution. What can be done to reduce the number of pathogens that reach our freshwater supplies?
- Ocean pollution harms some of the most productive sources of marine life. How can we change our behaviors to protect marine life?

21.4 Protecting the Water Supply

Learning Objectives

- Describe several ways water can be conserved.
- Discuss how water is treated to eliminate harmful particles.
- State what governments and international organizations can do to reduce water pollution.

Water Treatment

The goal of water treatment is to make water suitable for such uses as drinking water, 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 to their people. Many undeveloped nations have few or no water treatment facilities.

Water treatment is any process used to remove unwanted contaminants from water (**Figure** 21.22). Water treatment processes are designed to reduce harmful substances such as suspended solids, oxygen-demanding materials, dissolved inorganic compounds, and harmful

Figure 21.22: Wastewater Treatment: Most wastewater treatment facilities separate contaminants from water by passing wastewater through a series of settlement containers. At each step, solids and particles are separated from water. Chemical and biological agents are also used to remove any remaining impurities. (10)

bacteria. Ideally, water treatment produces both liquids and solid materials that are not harmful the natural environment.

Water can contain hundreds of contaminants. Not all treatment processes are able to remove all of these particles and not all treated water is pure enough to qualify as safe drinking water. **Sewage treatment** is any process that removes contaminants from sewage or wastewater. **Water purification** is any process used to produce drinking water for humans by removing contaminants from untreated water. Purification processes remove bacteria, algae, viruses, and fungi, unpleasant elements such as iron and sulphur, and man-made chemical pollutants.

The choice of treatment method used depends on the kind of wastewater being treated. Most wastewater is treated using a series of steps, increasingly purifying the water at each step. Treatment usually starts with separating solids from liquids. Water may then be filtered or treated with chlorine. With each subsequent step, the water has fewer contaminants and the effluent is increasingly pure.

Reducing Water Pollution

How can people reduce water pollution? And who is responsible for doing it?

People have two ways to reduce any kind of pollution: We can prevent people from polluting water. And, we can use science to clean contaminants from water that is already polluted.

Governments can:

- Pass laws to control pollution emissions from different sources, such as factories and agriculture.
- Pass laws that require polluters to clean up water they pollute.
- Provide money to build and run water treatment facilities (and fund research to improve water quality technology).
- Educate the public, teach them how to prevent and clean up water pollution.
- Enforce laws.

The United Nations and other international groups have established organizations to improve global water quality standards. Some international organizations provide developing nations with the technology and education to collect, treat, and distribute water. Another priority is educating the people in these countries about how they can help improve the quality of the water they use.

In the United States, legislators passed the Clean Water Act which gives the Environmental Protection Agency the authority to sets standards for water quality for industry, agriculture and domestic uses (**Figure** 21.23).

Figure 21.23: Scientists control water pollution by sampling the water and studying the pollutants are in the water. (19)

One of the toughest problems is enforcement, catching anyone who is not following water regulations. Scientists are working to create methods to accurately track the source of water pollutants. Monitoring (tracking) methods allow the government to identify, catch and punish violators.

Who is responsible for reducing water pollution? Everyone who pollutes water is responsible for helping to clean it up. This includes individuals, communities, industries, and farmers.

Just a few of the things you can do to protect water quality include:

- Find approved recycling or disposal facilities for motor oil and household chemicals so these substances do not end up in the water.
- 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 gutters and storm drains.

Controlling Ocean Pollution

Controlling seawater pollution and fresh water pollution are similar, but not exactly the same. We can try to prevent polluters from further spoiling the ocean and we can require polluters to clean up any pollution they cause. Government and international agencies can pass laws, provide funding, and enforce laws to prevent and clean up ocean pollution (**Figure** 21.24).

Several national and international agencies monitor and control ocean pollution. The agencies include the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency, the Department of Agriculture as well as other federal and state agencies.

When runoff pollution does cause problems, NOAA scientists help track down the exact causes and find solutions. This organization is also one of many organizations trying to educate the public on ways to prevent ocean pollution.

Conserving Water

As human population growth continues, water conservation will become increasingly important globally (**Figure** 21.25). Yet, the methods to conserve water are likely to differ between developing nations and developed countries.

For example, some people in undeveloped countries use so little water, that they may not gain much water by reducing their personal use. Meanwhile, large quantities of water can be conserved in the United States by finding ways to stop overconsumption of water.

At Earth Summit 2002 many governments approved a Plan of Action to address the scarcity of water and safe drinking water in developing countries. One goal of this plan is to cut in half, the number of people without access to safe drinking water by 2015.

Developed countries have many options to reduce water consumption. A farmer can cut water consumption drastically by using more efficient irrigation methods. People also have many opportunities to reduce our personal and household water demand with such measures as low flow shower heads, toilets that use less water, and drip irrigation to water lawns.

Figure 21.24: Many forms of marine pollution can be controlled by regulation such as the pumping of ballast water from ships. (16)

Figure 21.25: Low flow showerheads reduce the amount water used during showers. (18)

During prolonged droughts and other water shortages, some communities ration water use and prohibit such water intensive uses as watering lawns during the day and hosing down sidewalks. Often legislation is needed to provide incentives for individuals to reduce their water consumption.

Lesson Summary

- Many technologies are available to conserve water as well as to prevent and treat water pollution. Yet, most undeveloped countries cannot afford the technology they need to collect, treat and distribute water to their people.

- Developing countries may be able to afford water treatment systems, but people still need incentives to use conservation steps.

Review Questions

1. What is the purpose of water treatment and purification?
2. How can governments and international organizations help to reduce water pollution?
3. Name three things that a person could do to reduce pollution? Use lawn, garden or farming chemicals sparingly or use short term, specific chemicals, rather than long term broad spectrum chemicals. Repair engine leaks immediately. Keep litter, pet waste, leaves and grass clippings out of storm drains. Use an approved recycling center to dispose of motor oil and household chemicals and batteries.

4. Name three ways that you could reduce your personal water use.

Further Reading / Supplemental Links

- The American Association for the Advancement of Science, *AAAS Atlas of Population and Environment.* University of California Press, 2000.
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- http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2007/12/09/IN2HTP07B.DTL
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- http://www.worldbank.org/
- http://www.epa.gov/r5water/cwa.htm
- http://www.epa.gov/lawsreg/laws/cwa.html
- http://en.wikibooks.org/wiki/Main_Page

Vocabulary

sewage treatment; Any process that removes contaminants from sewage or wastewater.

water purification Any process used to produce safe drinking water by removing contaminants.

Points to Consider

- Who is responsible for controlling water pollution?
- What can governments and international organizations do to control pollution?
- It is usually cheaper to dump polluted water without spending money to treat and purify the water. What incentives would convince industry to control water pollution?

Image Sources

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Chapter 22

Human Actions and the Atmosphere

22.1 Air Pollution

Lesson Objectives

- Describe the different types of air pollutants.
- Discuss what conditions lead some cities to become more polluted than others.
- Describe the sources of air pollutants.

Introduction

Earth's atmosphere supports life by providing the necessary gases for photosynthesis and respiration. The ozone layer protects life on Earth from the Sun's ultraviolet radiation. People also use the atmosphere as a dump for waste gases and particles. Pollutants include materials that are naturally-occurring but present in larger quantities than normal. In addition, pollutants consist of 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. Excess greenhouse gases raise global temperatures.

Air Quality

Air pollution problems began centuries ago when fossil fuels began to be burned for heat and power. The problem grew into a crisis in the developed nations in the mid-20th century. Coal smoke and auto exhaust combined to create toxic smog that in some places caused lung damage and sometimes death. In Donora, Pennsylvania in October 1948, 20 people died and 4,000 became ill when coal smoke was trapped by an inversion. Even worse, in London in December 1952, the "Big Smoke" killed 4,000 people over five days, and it is likely that thousands more died of health complications from the event in the next several months (**Figure** 22.1).

Figure 22.1: A film crew recreates London smog in the Victorian Era. (2)

A different type of air pollution became a problem in Southern California after World War II. Although there was no coal smoke, cars and abundant sunshine produced **photochemical smog**. This smog is the result of a chemical reaction between some of the molecules in auto exhaust or oil refinery emissions, and sunshine. Photochemical smog consists of more than 100 compounds, most importantly ozone.

In the United States, these events led to the passage of the Clean Air Act in 1970. The act now regulates 189 pollutants. The six most important pollutants 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. Some of these will be discussed in the following section.

Besides human-caused emissions, air quality is affected by environmental factors. A mountain range can trap pollutants on its leeward side. Winds can move pollutants into or out of a region. Pollutants can become trapped in an air mass as a temperature inversion traps cool air beneath warm air. 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.

As a result of the Clean Air Act, air in the United States is much cleaner. Visibility is better and people are no longer incapacitated by industrial smog. Still, in the United States, 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 (**Figure** 22.2).

Table 22.1 lists the smoggiest cities in 2007: six of the 10 are in California. The state has the right conditions for collecting pollutants including mountain ranges that trap smoggy air, arid and sometimes windless conditions, and lots and lots of cars.

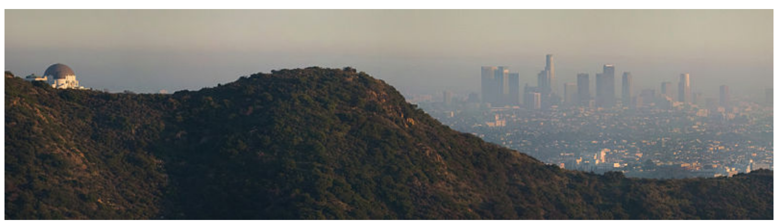

Figure 22.2: Smog over Los Angeles as viewed from the Hollywood Hills. (10)

Table 22.1: **Smoggiest Cities, 2007**

Rank	City, State
1	Los Angeles, California
2	Bakersfield, California
3	Visalia-Porterville, California
4	Fresno, California
5	Houston, Texas
6	Merced, California
7	Dallas-Fort Worth, Texas
8	Sacramento, California
9	New York, New York
10	Philadelphia, Pennsylvania

(*Source:* American Lung Association)

Types of Air Pollution

Most air pollutants enter the atmosphere directly; these are primary pollutants. Secondary pollutants become pollutants only after undergoing a chemical reaction. Primary pollutants include toxic gases, particulates, compounds that react with water vapor to form acids, heavy metals, ozone, and greenhouse gases. Ozone is one of the major secondary pollutants. It is created by a chemical reaction that takes place in exhaust and in the presence of sunlight.

Primary Pollutants

Some primary pollutants are natural, such as dust and volcanic ash, but most are caused by human activities. Primary pollutants are direct emissions from vehicles and smokestacks. Some of the most harmful pollutants that go directly into the atmosphere from human activities include:

- **Carbon oxides** include carbon monoxide (CO) and carbon dioxide (CO_2). Both are colorless, odorless gases. CO is toxic to both plants and animals. CO and CO_2 are both greenhouse gases.
- **Nitrogen oxides** are produced when nitrogen and oxygen from the atmosphere come together at high temperatures. This occurs in hot exhaust gas from vehicles, power plants or factories. Nitrogen oxide (NO) and nitrogen dioxide (NO_2) are greenhouse gases. Nitrogen oxides contribute to acid rain.
- **Sulfur oxides** include sulfur dioxide (SO_2) and sulfur trioxide (SO_3). These form when sulfur from burning coal reaches the air. Sulfur oxides are components of acid rain.
- **Particulates** are solid particles, such as ash, dust and fecal matter. They are commonly formed from combustion of fossil fuels, and can produce smog. In addition, particulate matter can contribute to asthma, heart disease, and some types of cancers.
- **Lead** was once widely used in automobile fuels, paint, and pipes. This heavy metal causes can cause brain damage or blood poisoning.
- **Volatile organic compounds** (VOCs) are mostly hydrocarbons, compounds made of hydrogen and carbon. Important VOCs include methane (a naturally occurring greenhouse gas that is increasing due to human activities), chlorofluorocarbons (human-made compounds that are being phased out because of their effect on the ozone layer), and dioxin (a byproduct of chemical production that serves no useful purpose, but is harmful to humans and other organisms).

Photochemical Smog

Any city can have photochemical smog, but it is most common in arid locations. A rise in the number of vehicles in cities worldwide has increased photochemical smog. This smog forms when car exhaust is exposed to sunlight. Nitrogen oxides are created in car combustion chambers. If there is sunshine, the NO_2 splits and releases an oxygen atom (O). The oxygen ion then combines with an oxygen molecule (O_2) to form ozone (O_3). This reaction can also go in reverse: Nitric oxide (NO) removes an oxygen atom from ozone to make it O_2. The direction the reaction proceeds depends on how much NO_2 and NO there is. If NO_2 is three times more abundant than NO, ozone will be produced. If nitrous oxide levels are high, ozone will not be created.

Ozone is an acrid-smelling, whitish gas. Warm, dry cities surrounded by mountains, such as Los Angeles, Phoenix, and Denver, are especially prone to photochemical smog (**Figure** 22.3). Photochemical smog peaks at midday on the hottest days of summer. Other compounds in addition to ozone are found in photochemical smog. Ozone is also a greenhouse gas.

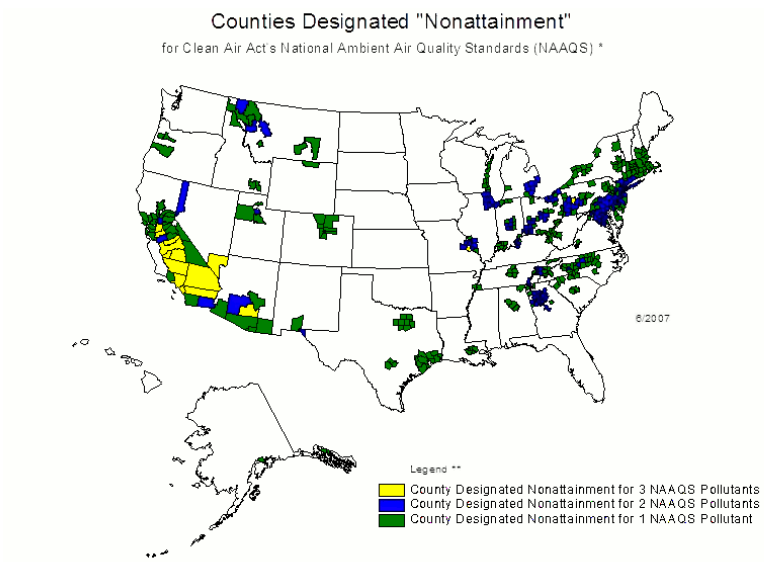

Figure 22.3: Counties with such high ozone levels that they do not attain federal air quality standards. (5)

Causes of Air Pollution

Most air pollutants come from burning fossil fuels or plant material. Some are the result of evaporation from human-made materials. Nearly half (49%) of air pollution comes from transportation, 28% from factories and power plants, and the remaining pollution from a variety of other sources.

Fossil Fuels

Fossil fuels are burned in most motor vehicles and power plants (**Figure** 22.4). They fuel manufacturing and other industries. Pure coal and petroleum can theoretically burn cleanly, emitting only carbon dioxide and water, which are both greenhouse gases. But most of the time, these fossil fuels do not completely burn, so these incomplete chemical reactions produce pollutants. In addition, few fossil fuels are pure and so other pollutants are usually released. These pollutants include carbon monoxide, nitrogen dioxide, sulfur dioxide and hydrocarbons.

Figure 22.4: A power plant and its emissions before emission control equipment was added. (8)

In large car-dependent cities such as Los Angeles and Mexico City, 80% to 85% of air pollution is from motor vehicles. Auto emissions are the most common source of ozone. Carbon monoxide is toxic in enclosed spaces like tunnels. Nitrous oxides come from the exhaust from a vehicle or a factory. Lead was once put in gasoline to improve engine knock, but is now banned in the United States. Still, enormous quantities of lead are released into the air every year from other sources.

A few pollutants come primarily from power plants or industrial plants. They pour out of smokestacks that burn coal or oil. Sulfur dioxide (SO_2) is a major component of industrial air pollution. It is released whenever coal and petroleum are burned. SO_2 mixes with H_2O in the air to produce sulfuric acid (H_2SO_4). The heavy metal mercury is released when coal and some types of wastes are burned. Mercury is emitted as a gas, but as it cools, it becomes a droplet. Mercury droplets eventually fall to the ground. If they fall into sediments, bacteria convert them to the most dangerous form of mercury: methyl mercury. Highly toxic, methyl mercury is one of the metal's organic forms.

Biomass Burning

Fossil fuels are ancient plants and animals that have been converted into usable hydrocarbons. Burning plant and animal material directly also produces pollutants. **Biomass** is the total amount of living material found in an environment. The biomass of a rainforest is the amount of living material found in that rainforest.

The primary way biomass is burned is by **slash-and-burn agriculture** (**Figure** 22.5). The rainforest is slashed down and then the waste is burned to clear the land for farming. Biomass from other biomes, like savannah, is also burned to clear farmland. The pollutants are much the same as from burning fossil fuels: CO_2, carbon monoxide, methane, particulates, nitrous oxide, hydrocarbons, and organic and elemental carbon. Burning forests increase greenhouse gases in the atmosphere by releasing the CO_2 stored in the biomass and also by removing the forest so that it cannot store CO_2 in the future. As with all forms of air pollution, the smoke from biomass burning often spreads far and pollutants can plague neighboring states or countries.

Figure 22.5: A forest that has been slash-and-burned to make new farmland. (7)

Particulates result when anything is burned. About 40% of the particulates that enter the atmosphere above the United States are from industry and about 17% are from vehicles. Particulates also occur naturally from volcanic eruptions or windblown dust. Like other pollutants, they travel all around the world on atmospheric currents.

Evaporation

Volatile organic compounds (VOCs) enter the atmosphere by evaporation. VOCs evaporate from human-made substances, such as paint thinners, dry cleaning solvents, petroleum, wood preservatives, and other liquids. Naturally occurring VOCs evaporate off of pine and citrus trees. The atmosphere contains tens of thousands of different VOCs, nearly 100 of which are monitored. The most common is methane, a greenhouse gas. Methane occurs naturally, but human agriculture is increasing the amount of methane in the atmosphere.

Lesson Summary

- Industrial pollution causes health problems and even death, though the Clean Air Act has decreased these health problems in the United States by forcing industry to clean their emissions.
- The increase in motor vehicles in arid cities has increased ozone and other secondary pollutants in these regions.
- Burning fossil fuels is the greatest source of air pollution.
- Biomass burning is also a large source, especially in places where slash-and-burn agriculture is practiced.

Review Questions

1. What is the difference between the type of smog experienced by cities in the eastern United States and that found in Southern California?
2. London has suffered from terrible air pollution for at least seven centuries. Why is the city so prone to its famous "London fog?" What did London do to get rid of its air pollution?
3. Imagine two cities of the same size with the same amount of industrialization and the same number of motor vehicles. City A is incredibly smoggy most of the time and City B usually has very little air pollution. What factors are important for creating these two different situations?
4. What might be a reason why the city of San Francisco and its metropolitan area not on the list of smoggiest cities for 2007?
5. Why are naturally-occurring substances, like particulates or carbon dioxide, sometimes considered pollutants?
6. How does ozone form from vehicle exhaust?
7. What are the necessary ingredients for ozone creation, excluding those that are readily available in the atmosphere? Why could there be a city with a lot of cars but relatively little ozone pollution?
8. Some people say that we need to phase out fossil fuel use and replace it with clean energy. Why is fossil fuel use becoming undesirable?

9. Mercury is not particularly toxic as a metal but it is very dangerous in its organic form. How does mercury convert from the metal to the organic form?
10. In what two ways does deforestation contribute to air pollution?

Vocabulary

lead A heavy metal found in a large number of products. Exposure to too much lead causes lead poisoning, which harms people's brain and blood.

mercury A heavy metal that enters the atmosphere primarily from coal-burning power plants. Mercury that has been converted to an organic form (methylmercury) is highly toxic.

ozone Three oxygen atoms bonded together in an O_3 molecule. Ozone in the lower atmosphere is a pollutant but in the upper atmosphere protects life from ultraviolet radiation.

particulates Particles like ash, dust and fecal matter in the air. Particulates may be caused by natural processes, such as volcanic eruptions or dust storms, or they may be caused by human activities, like burning fossil fuels or biomass.

photochemical smog This type of air pollution results from a chemical reaction between pollutants in the presence of sunshine.

slash-and-burn agriculture In the tropics, rainforest plants are slashed down and then burned to clear the land for agriculture.

volatile organic compounds (VOCs) Pollutants that evaporate into the atmosphere from solvents and other humanmade compounds. Some VOCs occur naturally.

Points to Consider

- Despite the Clean Air Act, the air over many regions in the United States is still not clean. Why?
- How do pollutants damage human health?
- In what ways does air pollution harm the environment?

22.2 Effects of Air Pollution

Lesson Objectives

- Describe the damage that is being done by smog.
- Discuss how acid rain is formed and the damage it does.
- Discus how chlorofluorocarbons destroy the ozone layer.

Introduction

People in developing countries often do not have laws to protect the air that they breathe. The World Health Organization estimates that 22 million people die each year from complications due to air pollution. Even in the United States, more than 120 million Americans live in areas where the air is considered unhealthy. This lesson looks at the human health and environmental problems caused by different types of air pollution.

Smog

All air pollutants cause some damage to living creatures and the environment. Different types of pollutants cause different types of harm. Particulates reduce visibility. For example, 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, visibility is worse. People can only see about 40 to 60 kilometers (25-35 miles), which is one-fifth the distance they could see without any air pollution.

Particulates reduce the amount of sunshine that reaches the ground. Since plants also receive less sunlight, there may be less photosynthesis. Particulates also form the nucleus for raindrops, snowflakes or other forms of precipitation. 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. 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 U.S (**Figure** 22.6). Imagine how much all of the sources of particulates combine to reduce temperatures.

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, since animals and plants may not be able to survive without the habitats created by the native trees.

Some crop plants show ozone damage. When exposed to ozone, spinach leaves become

Figure 22.6: Jet contrails block sunlight. (9)

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. Many of these nations, like China and India, also have heavy air pollution. Some pollutants have a positive effect on plant growth. Increased CO_2 seems to lessen ozone damage to some plants and it may promote growth. Unfortunately, CO_2 and other greenhouse gases cause other problems that harm the ecosystem and reduce growth of some plants.

Other air pollutants damage the environment (**Figure** 22.7). 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. Human health suffers in locations with high levels of air pollution. Lead is the most common toxic material for humans and is responsible for lead poisoning. Carbon monoxide is a toxic gas and can kill people in poorly ventilated spaces, like tunnels. Nitrogen and sulfur-oxides cause lung disease and increase rates of asthma, emphysema, and viral infections like flu. Ozone also damages the human respiratory system, causing lung disease. High ozone levels are also associated with increased heart disease and cancer. Particulates enter the lungs and cause heart or lung disease. When particulate levels are high, asthma attacks are more common. By some estimates, 30,000 deaths a year in the United States are caused by fine particle pollution.

Although not all cases of asthma can be linked to air pollution, many can. During the 1996 Olympic Games, Atlanta, Georgia closed off their downtown to private vehicles. As a result, ozone levels decreased by 28%. At the same time, there were 40% fewer hospital visits for asthma.

Lung cancer among non-smokers is also increasing. One study showed that the risk of being afflicted with lung cancer increases directly with a person's exposure to air pollution. The

Figure 22.7: Smog in New York City. (12)

study concluded that no level of air pollution should be considered safe. Exposure to smog also increased the risk of dying from any cause, including heart disease.

Children are more vulnerable to problems from breathing dirty air than adults because their lungs are still growing and developing. Children take in 50% more air for their body weight than adults. Children spend more time outside in unfiltered air and are more likely to breathe hard from playing or exercising. One study found that in the United States, children develop asthma at more than twice the rate of two decades ago and at four times the rate in Canada. Adults also suffer from air pollution-related illnesses that include lung disease, heart disease, lung cancer, and weakened immune systems. The asthma rate worldwide is rising 20% to 50% every decade.

Especially dangerous are pollutants that remain in an organism throughout its life, called **bioaccumulation**. In this process, an organism accumulates the entire amount of a toxic compound that it consumes over its lifetime. Not all substances bioaccumulate. A person who takes a daily dose of aspirin only has that day's worth of aspirin in her system, because aspirin does not stay within her system. When a compound bioaccumulates, the person has all of that compound she's ever eaten in her system. Compounds that bioaccumulate are usually stored in the organism's fat.

Mercury is a good example of a substance that bioaccumulates. Bacteria and plankton store all of the mercury from all of the seawater they ingest. A small fish that eats bacteria and plankton accumulates all of the mercury from all of the tiny creatures it eats over its lifetime. A big fish accumulates all of the mercury from all of the small fish it eats over its lifetime. The organisms that accumulate the most mercury are the large predators that eat high on the food chain. Tuna pose a health hazard to anything that eats them because their bodies are so high in mercury. This is why the government recommends limits on the amount of tuna that people eat. These limits are especially important for children and pregnant women, since mercury particularly affects young people. If the mercury just stayed in fat, it would not be harmful, but that fat is used when a woman is pregnant or nursing a baby, or when she burns the fat while losing weight. Methyl mercury poisoning can cause nervous system or brain damage, especially in infants and children. Children may experience brain damage or developmental delays. Like mercury, other metals and VOCS can bioaccumulate, causing harm to animals and people high on the food chain.

Acid Rain

Acid rain is caused by sulfur and nitrogen oxides. These pollutants are emitted into the atmosphere from power plants or metal refineries. The oxides come out of smokestacks that have been built tall so that pollutants don't sit over cities. The high smokestacks allow the emissions to rise high into the atmosphere and travel up to 1000 km (600 miles) downwind. As they move, these pollutants combine with water vapor to form sulfuric and nitric acids. The acid droplets form acid fog, rain, snow, or they may be deposited dry. Most typical is **acid rain** (**Figure** 22.8).

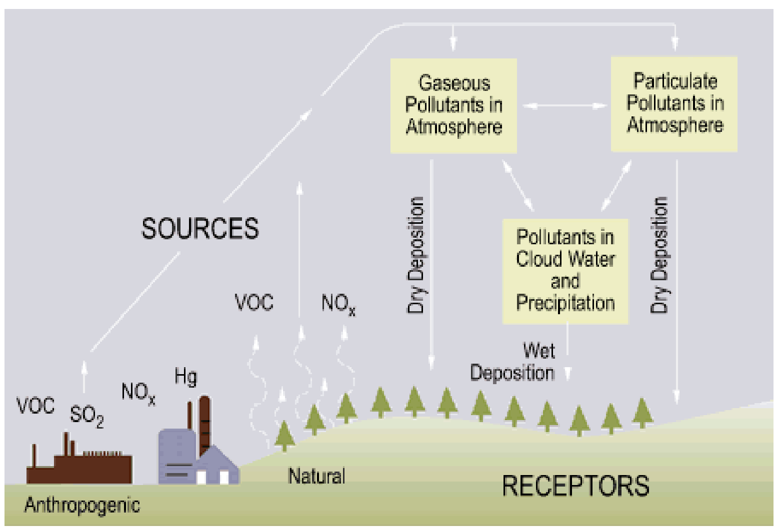

Figure 22.8: How acid rain is formed. Anthropogenic pollutants are those that are human-made. Deposition of a pollutant occurs when it is placed on a surface. Rain can bring wet deposition or a pollutant can be blown onto the ground for dry deposition. (4)

Acid rain water is more acidic than normal rain water. To be called acid rain, it must have a pH of less than 5.0. Acidity is measured on the **pH scale**, which goes from 1 to 14. A value of 7 is neutral. Lower numbers are more acidic and higher numbers are less acidic (also called more **alkaline**). The strongest acids are at the low end of the scale and the strongest bases are at the high end. Natural rain is somewhat acidic with a pH of 5.6. The acid comes from carbonic acid that forms when CO_2 combines with water in the atmosphere. A small change in pH represents a large change in acidity: rain with a pH of 4.6 is 10 times more acidic than normal rain (with a pH of 5.6). Rain with a pH of 3.6 is 100 times more acidic.

Regions that have a lot of coal-burning power plants have the most acidic rain. The acidity of average rainwater in the northeastern United States has fallen to between 4.0 and 4.6. Acid fog has even lower pH with an average of around 3.4. One fog in Southern California in 1986 had a pH of 1.7, equal to toilet bowl cleaner. In arid climates, like in Southern California, acids deposit on the ground dry. Acid precipitation ends up on the land surface and in water bodies. Some forest soils in the northeast are 5 to 10 times more acidic than they were two or three decades ago. Acid droplets move down through acidic soils to lower the pH of streams and lakes even more. Acids strip soil of metals and nutrients, which collect in streams and lakes. As a result, stripped soils may no longer provide the nutrients that native plants need.

Acid rain takes a toll on ecosystems (**Figure** 22.9). Plants that are exposed to acids become weak and are more likely to be damaged by bad weather, insect pests, or disease. Snails die in acid soils, so songbirds do not have as much food to eat. Young birds and mammals do not build bones as well and may not be as strong. Eggshells may also be weak and break more easily.

Figure 22.9: Acid rain has killed trees in this forest in the Czech Republic. (3)

The nitrates found in acid rain cause some plants to grow better. These nitrate-lovers can drive out other plants, which may cause the ecosystem to change. Nitrates also fertilize the oceans, which makes more algae grow. The algae use up all the oxygen in the water, which can bring about disastrous ecological changes, including the deaths of many fish. As lakes become acidic, organisms die off. If the pH drops below 4.5, all the fish die. Organic material cannot decay, and mosses take over the lake. Wildlife that depend on the lake for drinking water suffer population declines. Crops are damaged by acid rain. This is most noticeable in poor nations where people can't afford to fix the problems with fertilizers or other technology. Buildings and monuments are damaged by acid precipitation (**Figure** 22.10). These include the U.S. Capital and many buildings in Europe, such as Westminster Abbey.

Figure 22.10: Acid rain damages cultural monuments like buildings and statues. (6)

Carbonate rocks can neutralize acids and so some regions do not suffer the effects of acid rain nearly as much. The Midwestern United States is protected by the limestone rocks throughout the area, which are made up of calcium carbonate. One reason that the northeastern United States is so vulnerable to acid rain damage is that the rocks are not carbonates.

Because pollutants can travel so far, much of the acid rain that falls hurts states or nations other than ones where the pollutants were released. All the rain that falls in Sweden is acidic and fish in lakes all over the country are dying. The pollutants come from the United Kingdom and Western Europe, which are now working to decrease their emissions. Canada also suffers from acid rain that originates in the United States, a problem that is also improving. Southeast Asia is experiencing more acid rain between nations as the region industrializes.

Ozone Depletion

At this point you might be asking yourself, "Is ozone bad or is ozone good?" There is no simple answer to that question: It depends on where the ozone is located. In the troposphere, ozone is a pollutant. Higher up, in the stratosphere, ozone screens out high energy ultraviolet radiation and thus makes Earth habitable. This protective ozone is found in the ozone layer.

The ozone layer is being attacked by human-made chemicals that break ozone molecules apart in the stratosphere. The most common of these chemicals are chlorofluorocarbons (CFCs), but includes others such as halons, methyl bromide, carbon tetrachloride, and methyl chloroform. CFCs were once widely used because they are cheap, nontoxic, nonflammable, and non-reactive. They were used as spray-can propellants, refrigerants, and in many other products.

Once they are released into the air, CFCs float up to the stratosphere. Air currents move them toward the poles. In the winter, they freeze onto nitric acid molecules in polar stratospheric clouds (PSC). PSCs form only where the stratosphere is coldest, and are most common above Antarctica in the wintertime. In the spring, the sun's warmth starts the air moving, and ultraviolet light breaks the CFCs apart. The chlorine atom floats away and attaches to one of the oxygen atoms on an ozone molecule. The chlorine pulls the oxygen atom away, leaving behind an O_2 molecule, which provides no UV protection. The chlorine then releases the oxygen atom and moves on to destroy another ozone molecule. One CFC molecule can destroy as many as 100,000 ozone molecules.

Ozone destruction creates the **ozone hole** where the layer is dangerously thin (**Figure** 22.11). As air circulates over Antarctica in the spring, the ozone hole expands northward over the southern continents, including Australia, New Zealand, southern South America, and southern Africa. UV levels may rise as much as 20% beneath the ozone hole. The hole was first measured in 1981 when it was 2 million square km (900,000 square miles)). The 2006 hole was the largest ever observed at 28 million square km (11.4 million square miles). It had the lowest ozone levels ever recorded and also lasted the longest. The difference in the size of the ozone hole each year depends on many factors, including whether conditions are right for the formation of polar stratospheric clouds.

Ozone loss also occurs over the north polar region, but it is not enough for scientists to call it a hole. The region of low ozone levels is small because the atmosphere is not as cold and PSCs do not form as readily. Still, springtime ozone levels are relatively low. This low moves south over some of the world's most populated areas in Europe, North America, and Asia. At 40°N, the latitude of New York City, UV-B has increased about 4% per decade since 1978. At 55°N, the approximate latitude of Moscow and Copenhagen, the increase has been 6.8% per decade since 1978.

Ozone losses in population centers increase sunburns, cataracts (clouding of the lens of the eye), and skin cancers. A loss of ozone of only 1% is estimated to increase skin cancer cases by 5 to 6%. People may also suffer from decreases in their immune system's ability to fight off infectious diseases. Ozone loss may reduce crop yields, since many plants are sensitive to ultraviolet light. Excess UV appears to be decreasing the productivity of plankton in the oceans. A decrease of 6 to 12% has been measured around Antarctica, which may be at least partly related to the ozone hole. The effects of excess UV on other organisms is not known. When the problem with ozone depletion was recognized, world leaders took action. CFCs were banned in spray cans in some nations in 1978. The greatest production of CFCs was in 1986, but has declined since then. This will be discussed more in the next lesson.

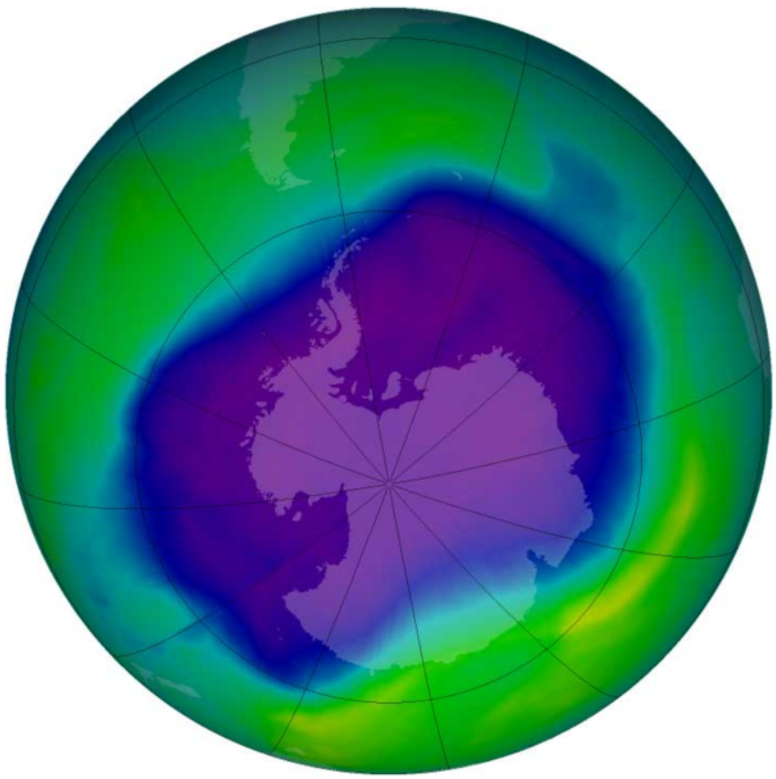

Figure 22.11: The September 2006 ozone hole, the largest ever observed. Blue and purple colors show particularly low levels of ozone. (13)

Lesson Summary

- Air pollutants damage human health and the environment. Particulates reduce visibility, alter the weather, and cause lung problems like asthma attacks.
- Ozone damages plants and can also cause lung disease. Acid rain damages forests, crops, buildings and statues.
- The ozone hole, caused by ozone-destroying chemicals, allows more UV radiation to strike the Earth.
- This can cause plankton populations to decline and skin cancers in humans to increase, along with other effects.

Review Questions

1. Why is visibility so reduced in the United States?
2. Why do health recommendations suggest that people limit the amount of tuna they eat?
3. Why might ozone pollution or acid rain change an entire ecosystem?
4. Why does air pollution cause problems in developing nations more than in developed ones?
5. Why are children more vulnerable to the effects of air pollutants than adults?
6. Describe bioaccumulation.
7. How does pollution indirectly kill or harm plants?
8. What do you think the effect is of jet airplanes on global warming?
9. Why is air pollution a local, regional and global problem?
10. How do CFCs deplete the ozone layer?

Vocabulary

acid rain Rain that has a pH of less than 5.0.

alkaline Also called basic. Substances that have a pH of greater than 7.0.

bioaccumulation The accumulation of toxic substances within organisms so that the concentrations increase up the food web.

ozone hole A region around Antarctica in which ozone levels are reduced in springtime, due to the action of ozone-destroying chemicals.

pH scale A scale that measures the acidity of a solution. A pH of 7 is neutral. Smaller numbers are more acidic and larger numbers are more alkaline.

polar stratospheric clouds (PSC) Clouds that form in the stratosphere when it is especially cold; PSCs are necessary for the breakup of CFCs.

Points to Consider

- Since mercury bioaccumulates and coal-fired power plants continue to emit mercury into the atmosphere, what will be the consequence for people who like to eat tuna and other large predatory fish?
- What are the possible causes of rising asthma rates in children?
- A ban has been imposed on CFCs and some other ozone-depleting substances. How will the ozone hole change in response to this ban?

22.3 Reducing Air Pollution

Lesson Objectives

- Describe the major ways that energy use can be reduced.
- Discuss new technologies that are being developed to reduce air pollutants, including greenhouse gases.
- Describe the difference between placing caps on emissions and reducing emissions.

Introduction

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-20$^{\text{th}}$ 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.

Ways to Reduce Air Pollution

Air pollution can be reduced in a number of ways. Using less fossil fuel is one way to lessen pollution. People use less fuel by engaging in conservation, which means not using a resource or using less of it. For example, riding a bike or walking instead of driving doesn't use any fossil fuel. Taking a bus uses less than driving or riding by yourself in a car, as does carpooling. If you need to drive, buying a car that has greater fuel efficiency is important.

You can conserve electricity (and thus fossil fuels) at home by turning off light bulbs and appliances when they are not in use, using energy efficient light bulbs and appliances, and even buying less stuff. All these actions reduce the amount of energy that power plants need to produce.

There are many reasons for people in North America and Europe to try to reduce their use of fossil fuels. As you have already seen, air pollution has tremendous health and environmental costs. There are other reasons as well. Much of the oil we use comes from the Middle East, which is a politically unstable region of the world. Also, fossil fuels are running out, although some will run out sooner than others. The most easily accessible fossil fuels are mostly already gone and harder to use or recover fuels are now being used. There are other types of fossil fuels that can eventually replace coal and petroleum, such as tar sands and oil shale. But these have even more environmental problems than traditional fossil fuels have: mining them from the ground causes severe environmental damage and burning them releases pollutants, including greenhouse gases.

Alternative energy sources are important. They currently are not a large part of the energy supply, but they will increase rapidly over the coming years and decades. Several sources of alternative energy, including solar and wind are not currently being used much because the technologies are not well enough developed. Converting sunlight into usable solar power, for example, is still very expensive relative to using fossil fuels. For solar to be used more widely, technology will need to advance so that the price falls. Also, solar power is not practiced in all parts of the United States because some areas get low amounts of sunlight. These locations will need to develop different power sources. 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 like safety and waste disposal.

Some pollutants can be filtered out of the exhaust stream before they are released into the atmosphere. Other pollutants can be broken down into non-toxic compounds before they are released. Some of these technologies will be described in the following sections.

Reducing Air Pollution from Vehicles

Reducing air pollution from vehicles can be done in a number of ways. Pollutants can be broken down before they are released into the atmosphere. The vehicles can be more fuel efficient. New technologies can be developed so that they do not rely on fossil fuels at all.

Motor vehicles emit less pollution than they once did due to **catalytic converters** (**Figure** 22.12). Catalytic converters are placed on modern cars in the United States. These devices reduce emissions of nitrous oxides, carbon monoxide and VOCs. A **catalyst** speeds up chemical reactions without being used up in the reaction itself. For nitrous oxides, the catalyst breaks the nitrogen and oxygen atoms apart. The nitrogen then combines with another nitrogen ion to form nitrogen gas (N_2) and the oxygen forms O_2. VOCs and CO are similarly broken apart into the greenhouse gases H_2O and CO_2. Catalytic converters only work when they are hot, so a lot of exhaust escapes as the car is warming up.

Figure 22.12: A large catalytic converter on an SUV. (11)

There are several simple ways to make a vehicle more fuel efficient. Lighter vehicles need less energy to move. Streamlined vehicles experience less resistance from the wind. So, small, lightweight, streamlined cars get much better gas mileage than chunky, heavy SUVs. **Hybrid vehicles** are among the most efficient vehicles that are now widely available. Hybrids have a small internal combustion engine that works like an ordinary car. They also have an electric motor and a rechargeable battery. During braking, a normal car loses the energy it has because it is in motion. In a hybrid, that energy is instead funneled into charging the battery. When the car accelerates again, it uses the power stored in the battery. The internal combustion engine only takes over when power in the battery has run out. Hybrids get excellent gas mileage in cities where the vehicle frequently stops and starts. Hybrid vehicles also have catalytic converters: the battery preheats the converter so that it begins to work much sooner after the car is turned on. Hybrids can reduce auto emissions by 90% or more. Unfortunately, in many hybrid vehicles the hybrid technology is used to improve acceleration more than gas mileage.

A new technology that is in development is a plug-in hybrid. The vehicle is plugged into an electricity source when it is not in use, perhaps in a garage. The car uses the power stored in that battery when it is next used. Plug-in hybrids are less polluting than regular hybrids, since they can run for a longer time on electricity. Automakers expect that plug-in hybrids will become available around 2010.

Fuel cells are another technology that is in development (**Figure** 22.13). Hydrogen fuel cells harness the energy released when hydrogen and oxygen come together to create water. Fuel cells are extremely efficient and they produce no pollutants. But developing fuel cell technology has its problems. The oxygen the fuel cell uses comes from the atmosphere, but there is no easy source of hydrogen. Natural gas is a source, but converting it into usable hydrogen decreases the efficiency of the fuel cells and increases pollution, including greenhouse gases. Natural gas also has other important uses. A few fuel cell cars are now being produced as models. Right now these cars are extremely expensive and fueling stations are rare. Some automakers say that for fuel cell vehicles to become widespread the cost of production must decrease to 1% of its current price.

Figure 22.13: A hydrogen fuel cell car looks like a gasoline-powered car. (15)

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, while sulfur and nitric oxides are broken down by catalysts. Removing these oxides reduces the pollutants that cause acid rain.

Particles are relatively easy to remove from emissions. Baghouses work like a giant vacuum cleaner bag, filtering dust as it streams past. Baghouses collect about 98% of dry particulates. Cyclones are air streams that rotate quickly through a container shaped like a cylinder or a cone. Large particles are forced toward the edges of the air stream. When they hit the outside wall of the container, they fall to the bottom and are swept up. Smaller particles can be picked up as the radius of the cyclone is reduced. Particles can also be collected and removed by static electricity. These electrostatic precipitators are useful for removing materials from very hot gases.

Scrubbers remove particles and waste gases from exhaust (**Figure** 22.14). Wet scrubbers use a liquid solution to scrub pollutants. Dry scrubbers use alkali or other materials to neutralize acid gas pollutants. Other techniques are used to eliminate other toxic gases. Nitrogen oxides, for example, can be broken down at very high temperatures.

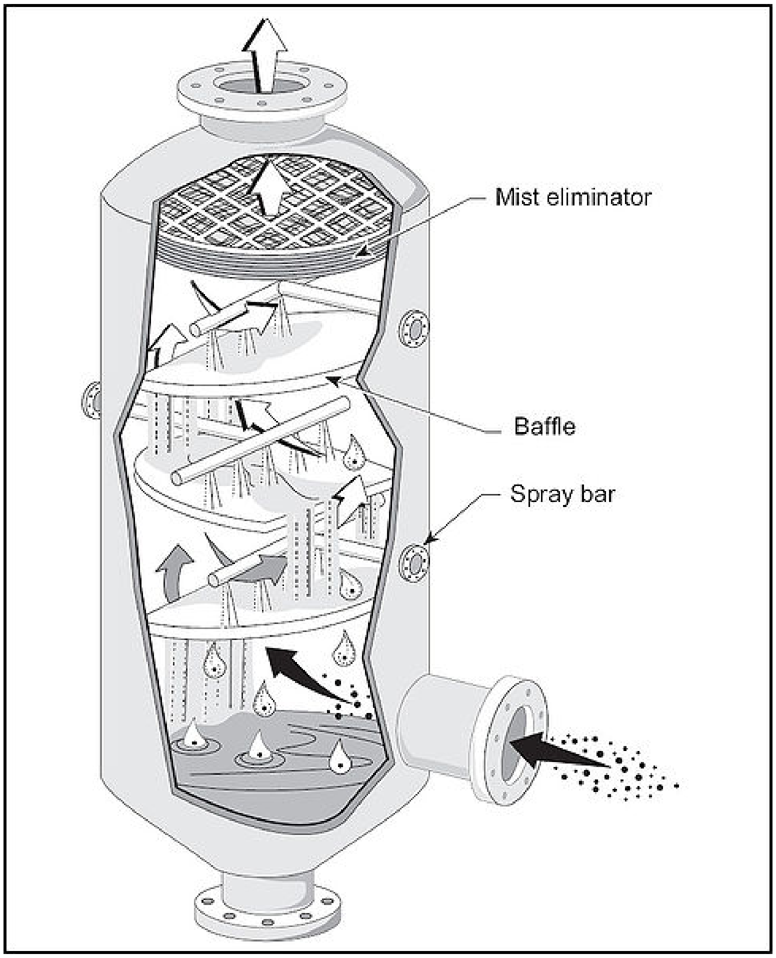

Figure 22.14: Diagram of one type of scrubber. (14)

Gasification is a developing technology. This method removes some of the toxins present in coal before they are released into the atmosphere. In gasification, coal is heated to extremely high temperatures. The gas that is produced is filtered and the energy goes on to drive a generator. About 80% less pollution is released over 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 and so they are seldom built. Also, heating the coal to high enough temperatures uses a great deal of energy, so the technology not very energy efficient. In addition, large amounts of the greenhouse gas CO_2 are still released even with clean coal technology.

Reducing Ozone Destruction

One success story in reducing pollutants that harm the atmosphere concerns ozone-destroying chemicals. In 1973, scientists calculated that CFCs could reach the stratosphere and break apart. This would release chlorine atoms, which would then destroy ozone. Based only on their calculations, the United States and most Scandinavian countries banned CFCs in spray cans in 1978.

More confirmation that CFCs break down ozone was needed before more was done to reduce production of ozone-destroying chemicals. In 1985, members of the British Antarctic Survey reported that a 50% reduction in the ozone layer had been found over Antarctica in the previous three springs. Two years later, the 'Montreal Protocol on Substances that Deplete the Ozone Layer' was ratified by nations all over the world.

The Montreal Protocol controls the production and consumption of 96 chemicals that damage the ozone layer. Hazardous substances are phased out first by developed nations and one decade later by developing nations. More hazardous substances are phased out more quickly. CFCs have been mostly phased out since 1995, although some will be used in developing nations until 2010. The Protocol also requires that wealthier nations donate money to develop technologies that will replace these chemicals.

If CFCs were not being phased out, by 2050 they would have been probably been 10 times more abundant than they were in 1980. The result would have been about 20 million more cases of skin cancer in the United States and 130 million cases globally. Even though governments have acted to reduce CFC's, they take many years to reach the stratosphere and they can survive there a long time before they break down. So the ozone hole will probably continue to grow for some time before it begins to shrink. The ozone layer will reach the same levels it had before 1980 in around 2068 and 1950 levels in one or two centuries.

Reducing Greenhouse Gases

Reducing greenhouse gas emissions is related to air pollution control. Unlike many other air pollutants, climate change is a global problem. Climate scientists agree that all nations must come together to reduce greenhouse gas emissions. So far, this has not occurred.

The first attempt to cap greenhouse gas emissions was the Kyoto Protocol. The Kyoto Protocol limits greenhouse gas emissions for developed nations to below 1990 levels. Kyoto has not achieved the success of the Montreal Protocol for several reasons. The largest emitter of greenhouse gases, the United States, did not sign and was not bound by the agreement. Developing nations, most notably China, signed the treaty but are not obligated to make changes in their greenhouse gas emissions. Of the nations that agreed to reduce their emissions, few are on track to achieve their target. More importantly, several years have passed since this process was begun and climate scientists agree that the Protocol does not reduce emissions nearly enough. Some say that reductions 40 times those required by

Kyoto are needed to avoid dangerous climate change. Plans are now being made to replace the Kyoto Protocol with a more effective treaty in 2012.

The Kyoto Protocol set up a cap-and-trade system. Each participating nation was given a cap on greenhouse gas emissions that it should not go over. If a nation is likely to go over its cap, it can buy credits from a nation that will emit less greenhouses gases than allowed by the cap. 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, since they believe that the federal government is not doing enough to address the problem of climate change.

However it is done, climate scientists and many others agree that greenhouse gas emissions must be lowered. The easiest and quickest way is to increase energy efficiency. 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 to encourage conservation. For example, when people make a purchase of a new car, they will be more likely to purchase an energy efficient model. The money from the carbon tax can then 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.

More energy efficient vehicles and appliances can be developed. Some, like hybrid cars are currently available. Agricultural practices that lessen the amount of methane produced can be used.

Beyond increasing efficiency, new technologies can be developed. Alternative energy sources, like solar and wind can be developed and expanded. **Biofuels** can replace gasoline in vehicles, but they must be developed sensibly (**Figure** 22.15). So far much of the biofuel is produced from crops like corn. But when food crops are used for fuel, the price of food goes up. Also modern agriculture is 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 useable oil than crops like corn.

Greenhouse gases can also be removed from the atmosphere after they are emitted. **Carbon sequestration** occurs when carbon dioxide is removed from the atmosphere. Carbon is sequestered naturally in forests, but unfortunately, more forest land is currently being lost than gained. Another idea is to artificially sequester carbon. For example, carbon can be captured from the emissions from gasification plants. That carbon is then stored underground in salt layers or coal seams, which keeps it out of the atmosphere. While some small sequestration projects are underway, no large-scale sequestration has yet been attempted. While it is a promising new technology, carbon sequestration is also untested and may not prove to be significant in fighting global warming.

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

Figure 22.15: A bus that runs on soybean oil shows the potential of biofuels. (1)

to make sound choices on energy policy.

Lesson Summary

- Air pollutants can be reduced in many ways. The best method is to not use the energy that produces the pollutants by conservation or increasing energy efficiency.
- Alternative energy sources are another good way to reduce pollution. Most of these alternate energy technologies are still being refined (solar, wind) and some have other problems associated with them (nuclear, biofuels).
- Pollutants can be removed from an exhaust stream by being filtered out or broken down. Some pollutants are best not released at all like CFCs.

Review Questions

1. Since the Clean Air Act was passed in 1970, why is the air still not clean?
2. What are some ways that you can conserve energy?
3. How does reducing air pollutants, as described in the Clean Air Act of 1970, affect greenhouse gas emissions?
4. What has to be done before alternative energy sources can replace fossil fuels?
5. What are catalytic converters?
6. Why are hybrid vehicles more energy efficient than regular vehicles powered by internal combustion engines?
7. Why aren't fuel cell vehicles widely available yet?

8. How does a cyclone reduce particulate pollution?
9. How can coal power be made so that it has nearly zero carbon contribution to the atmosphere?
10. Why is it that the ozone hole will not be healed for several decades?
11. Many people think that biofuels are the solution to a lot of the problem of climate change, but others disagree. What requirements would biofuels have to meet if they were to be really effective at replacing gasoline in motor vehicles?

Vocabulary

biofuel A fuel made from living materials, usually crop plants.

carbon sequestration Removal of carbon dioxide from the atmosphere, so that it does not act as a greenhouse gas in the atmosphere.

catalyst A substance that increases (or decreases) the rate of a chemical reaction but is not used up in the reaction.

catalytic converter Found on modern motor vehicles, these devices use a catalyst to break apart pollutants.

fuel cell An energy cell in which chemical energy is converted into electrical energy.

gasification A technology that cleans coal before it is burned, which increases efficiency and reduces emissions.

hybrid vehicle A very efficient vehicle that is powered by an internal combustion engine, an electric motor and a rechargeable battery.

Points to Consider

- Why is it important to reduce air pollution?
- What can you do in your own life to reduce your impact on the atmosphere?
- Why is a worldwide effort needed to reduce the threat of global climate change?

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Chapter 23

Observing and Exploring Space

23.1 Telescopes

Lesson Objectives

- Explain how astronomers use the whole electromagnetic spectrum to study the universe beyond Earth.
- Identify different types of telescopes.
- Describe historical and modern observations made with telescopes.

Introduction

Many scientists can interact directly with what they are studying. Biologists can collect cells, seeds, or sea urchins and put them in a controlled laboratory environment. Physicists can subject metals to stress or smash atoms into each other. Geologists can chip away at rocks to see what is inside. But astronomers, scientists who study the universe beyond Earth, rarely have a chance for direct contact with their subject. Instead, astronomers have to observe their subjects at a distance, usually a very large distance!

Electromagnetic Radiation

Earth is separated from the rest of the universe by very large expanses of space. Occasionally, matter from the outside reaches Earth, such as when a meteorite makes it through the atmosphere. But for the most part, astronomers have one main source for their data—light. Light can travel across empty space, and as it does so, it carries both energy and information. Light is one type of **electromagnetic (EM) radiation,** or energy transmitted through space as a wave.

The Speed of Light

Light travels faster than anything else in the universe. In the almost completely empty vacuum of space, light travels at a speed of approximately 300,000,000 meters per second (670,000,000 miles per hour). To give you an idea of how fast that is, a beam of light could travel from New York to Los Angeles and back again nearly 40 times in just one second. Even though light travels extremely fast, objects in space are so far away that it takes a significant amount of time for light from those objects to reach us. For example, light from the Sun takes about 8 minutes to reach Earth.

Light-Years

Because astronomical distances are so large, it helps to have a unit of measurement that is good for expressing those large distances. A **light-year** is a unit of distance that is defined as the distance that light travels in one year. One light-year is approximately equal to 9,500,000,000,000 (9.5 trillion) kilometers, or 5,900,000,000,000 (5.9 trillion) miles. That's a long way! By astronomical standards, it's actually a pretty short distance.

Proxima Centauri, the closest star to us after the Sun, is 4.22 light-years away. That means the light from Proxima Centauri takes 4.22 years to reach us. The galaxy we live in, the Milky Way Galaxy, is about 100,000 light-years across. So, how long does it take light to travel from one side of the galaxy to the other? 100,000 years! Even 100,000 light years is a short distance on the scale of the whole universe. The most distant galaxies we have detected so far are more than 13 billion light-years away. That's over a hundred-billion-trillion (100,000,000,000,000,000,000,000) kilometers!

Looking Back in Time

When we look at astronomical objects such as stars and galaxies, we are not just seeing over great distances—we are also seeing back in time. Because light takes time to travel, the image we see of a distant galaxy is an image of how the galaxy used to look. For example, the Andromeda Galaxy, shown in **Figure** 23.1, is about 2.5 million light years from Earth. If you look at the Andromeda Galaxy in a telescope, you will see the galaxy as it was 2.5 million years ago. If you want to see the galaxy as it is now, you will have to wait and look again 2.5 million years into the future!

Electromagnetic Waves

Earlier, we said that light is one type of electromagnetic (EM) radiation. That means light is energy that travels in the form of an *electromagnetic wave.* **Figure** 23.2 shows a diagram of an electromagnetic wave. An EM wave has two components: an electric field and a magnetic

Figure 23.1: This recent picture of the Andromeda Galaxy actually shows the galaxy as it was about 2.5 million years ago. (35)

field. Each of these components oscillates between positive and negative values, which is what makes the "wavy" shape in the diagram.

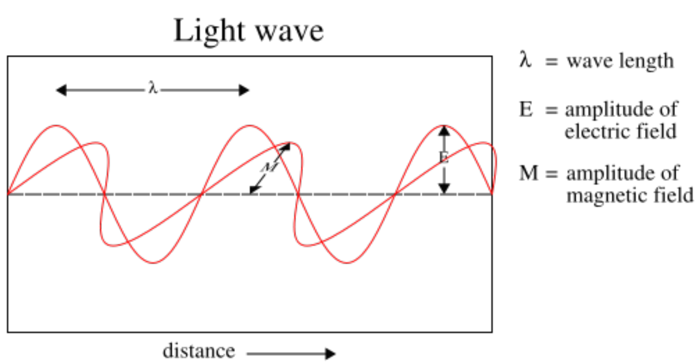

Figure 23.2: An electromagnetic wave consists of oscillating electric and magnetic fields. The distance between two adjacent oscillations is called wavelength. (33)

Notice the horizontal arrow at the top left of the diagram. This measurement corresponds to the **wavelength**, or the distance between two adjacent points on the wave. A related value is **frequency**, which measures the number of wavelengths that pass a given point every second. Wavelength and frequency are reciprocal, which means that as one increases, the other decreases.

The Electromagnetic Spectrum

Visible light—the light that human eyes can see—comes in a variety of colors. The color of visible light is determined by its wavelength. Visible light ranges from wavelengths of 400 nm to 700 nm, corresponding to the colors violet through red. But what about EM radiation with wavelengths shorter than 400 nm or longer than 700 nm? Such radiation exists all around you—you just can't see it! Visible light is part of a larger **electromagnetic spectrum,** as **Figure** 23.3 illustrates.

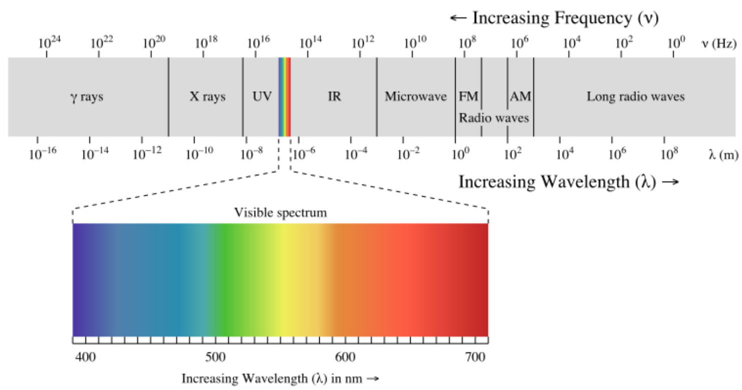

Figure 23.3: Visible light is part of a larger electromagnetic spectrum. The EM spectrum ranges from gamma rays with very short wavelengths, to radio waves with very long wavelengths. (19)

What does the electromagnetic spectrum have to do with astronomy? Every star, including our Sun, emits light at a wide range of wavelengths, all across the visible spectrum, and even outside the visible spectrum. Astronomers can learn a lot from studying the details of the spectrum of light from a star.

Some very hot stars emit light primarily at **ultraviolet** wavelengths, while some very cool stars emit mostly in the **infrared**. There are extremely hot objects that emit **X-rays** and even **gamma rays**. Light from some of the faintest, most distant objects is in the form of **radio waves**. In fact, a lot of the objects most interesting to astronomers today can't even be seen with the naked eye. Astronomers use telescopes to detect the faint light from distant objects and to see objects at wavelengths all across the electromagnetic spectrum.

Types of Telescopes

Optical Telescopes

Humans have been making and using lenses for magnification for thousands and thousands of years. However, the first true telescopes were made in Europe in the late 16^{th} century. These telescopes used a combination of two lenses to make distant objects appear both nearer and larger. The term *telescope* was coined by the Italian scientist and mathematician Galileo Galilei (1564–1642). Galileo built his first telescope in 1608 and subsequently made many improvements to telescope design.

Telescopes that rely on the refraction, or bending, of light by lenses are called **refracting telescopes,** or simply *refractors.* The earliest telescopes, including Galileo's, were all refractors. Many of the small telescopes used by amateur astronomers today are refractors with a design similar to Galileo's. Refractors are particularly good for viewing details within our solar system, such as the surface of Earth's moon or the rings around Saturn. **Figure** 23.4 shows the biggest refracting telescope in the world.

Figure 23.4: The largest refracting telescope in the world is at the University of Chicago's Yerkes Observatory in Wisconsin. This telescope was built in 1897. Its largest lens has a diameter of 102 cm. (20)

Around 1670, another famous scientist and mathematician—Sir Isaac Newton (1643–1727)—built a different kind of telescope. **Figure** 23.5 shows a telescope similar in design to Newton's.

Figure 23.5: The telescope still looks much the same today. (22)

Newton's telescope used curved mirrors instead of lenses to focus light. Telescopes that use mirrors are called **reflecting telescopes,** or *reflectors* (**Figure** 23.6). The mirrors in a reflecting telescope are much lighter than the heavy glass lenses in a refractor. This is significant, because thick glass lenses in a telescope mean that the whole telescope must be much stronger to support the heavy glass. In addition, it's much easier to precisely make mirrors than to precisely make glass lenses. For that reason, reflectors can be made larger than refractors. Larger telescopes can collect more light, which means they can study dimmer or more distant objects. The largest optical telescopes in the world today are reflectors, like the one in **Figure** 23.7.

Figure 23.6: Reflecting telescopes used by amateur astronomers today are similar to the one designed by Isaac Newton in the 17th century. (13)

Many consumer telescopes today use a combination of mirrors and lenses to focus light. These telescopes are called **catadioptric telescopes**. By using both kinds of elements,

Figure 23.7: The South African Large Telescope (SALT) is one of the largest reflecting telescopes on Earth. SALT's primary mirror consists of 91 smaller hexagonal mirrors, each with sides 1 m long. (21)

catadioptric telescopes can be made with large diameters but shorter lengths so they are less awkward to move around. **Figure** 23.8 shows a typical catadioptric telescope.

Radio Telescopes

Notice it says above that the largest *optical* telescopes in the world are reflectors. Optical telescopes are designed to collect visible light. There are even larger telescopes that collect light at longer wavelengths—radio waves. These telescopes are called—can you guess?—**radio telescopes.** Radio telescopes look a lot like satellite dishes. In fact, both are designed to do the same thing—to collect and focus radio waves or microwaves from space.

The largest single telescope in the world is at the Arecibo Observatory in Puerto Rico (see **Figure** 23.9). This telescope is located in a naturally-occurring sinkhole that formed when water flowing underground dissolved the limestone rock. If this telescope were not supported by the ground, it would collapse under its own weight. The downside of this design is that the telescope cannot be aimed to different parts of the sky—it can only observe the part of the sky that happens to be overhead at a given time.

A group of radio telescopes, such as those shown in **Figure** 23.10, can be linked together with a computer so that they are all observing the same object. The computer can combine the data from each telescope, making the group function like one single telescope.

Figure 23.8: Many amateur astronomers today use catadioptric telescopes. These telescopes have large mirrors to collect a lot of light, but short tubes for portability. (34)

Figure 23.9: The radio telescope at the Arecibo Observatory in Puerto Rico has a diameter of 305 m. (1)

Figure 23.10: The Very Large Array in New Mexico has 27 radio dishes, each 25 meters in diameter. When all the dishes are spread out and pointed at the same object, they act like a single telescope with a diameter of 22.3 mi. (7)

Space Telescopes

Telescopes on Earth all have one significant limitation: the electromagnetic radiation they gather must pass through Earth's atmosphere. The atmosphere blocks some radiation in the infrared part of the spectrum and almost all radiation in the ultraviolet and higher frequency ranges. Furthermore, motion in the atmosphere distorts light. You see evidence of this distortion when you see stars twinkling in the night sky. To minimize these problems, many observatories are built on high mountains, where there is less atmosphere above the telescope. **Space telescopes** avoid such problems completely because they are outside Earth's atmosphere altogether—in space.

The Hubble Space Telescope (HST), shown in **Figure** 23.11, is perhaps the best known space telescope. The Hubble was put into orbit by the Space Shuttle Atlantis in 1990. Once it was in orbit, scientists discovered that there was a flaw in the shape of the mirror. A servicing mission to the Hubble by the Space Shuttle Endeavor in 1994 corrected the problem. Since that time, the Hubble has provided huge amounts of data that have helped to answer many of the biggest questions in astronomy.

Figure 23.11: The Hubble Space Telescope orbits Earth at an altitude of 589 km (366 mi). It collects data in visible, infrared, and ultraviolet wavelengths. (12)

In addition to the Hubble, the National Aeronautics and Space Administration (NASA) has placed three other major space telescopes in orbit: the Compton Gamma-Ray Observatory (CGRO), the Chandra X-Ray Observatory (CXO) , and the Spitzer Space Telescope (SST). Together, these four telescopes comprise what NASA calls the 'Great Observatories'. **Figure** 23.12 shows how each of these telescopes specializes in a different part of the electromagnetic spectrum. Of these, all but the Compton are still in orbit and active. NASA is planning for another telescope, the James Webb Space Telescope, to serve as a replacement for the aging Hubble. The James Webb is scheduled to launch no earlier than 2013.

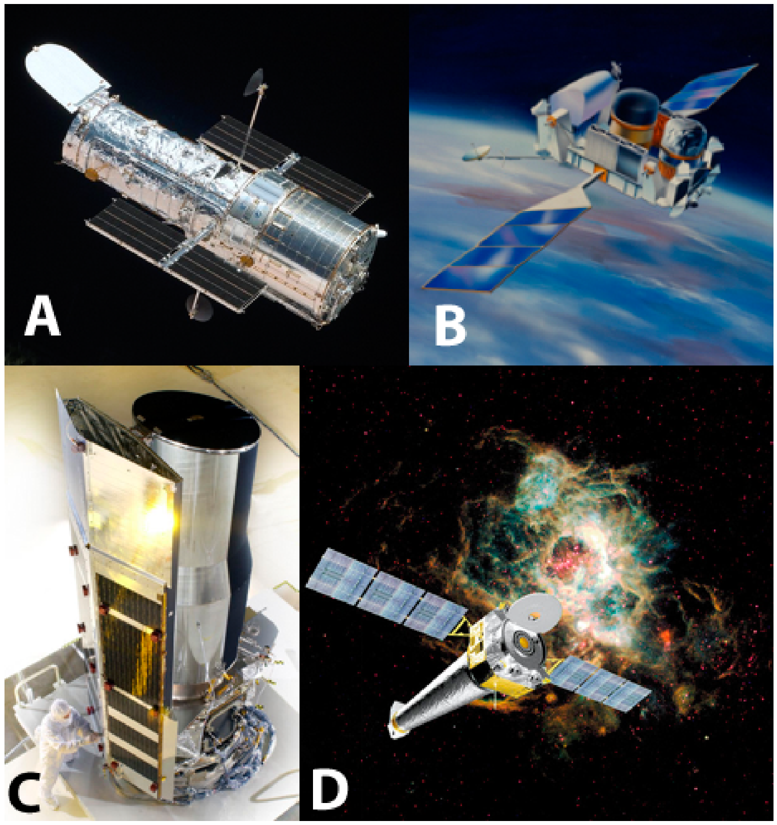

Figure 23.12: NASA's four space based Great Observatories were designed to view the universe in different ranges of the electromagnetic spectrum. A. Hubble Space Telescope: visible light, B. Compton Gamma Ray Observatory: gamma ray, C. Spitzer Space Telescope: infrared, D. Chandra X-ray Observatory: X-ray. (26)

Observations with Telescopes

Ancient Astronomers

Humans have been studying the night sky for thousands of years. Observing the patterns and motions in the sky helped ancient peoples keep track of time. This was important to them because it helped them know when to plant crops. They also timed many of their religious ceremonies to coincide with events in the heavens.

The ancient Greeks made careful observations of the locations of stars in the sky. They noticed that some of what they thought were 'stars' moved against the background of other stars. They called these bright spots in the sky **planets**, which in Greek means "wanderers." Today we know that the planets are not stars, but members of our solar system that orbit the Sun. The Greeks also identified **constellations**, patterns of stars in the sky. They associated the constellations with stories and myths from their culture. Constellations still help astronomers today; they are used to identify different regions of the night sky.

Galileo's Observations

Ancient astronomers knew a lot about the patterns of stars and the movement of objects in the sky, but they did not know much about what these objects actually were. All of that changed in the year 1610, when Galileo turned a telescope toward the heavens. Using a telescope, Galileo made the following discoveries (among others):

- There are more stars in the night sky than the naked eye can see.
- The band of stars called the Milky Way, consists of many stars.
- The Moon has craters (See **Figure** 23.13).
- Venus has phases like the Moon.
- Jupiter has moons orbiting around it.
- There are dark spots that move across the surface of the Sun.

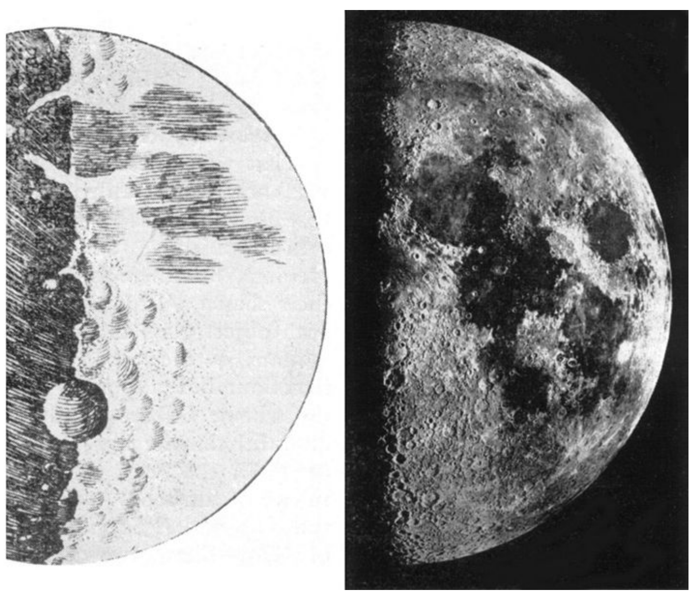

Figure 23.13: Galileo was the first person known to look at the Moon through a telescope. Galileo made the drawing on the left in 1610. The image on the right is a modern photograph of the Moon. (24)

Galileo's observations challenged people to think in new ways about the universe and Earth's place in it. About 100 years before Galileo, Nicolaus Copernicus had proposed a controversial new model of the universe. According to Copernicus's model, Earth and the other planets revolve around the Sun. In Galileo's time, most people believed that the Sun and planets revolved around Earth. Galileo's observations provided direct evidence to support Copernicus' model.

Observations with Modern Telescopes

Today, equipped with no more than a good pair of binoculars, you can see all of the things Galileo saw, and more. You can even see sunspots, but you need special filters on the lenses to protect your eyes. Never look directly at the Sun without using the proper filters! With a basic telescope like those used by many amateur astronomers, you can also see polar caps on Mars, the rings of Saturn, and bands in the atmosphere of Jupiter.

We now know that all of these objects are within our solar system. You can also see many times more stars with a telescope than without a telescope. However, stars seen in a telescope still look like single points of light. Because they are so far away, stars continue to appear as points of light in even the most powerful professional telescopes. **Figure** 23.14 shows one rare exception.

Today, very few professional astronomers look directly through the eyepiece of a telescope. Instead, they attach sophisticated instruments to telescopes. These instruments capture and process the light from a telescope, and astronomers then look at the images or data shown on these instruments. Most of the time, the instruments then pass the data on to a computer where the data can be stored for later use. It can take an astronomer weeks or months to analyze all the data collected from just a single night!

A **spectrometer** is a tool that astronomers commonly use to study the light from a telescope. A spectrometer uses a prism or other device to break light down into its component colors. This produces a spectrum like the one shown in **Figure** 23.15. The dark lines in the spectrum of light from a star are caused by gases in the outer atmosphere of the star absorbing light. This spectrum can be observed directly, captured on film, or stored digitally on a computer.

From a single spectrum of a star, an astronomer can tell:

- How hot the star is (by the relative brightness of different colors).
- What elements the star contains (by the pattern of dark lines).
- Whether and how fast the star is moving toward or away from Earth (by how far the dark lines are shifted from their normal positions).

Using telescopes, astronomers can also learn how stars evolve, what kind of matter is found throughout the universe, and how it is distributed, and even how the universe might have formed.

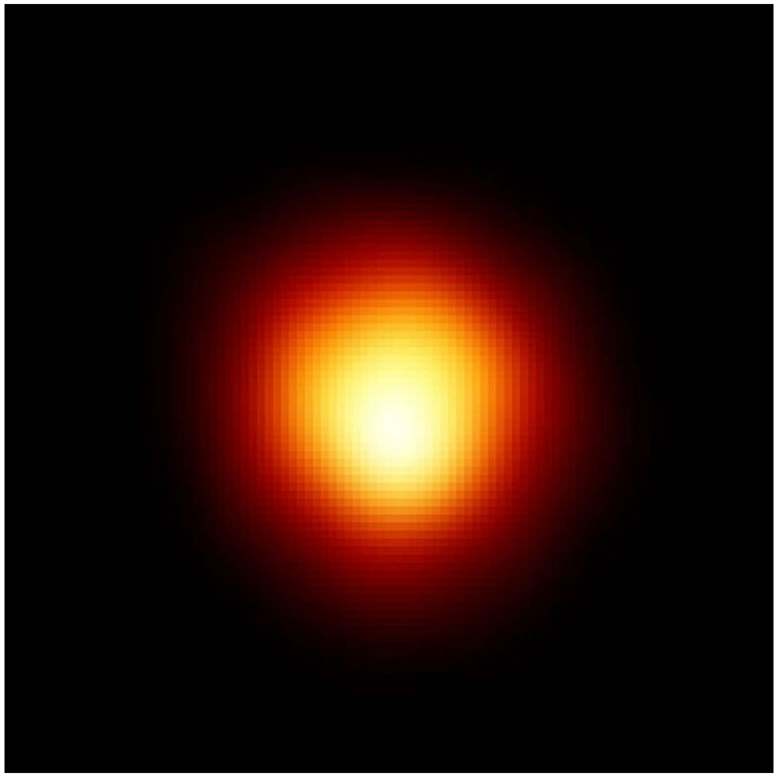

Figure 23.14: This is an ultraviolet image of the red supergiant star Betelgeuse taken with the Hubble Space Telescope in 1996. This was the first direct image taken of the disk of a star other than the Sun. (31)

Figure 23.15: This is a simplified example of what light from a star looks like after it passes through a spectrometer. (2)

Lesson Summary

- Astronomers study light from distant objects.
- Light travels at 300,000,000 meters per second—faster than anything else in the universe.
- A light-year is a unit of distance equal to the distance light travels in one year, 9.5 trillion kilometers.
- When we see distant objects, we see them as they were in the past, because their light has been traveling to us for many years.
- Light is energy that travels as a wave.
- Visible light is part of the electromagnetic spectrum.
- Telescopes make distant objects appear both nearer and larger. You can see many more stars through a telescope than with the unaided eye.
- Optical telescopes are designed to collect visible light. The three main types of optical telescopes are reflecting telescopes, refracting telescopes, and catadioptric telescopes.
- Radio telescopes collect and focus radio waves from distant objects.
- Space telescopes are telescopes orbiting Earth. They can collect wavelengths of light that are normally blocked by the atmosphere.
- Galileo was the first person known to use a telescope to study the sky. His discoveries helped change the way humans think about the universe.
- Modern telescopes collect data that can be stored on a computer.
- A spectrometer produces a spectrum from starlight. Astronomers can learn a lot about a star by studying its spectrum.

Review Questions

1. Proxima Centauri is 4.22 light-years from Earth. Light travels 9.5 trillion kilometers in one year. How far away is Proxima Centauri in kilometers?
2. Identify four regions of the electromagnetic spectrum that astronomers use when observing objects in space.
3. List the 3 main types of optical telescopes, and describe their differences.
4. Explain the advantages of putting a telescope into orbit around Earth.
5. Describe two observations that Galileo was the first to make with his telescope.
6. List 3 things that an astronomer can learn about a star by studying its spectrum.

Further Reading / Supplemental Links

- http://science.nasa.gov/headlines/y2002/08feb_gravlens.htm
- http://www.nasa.gov/audience/forstudents/postsecondary/features/F_NASA_Great_Observatories_PS.html
- http://www.stargazing.net/David/constel/howmanystars.html

- http://www.astronomics.com/main/category.asp/catalog_name/Astronomics/category_name/V1X41SU50GJB8NX88JQB360067/Page/1
- http://galileo.rice.edu/sci/instruments/telescope.html
- http://www.nrao.edu/whatisra/index.shtml
- http://www.astronomy.pomona.edu/archeo/
- http://www.colorado.edu/physics/PhysicsInitiative/Physics2000/quantumzone/
- http://en.wikipedia.org

Vocabulary

catadioptric telescope Telescopes that use a combination of mirrors and lenses to focus light.

constellations Patterns of stars as observed from Earth.

electromagnetic radiation Energy transmitted through space as a wave.

electromagnetic spectrum The full range of electromagnetic radiation.

frequency The number of wavelengths that pass a given point every second.

gamma rays A penetrating form of electromagnetic radiation.

infrared light Electromagnetic waves with frequencies between radio waves and red light; about 1 mm to 750 nanometers.

light-year The distance light can travel in one year; 9.5 trillion kilometers.

microwaves The shortest wavelength radio waves.

planets Around celestial object orbiting a star that has cleared its neighboring region of planetesimals.

radio telescope A radio antenna that collects radio waves.

radio waves The longest wavelengths of the electromagnetic spectrum; from 1 mm to more than thousands of kilometers.

reflecting telescope Telescopes that use mirrors to collect and focus light.

refracting telescope Telescopes that use convex lenses to collect and focus light.

space telescope Telescopes in orbit above Earth's atmosphere.

spectrometer A tool that uses a prism to break light into its component colors.

ultraviolet Electromagnetic radiation having wavelengths shorter than the violet.

wavelength Horizontal distance measured from wave crest to wave crest, or wave trough to wave trough.

visible light The portion of light in the electromagnetic spectrum that is visible to humans.

X rays A band of electromagnetic radiation between gamma and ultraviolet.

Points to Consider

- Radio waves are used for communicating with spacecraft. A round-trip communication from Earth to Mars takes anywhere from 6 to 42 minutes. What challenges might this present for sending unmanned spacecraft and probes to Mars?
- The Hubble Space Telescope is a very important source of data for astronomers. The fascinating and beautiful images from the Hubble also help to maintain public support for science. However, the Hubble is growing old. Missions to service and maintain the telescope are extremely expensive and put the lives of astronauts at risk.
- Do you think there should be another servicing mission to the Hubble?

23.2 Early Space Exploration

Lesson Objectives

- Explain how a rocket works.
- Describe different types of satellites.
- Outline major events in early space exploration, including the Space Race.

Introduction

Humans have long dreamed of traveling into space. Greek mythology tells of Daedelus and Icarus, a father and son who took flight using wings made of feathers and wax. Daedelus warned his son not to fly too close to the sun, but Icarus, thrilled with the feel of flying, drifted higher and higher. When he got too close to the Sun, the wax melted, and Icarus fell into the sea. This myth is often interpreted to be about foolishness or excessive pride, but we can also relate to the excitement Icarus would have felt. Much later, science fiction writers, such as Jules Verne (1828–1905) and H.G. Wells (1866–1946), wrote about technologies that might make the dream of traveling beyond Earth into space possible.

Rockets

Humans did not reach space until the second half of the 20th century. However, the main technology that makes space exploration possible, the **rocket** has been around for a long time. A rocket is a device propelled by particles flying out of it at high speed. We do not know exactly who built the first rocket, or when, but there are records of the Chinese using rockets in war against the Mongols as early as the 13th century. The Mongols, in turn, spread rocket technology in their attacks on Eastern Europe. Early rockets were also used to launch fireworks and for other ceremonial purposes.

How Rockets Work

Rockets were used for centuries before anyone could explain exactly how they work. The theory to explain this did not arrive until 1687, when Isaac Newton (1643–1727) described three basic laws of motion, now referred to as Newton's Laws of Motion:

1. An object in motion will remain in motion unless acted upon by a net force.
2. Force equals mass multiplied by acceleration.
3. To every action, there is an equal and opposite reaction.

Newton's third law of motion is particularly useful in explaining how a rocket works. To better understand this law, consider the ice skater in **Figure** 23.16. When the skater pushes the wall, the skater's force—the "action"—is matched by an equal force by the wall on the skater in the opposite direction—the reaction.

Once the skater is moving, however, she has nothing to push against. Imagine now that the skater is holding a fire extinguisher. When she pulls the trigger on the extinguisher, a fluid or powder flies out of the extinguisher, and she moves backward. In this case, the action force is the pressure pushing the material out of the extinguisher. The reaction force of the material against the extinguisher pushes the skater backward.

For a long time, many believed that a rocket wouldn't work in space because there would be nothing for the rocket to push against. However, a rocket in space moves like the skater holding the fire extinguisher. Fuel is ignited in a chamber, which causes an explosion of gases. The explosion creates pressure that forces the gases out of the rocket. As these gases

Figure 23.16: When the skater pushes against the wall, the wall exerts an equal force on the skater in the opposite direction. (27)

rush out the end, the rocket moves in the opposite direction, as predicted by Newton's Third Law of Motion. The reaction force of the gases on the rocket pushes the rocket forward, as shown in **Figure** 23.17. The force pushing the rocket is also called **thrust**.

Figure 23.17: Explosions in a chamber create pressure that pushes gases out of a rocket. This in turn produces thrust that pushes the rocket forward. The rocket shown here is a Saturn V rocket, used for the Apollo 11 mission—the first to carry humans to the Moon. (4)

A Rocket Revolution

For centuries, rockets were powered by gunpowder or other solid fuels. These rockets could travel only fairly short distances. At the end of the 19^{th} century and the beginning of the 20^{th} century, several breakthroughs in rocketry would lead to rockets that were powerful enough to carry rockets—and humans—beyond Earth. During this period, three people independently came up with similar ideas for improving rocket design.

The first person to establish many of the main ideas of modern rocketry was a Russian schoolteacher, named Konstantin Tsiolkovsky (1857–1935). Most of his work was done even before the first airplane flight, which took place in 1903. Tsiolkovsky realized that in order for rockets to have enough power to escape Earth's gravity, they would need liquid fuel instead of solid fuel. He also realized that it was important to find the right balance between the amount of fuel a rocket uses and how heavy the rocket is. He came up with the idea of using multiple stages when launching rockets, so that empty fuel containers would drop away to reduce mass. Tsiolkovsky had many great ideas and designed many rockets, but he never built one.

The second great rocket pioneer was an American, named Robert Goddard (1882–1945). He independently came up with some of the same ideas as Tsiolkovsky, such as using liquid fuel and using multiple stages. He also designed a system for cooling the gases escaping from a rocket, which made the rocket much more efficient. Goddard was more practical than Tsiolkovsky and built rockets to test his ideas. **Figure** 23.18 shows Goddard with the first rocket to use liquid fuel. This rocket was launched on March 16, 1926 in Massachusetts. Over a lifetime of research, Goddard came up with many innovations that are still used in rockets today.

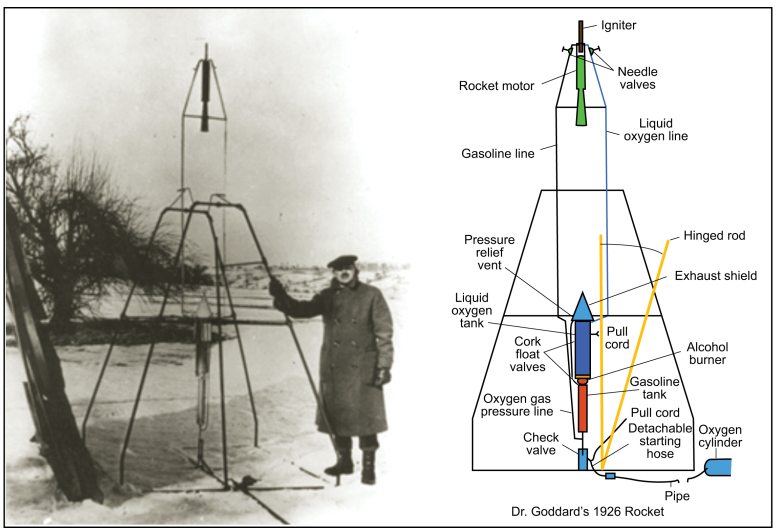

Figure 23.18: (Left) Robert Goddard launched the first liquid-fueled rocket on March 16, 1926; (Right) This schematic shows details of Goddard's rocket. (9)

The third great pioneer of rocket science was a Romanian-born German, named Hermann Oberth (1894–1989). In the early 1920's, Oberth came up with many of the same ideas as Tsiolkovsky and Goddard. His early work was not taken seriously by most scientists. Nonetheless, Oberth built a liquid-fueled rocket, which he launched in 1929. Later, he joined a team of scientists that designed the rocket shown in **Figure** 23.19 for the German military. This rocket, first called the A-4 and later the V-2, played a major role in World War II. The Germans used the V-2 as a missile to bomb numerous targets in Belgium, England,

and France. In 1942, the V-2 was launched to an altitude of 176 km (109 miles), making it the first human-made object to travel into space. An altitude of 100 km (62 miles) is generally considered to be the dividing line between Earth's atmosphere and space.

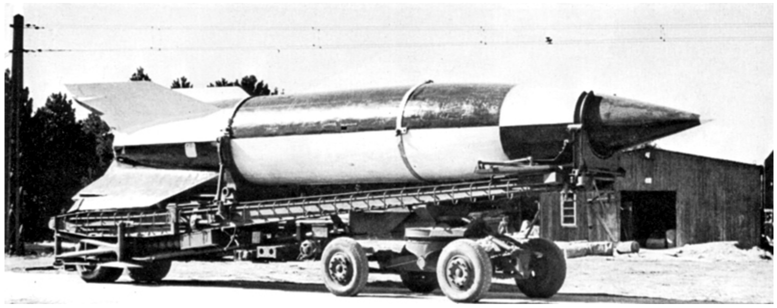

Figure 23.19: V-2 Rocket: Explosions in a chamber create pressure that pushes gases out of a rocket. This in turn produces thrust that pushes the rocket forward. (17)

The leader of the team that built the V-2 rocket was a German scientist, named Wernher von Braun. von Braun later fled Germany and came to the United States, where he helped the United States develop missile weapons and then joined the National Aeronautics and Space Administration (NASA) to design rockets for space travel. At NASA, von Braun designed the Saturn V rocket (**Figure** 23.17), which was eventually used to send the first humans to the Moon.

Satellites

One of the first uses of rockets in space was to launch **satellites.** A satellite is an object that orbits a larger object. To **orbit** something just means to travel in a circular or elliptical path around it. This path is also called an orbit. When you think of a satellite, you probably picture some kind of metallic spacecraft orbiting Earth, but the Moon is also a satellite. Human-made objects put into orbit are called *artificial satellites.* Natural objects in orbit, such as moons, are called *natural satellites.*

Newton's Law of Universal Gravitation

Isaac Newton, whose third law of motion explains how rockets work, also came up with the theory that explains why satellites stay in orbit. Newton's *law of universal gravitation* describes how every object in the universe is attracted to every other object. The same gravity that makes an apple fall to the ground, and keeps you from floating away into the sky, also holds the Moon in orbit around Earth, and Earth in orbit around the Sun.

Newton used the following example to explain how gravity makes orbits possible. Consider a cannonball launched from a high mountain, as shown in **Figure** 23.20. If the cannonball is launched at a slow speed, it will fall back to Earth, as in paths A and B in the figure. However, if it is launched at a fast enough speed, the Earth below will curve away at the same rate that the cannonball falls, and the cannonball will go into a circular orbit, as in path C. If the cannonball is launched even faster, it could go into an elliptical orbit (D) or leave Earth's gravity altogether (E).

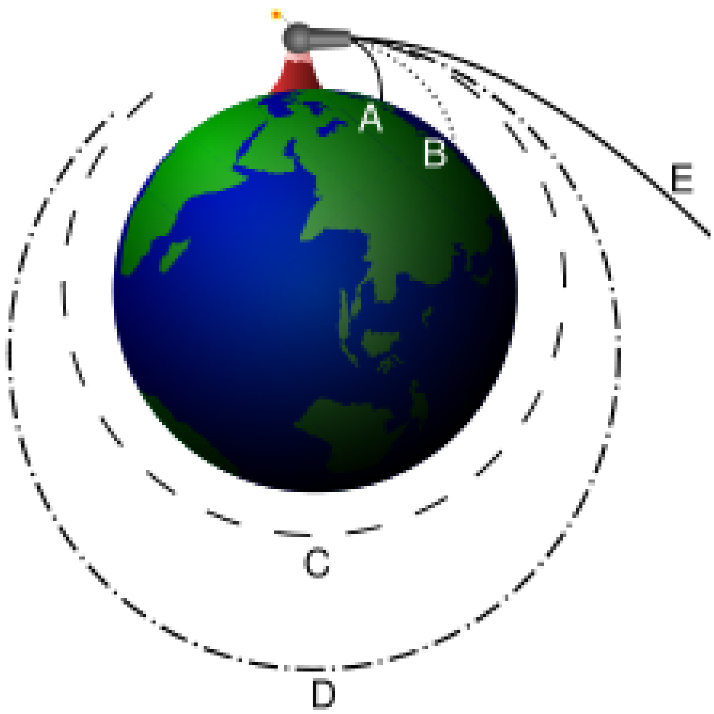

Figure 23.20: Isaac Newton explained how a cannonball fired from a high point with enough speed could orbit Earth. (25)

Note that Newton's idea would not actually work in real life; a cannonball launched from Mt. Everest, the highest mountain on Earth, would burn up in the atmosphere if launched at the speed required to put the cannonball into orbit. However, a rocket can launch straight up, then steer into an orbit. A rocket can also carry a satellite above the atmosphere and then release the satellite into orbit.

Types of Satellites

Since the launch of the first satellite over 50 years ago, thousands of artificial satellites have been put into orbit around Earth. We have even put satellites into orbit around the Moon, the Sun, Venus, Mars, Jupiter, and Saturn. Imaging satellites are designed for taking pictures of Earth's surface. The images can be used by the military, when taken by spy satellites or for scientific purposes, such as meteorology, if taken by weather satellites. Astronomers use imaging satellites to study and make maps of the Moon and other planets. Communications satellites, such as the one in **Figure** 23.21, are designed to receive and send signals for telephone, television, or other types of communications. Navigational satellites are used for navigation systems, such as the Global Positioning System (GPS). The largest artificial satellite is the International Space Station, designed for humans to live in space while conducting scientific research.

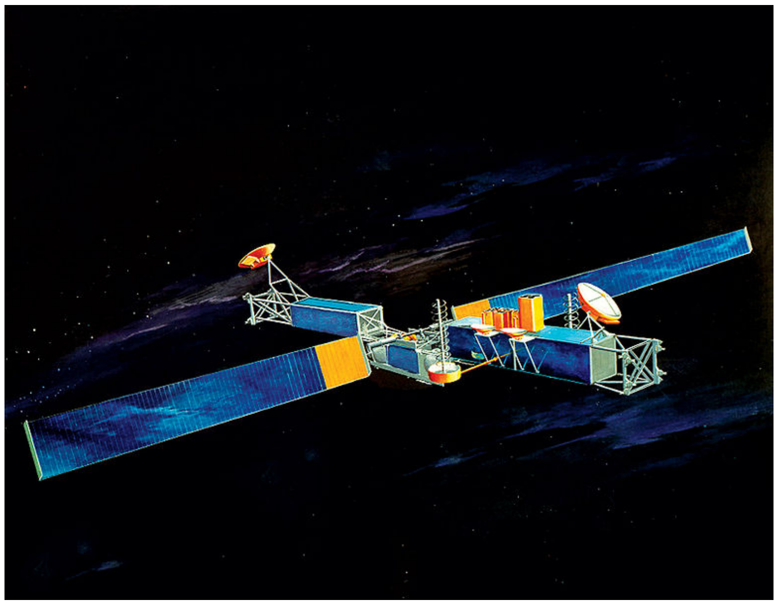

Figure 23.21: This is a Milstar communications satellite used by the U.S. military. The long, flat solar panels provide power for the satellite. Most of the other instruments you can see are antennas for sending or receiving signals. (3)

Types of Orbits

The speed of a satellite depends on how high it is above Earth or whatever object it is orbiting. Satellites that are relatively close to Earth are said to be in **low Earth orbit** (LEO). Satellites in LEO are also often in **polar orbit**, which means they orbit over the North and South Poles, perpendicular to Earth's spin. Because Earth rotates underneath the orbiting satellite, a satellite in polar orbit is over a different part of Earth's surface each time it circles. Imaging satellites and weather satellites are often put in low-Earth, polar orbits.

A satellite placed at just the right distance above Earth–35,786 km (22,240 miles)— orbits at the same rate that Earth spins. As a result, the satellite is always in the same position over Earth's surface. This type of orbit is called a **geostationary orbit** (GEO). Many communications satellites are put in geostationary orbits.

The Space Race

From the end of World War II in 1945 to the breakup of the Soviet Union (USSR) in 1991, the Soviet Union and the United States were in military, social, and political conflict. This period is known as the Cold War. While there were very few actual military confrontations, the two countries were in an arms race—continually developing new and more powerful weapons as each country tried to have more powerful weapons than the other. While this competition had many social and political consequences, it did also help to drive technology. The development of missiles for war significantly sped up the development of rocket technologies.

Sputnik

On October 4, 1957, the Soviet Union launched Sputnik 1, the first artificial satellite ever put into orbit. Sputnik 1, shown in **Figure** 23.22, was 58 cm in diameter and weighed 84 kg (184 lb). Antennas trailing behind the satellite sent out radio signals, which were detected by scientists and amateur radio operators around the world. Sputnik 1 orbited Earth in low Earth orbit on an elliptical path every 96 minutes. It stayed in orbit for about 3 months, until it slowed down enough to descend into Earth's atmosphere, where it burned up as a result of friction with Earth's atmosphere.

The launch of Sputnik 1 started the **Space Race** between the Soviet Union and the United States. Many people in the U.S. were shocked that the Soviets had the technology to put the satellite in orbit, and they worried that the Soviets might also be winning the arms race. On November 3, 1957, the Soviets launched Sputnik 2, which carried the first animal to go into orbit—a dog named Laika.

The Race Is On

In response to the Sputnik program, the U.S. launched their own satellite, Explorer I, on January 31, 1958. Shortly after that—March 17 1958—the U.S. launched another satellite, Vanguard 1. Later that year, the U.S. Congress and President Eisenhower established the National Aeronautics and Space Administration (NASA).

The Soviets still managed to stay ahead of the United States for many notable "firsts." On April 12, 1961, Soviet cosmonaut Yuri Gagarin became both the first human in space and the first human in orbit. Less than one month later—May 5, 1961—the U.S. sent their first astronaut into space: Alan Shepherd. The first American to orbit Earth was John Glenn, in February 1962. The first woman in space was a Soviet: Valentina Tereshkova, in June 1963. The timeline in **Table** 23.1 shows many other Space Race firsts.

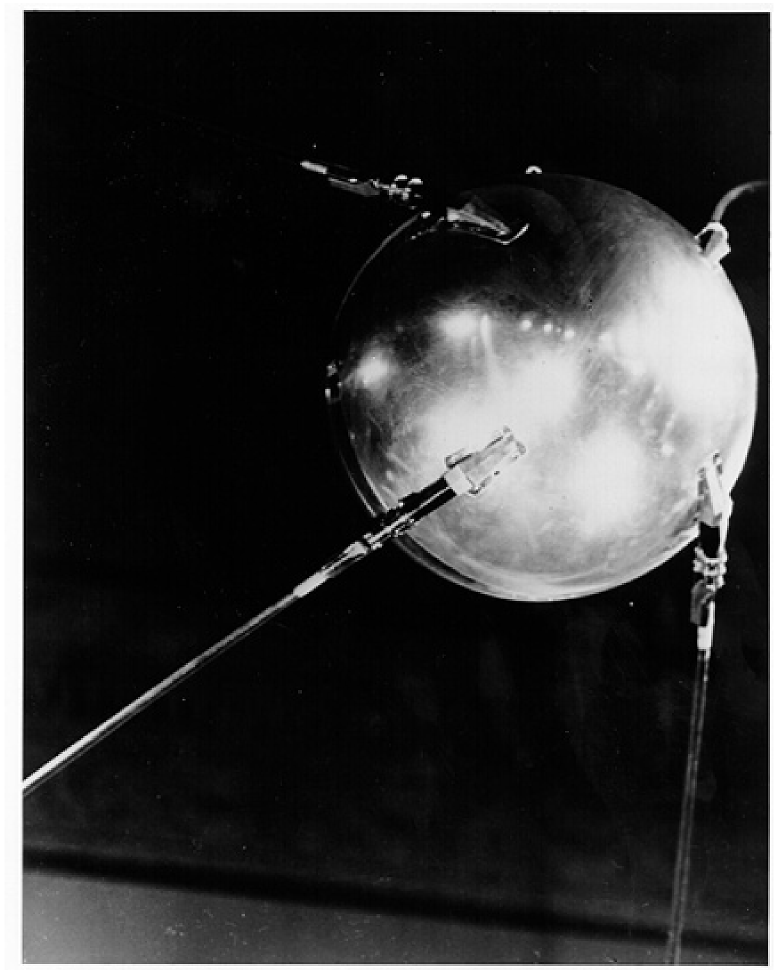

Figure 23.22: The Soviet Union launched Sputnik 1, the first artificial satellite,.on October 4, 1957. (16)

Table 23.1: **Space Race Timeline**

Date	Accomplished	Country	Name of Mission
October 4, 1957	First artificial satellite, first signals from space	USSR	Sputnik 1
November 3, 1957	First animal in orbit (the dog Laika)	USSR	Sputnik 2
January 31, 1958	USA's first artificial satellite	USA	Explorer I
January 4, 1959	First human-made object to orbit the Sun	USSR	Luna 1
September 13, 1959	First impact into another planet or moon (the Moon)	USSR	Luna 2
April 12, 1961	First manned spaceflight and first manned orbital flight (Yuri Gagarin)	USSR	Vostok 1
May 5, 1961	USA's first spaceflight with humans (Alan Shepherd)	USA	Mercury-Redstone 3 (Freedom 7)
February 20, 1962	USA's first orbital flight with humans (John Glenn)	USA	Mercury-Atlas 6 (Friendship 7)
December 14, 1962	First planetary flyby (Venus)	USA	Mariner 2
June 16, 1963	First woman in space, first woman in orbit (Valentina Tereshkova)	USSR	Vostok 6
March 18, 1965	First extra-vehicular activity ("spacewalk") (Aleksei Leonov)	USSR	Voskhod 2
February 3, 1966	First soft landing on another planet or moon (the Moon), first photos from another world	USSR	Luna 9

Table 23.1: (continued)

Date	Accomplished	Country	Name of Mission
March 1, 1966	First impact into another planet (Venus)	USSR	Venera 3
April 3, 1966	First artificial satellite around another world (the Moon)	USSR	Luna 10
June 2, 1966	USA's first soft landing on the Moon, USA's first photos from the Moon	USA	Surveyor 1
December 21, 1968	First humans to orbit another world (the Moon) (James Lovell, Frank Borman, Bill Anders)	USA	Apollo 8
July 21, 1969	First humans on the Moon (Neil Armstrong, Buzz Aldrin)	USA	Apollo 11

The Space Race between the United States and the Soviet Union reached a peak in 1969 when the U.S. put the first humans on the Moon. However, the competition between the two countries' space programs continued for many more years.

Reaching the Moon

On May 25, 1961, shortly after the first American went into space, President John F. Kennedy presented the following challenge to the U.S. Congress:

> "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him back safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

Eight years later, NASA's Apollo 11 mission achieved Kennedy's ambitious goal. On July 20, 1969, astronauts Neil Armstrong and Buzz Aldrin were the first humans to set foot on the moon, as shown in **Figure** 23.23.

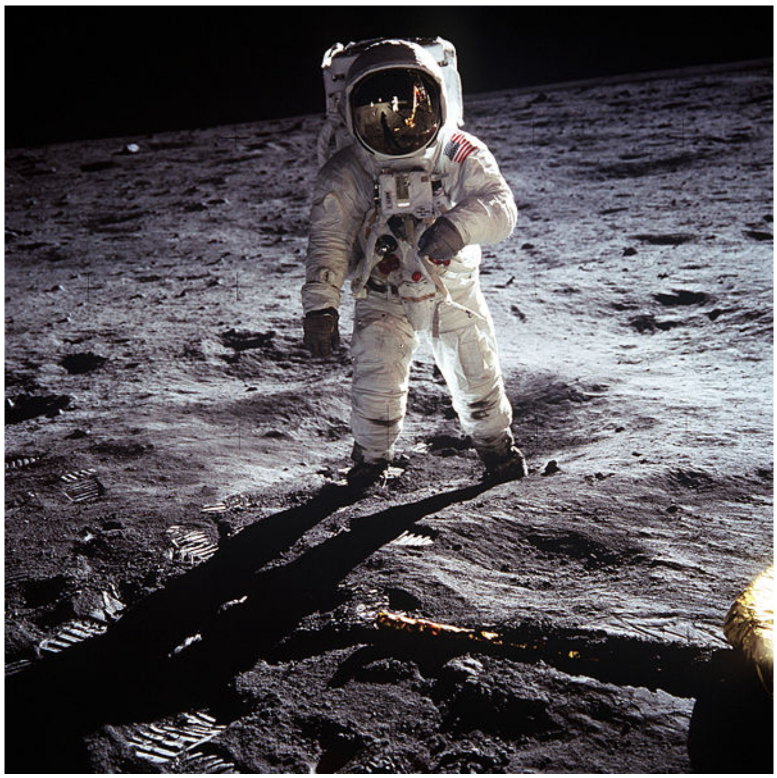

Figure 23.23: Neil Armstrong took this photo of Buzz Aldrin on the Moon during the Apollo 11 mission. Armstrong and the Lunar Module can be seen in the reflection in Aldrin's helmet. (28)

Following the Apollo 11 mission, four other American missions successfully put astronauts on the Moon. The last manned mission to the moon was Apollo 17, which landed on December 11, 1972. To date, no other country has put a person on the Moon.

In July 1975, the Soviet Union and the United States carried out a joint mission called the Apollo-Soyuz Test Project. During the mission, an American Apollo spacecraft docked with a Soviet Soyuz spacecraft, as shown in **Figure** 23.24. Many considered this to be the symbolic end of the Space Race.

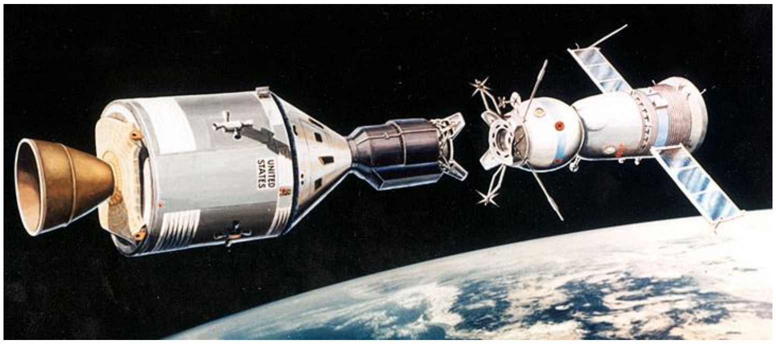

Figure 23.24: The docking of an Apollo spacecraft with a Soyuz spacecraft in 1975 was a symbolic end to the Space Race. (8)

Exploring Other Planets

Both the United States and the Soviet Union also sent probes to other planets during the Space Race. A **space probe** is a spacecraft that is sent without a crew to collect data by flying near or landing on an object in space, such as a planet, moon, asteroid, or comet. In the Venera missions, the USSR sent several probes to Venus, including some that landed on the surface. The U.S. sent probes to Mercury, Venus, and Mars in the Mariner missions, and landed two probes on Mars in the Viking missions.

In the Pioneer and Voyager missions, the U.S. also sent probes to the outer solar system, including flybys of Jupiter, Saturn, Uranus, and Neptune. The Pioneer and Voyager probes are still traveling, and are now beyond the edges of our solar system. We have lost contact with the two Pioneer probes, but expect to have contact with the two Voyager probes until at least 2020.

Lesson Summary

- Rockets have been used for warfare and ceremonies for many centuries.
- Newton's third law explains how a rocket works. The action force of the engine on the gases is accompanied by a reaction force of the gases on the rocket.

- Konstantin Tsiolkovsky, Robert Goddard, and Hermann Oberthall came up with similar ideas for improving rocket design. These included using liquid fuel and using multiple stages.
- A satellite is an object that orbits a larger object. Moons are natural satellites. Artificial satellites are made by humans.
- Newton's law of universal gravitation explains how the force of gravity works, both on Earth and across space. Gravity hold satellites in orbit.
- Artificial satellites are used for imaging Earth and other planets, for navigation, and for communication.
- The launch of the Sputnik 1 satellite started a Space Race between the United States and the Soviet Union.
- The United States' Apollo 11 mission put the first humans on the Moon.
- The U.S. and Soviet Union also sent several probes to other planets during the Space Race.

Review Questions

1. Use Newton's third law to explain how a rocket moves.
2. List the three great pioneers of rocket science.
3. What is the difference between a rocket and a satellite? How are they related?
4. What is the name of Earth's natural satellite?
5. Explain why a satellite in polar orbit will be able to take pictures of all parts of the Earth over time.
6. Describe three different types of orbits.
7. What event launched the Space Race?
8. What goal did John F. Kennedy set for the United States in the Space Race?
9. What are the advantages of a multi-stage rocket instead of a single-stage rocket?

Further Reading / Supplemental Links

- http://exploration.grc.nasa.gov/education/rocket/TRCRocket/history_of_rockets.html
- http://www.solarviews.com/eng/rocket.htm
- http://www.thespaceplace.com/history/rocket2.html
- Hermann_Oberth; Wernher_von_Braun; V-2_rocket; Satellites; Natural_satellite; Newton_cannonball; Sputnik_1; Sputnik_program; Space_Race; Cold_War; John_F._Kennedy; Apollo_program; List_of_planetary_probes.
- http://www.thespacesite.com/space_contents.html
- http://www.thespaceplace.com/history/space.html
- http://www.aero.org/education/primers/space/history.html
- http://science.howstuffworks.com/satellite.htm

- http://ctd.grc.nasa.gov/rleonard/index.html
- http://www.nasm.si.edu/exhibitions/gal114/gal114.htm
- http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_25th.html
- http://en.wikipedia.org/

Vocabulary

geostationary orbit A satellite place at just the right distance above Earth to orbit at the same rate that Earth spins.

low Earth orbit Satellites that orbit relatively close to Earth.

orbit To travel in a circular or elliptical path around another object.

polar orbit A path for a satellite that goes over the North and South Poles, perpendicular to Earth's spin.

rocket A device propelled by particles flying out of it at high speed.

satellite An object, either natural or human made, that orbits a larger object.

space probe A spacecraft that is sent without a crew to collect data by flying near or landing on an object in space.

Space Race A competition between the United States and the Soviet Union to have the best space technology.

thrust The forward force produced by gases escaping from a rocket engine.

Points to Consider

- The Space Race and the USA's desire to get to the Moon brought about many advances in science and technology.
- Can you think of any challenges we face today that are, could be, or should be a focus of science and technology?
- If you were in charge of NASA, what new goals would you set for space exploration?

23.3 Recent Space Exploration

Lesson Objectives

- Outline the history of space stations and space shuttles.
- Describe recent developments in space exploration.

Space Shuttles and Space Stations

While the United States continued missions to the Moon in the early 1970s, the Soviets had another goal: to build a **space station**. A space station is a large spacecraft on which humans can live for an extended period of time.

Early Space Stations

The Soviet Union put the first space station, Salyut 1, into orbit on April 19, 1971. At first, the station had no crew. Three cosmonauts boarded the station on June 7, 1971, and stayed for 22 days. Unfortunately, the cosmonauts died during their return to Earth, when the return capsule lost pressure while still in the airless vacuum of space. Salyut 1 left orbit on October 11, 1971, and burned up as a result of friction with the Earth's atmosphere.

Between 1971 and 1982, the Soviets put a total of seven Salyut space stations into orbit. **Figure** 23.25 shows the last of these, Salyut 7. These were all temporary stations that were launched and later inhabited by a human crew. Three of the Salyut stations were used for secret military purposes. The others were used to study the problems of living in space and for a variety of experiments in astronomy, biology, and Earth science. Salyut 6 and Salyut 7 each had two docking ports, so one crew could dock a spacecraft to one end, and later a replacement crew could dock to the other end.

The U.S. only launched one space station during this time—Skylab, shown in **Figure** 23.26. Skylab's design was based on a segment of the Saturn V rockets that were used in the Apollo missions to the Moon. Skylab was launched into low Earth orbit in May 1973. It was damaged as it passed out of Earth's atmosphere, but repairs were made when the first crew arrived.

Three crews visited Skylab, all within its first year in orbit. Skylab was used to study the effects of staying in space for long periods. It was also used for studying the Sun. Skylab reentered Earth's atmosphere in 1979, sooner than expected. It was so large that Skylab did not completely burn as it reentered the Earth's atmosphere. As a result, pieces of it fell across a large area, including some of western Australia. News headlines read, "The Skylab is Falling!"

Figure 23.25: The Soviet Salyut 7 space station was in orbit from 1982 to 1991. (14)

Figure 23.26: This image of Skylab was taken as the last crew left the station in January of 1974. (10)

Modular Space Stations

The first space station designed for very long-term use was the Mir space station (**Figure** 23.27). Mir was a *modular* space station, which means it was launched in several separate pieces and put together in space. The core of Mir was launched by the Soviet Union in 1986. Mir was put together in several phases between 1986 and 1996. Mir holds the current record for the longest continued presence in space. There were people living on Mir continuously for almost 10 years, falling short of the 10-year mark by just eight days. Mir was taken out of orbit in 2001; it fell into the Pacific Ocean, as the Russians had planned.

Mir was the first major space project in which the United States and Russia (after the fall of the USSR) worked together. In 1993, U.S. Vice President, Al Gore and Russian prime minister, Viktor Chernomyrdin announced plans for a new space station, which would later be called the International Space Station, or ISS. They also agreed that the U.S. would be involved in the Mir project in the years ahead. Space shuttles would take part in the transport of supplies and people to and from Mir. In addition, American astronauts would live on Mir for many months. This cooperation with Russia allowed the United States to learn from Russia's experience with long duration space flights. **Figure** 23.28 shows Mir with an American space shuttle attached.

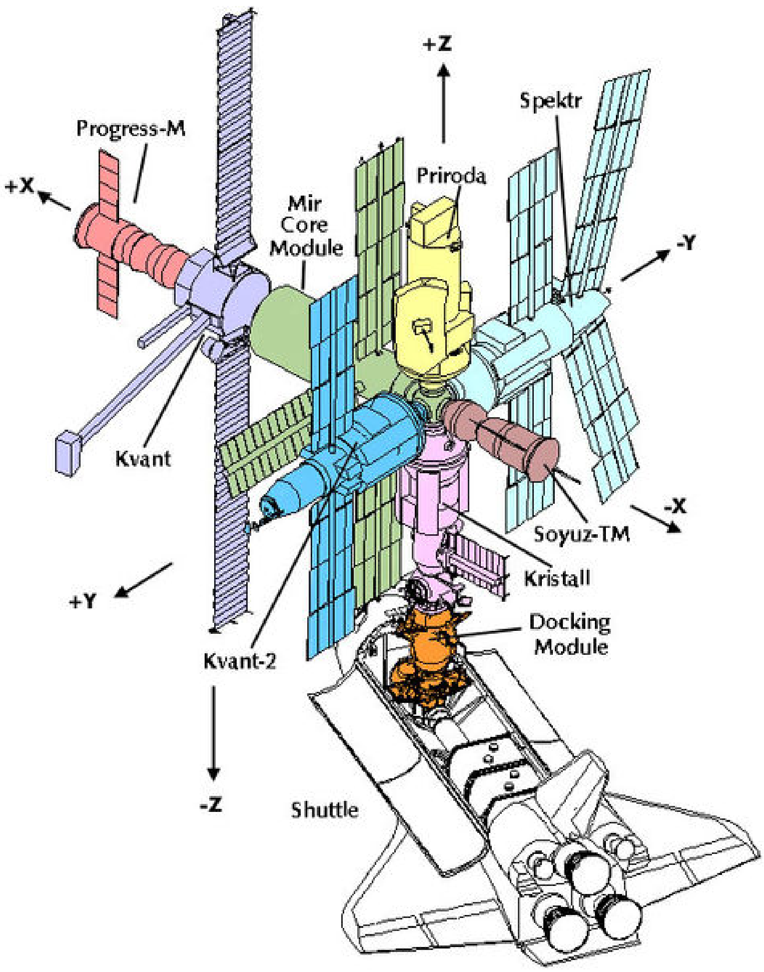

Figure 23.27: The Soviet/Russian space station Mir was designed to have several different parts attached to a core. (5)

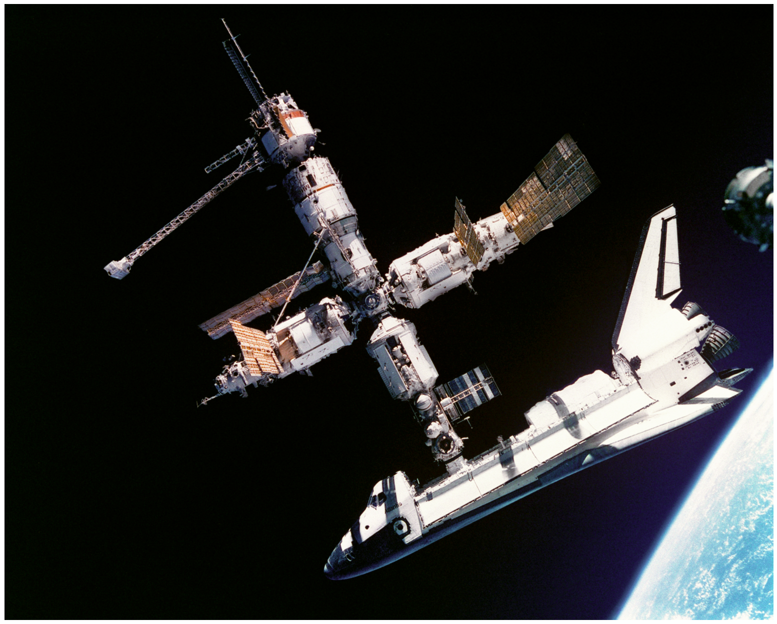

Figure 23.28: American space shuttles visited Mir several times during the 1990's. This picture was taken by Russian cosmonauts from their Soyuz spacecraft, as they flew around Mir and the Space Station to check on the space station. (32)

The International Space Station

Early space exploration was driven by competition between the United States and the Soviet Union. However, since the end of the Cold War, space technology and space exploration have benefited from a spirit of cooperation. The International Space Station, shown in **Figure** 23.29, is a joint project between the space agencies of the United States (NASA), Russia (RKA), Japan (JAXA), Canada (CSA) and several European countries (ESA). The Brazilian Space Agency also contributes.

The International Space Station is a very large station with many different sections. It is still being assembled. The first piece was launched in 1997. The first crew arrived in 2000, and the station has had people on board ever since. American space shuttles carry most of the supplies and equipment to the station, while Russian Soyuz spacecraft carry people. The primary purpose of the station is scientific research, especially in biology, medicine, and physics.

Space Shuttles

The spacecraft that NASA used for the Apollo missions were very successful, but they were very expensive, could not carry much cargo, and could be used only once. After the Apollo missions to the Moon, NASA wanted a new kind of space vehicle. They wanted this vehicle to

Figure 23.29: This photograph of the International Space Station was taken by the space shuttle Atlantis in June 2007. Construction of the station is scheduled to be finished in 2010. (18)

be reusable and able to carry large pieces of equipment, such as satellites, space telescopes, or sections of a space station. The resulting spacecraft was a **space shuttle**, shown in **Figure** 23.30. Although this vehicle is sometimes referred to as “the space shuttle,” the U.S. has actually had five working space shuttles—Columbia, Challenger, Discovery, Atlantis, and Endeavor. The Soviet Union built a similar shuttle called Buran, but it never flew a mission with humans aboard.

Figure 23.30: Since 1981, the space shuttle has been the United States' primary vehicle for carrying people and large equipment into space. This photo shows the space shuttle Atlantis on the launch pad in 2006. (30)

A space shuttle has three main parts, although you are probably most familiar with the

orbiter, the part that has wings like an airplane. When a space shuttle launches, the orbiter is attached to a huge fuel tank that contains liquid fuel. On the sides of the fuel tank are two large *booster rockets*.

Figure 23.31 shows the stages of a normal space shuttle mission. The launch takes place at Cape Canaveral, in Florida. The booster rockets provide extra power to get the orbiter out of Earth's atmosphere. When they are done, they parachute down into the ocean so they can be recovered and used again. When the fuel tank is empty, it also falls away, but it burns up in the atmosphere. Once in space, the orbiter can be used to release equipment such as a satellite or supplies to the International Space Station, to repair existing equipment such as the Hubble Space Telescope, or to do experiments directly on board the orbiter.

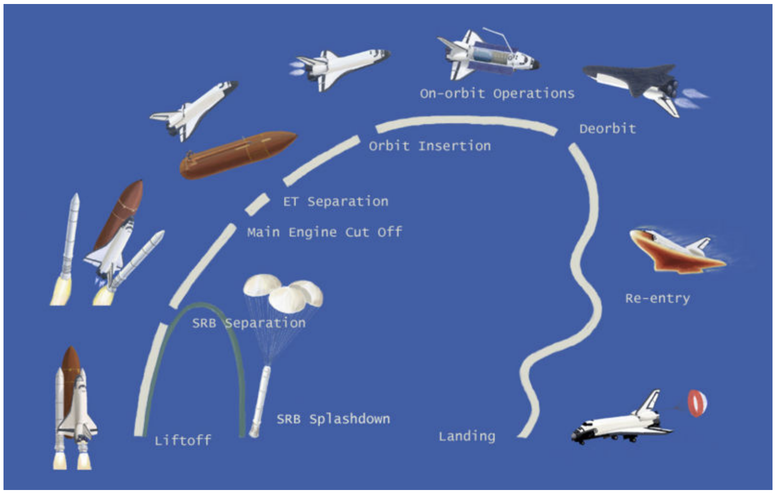

Figure 23.31: In a typical space shuttle mission, the orbiter takes off like a rocket and lands like an airplane. (15)

When the orbiter is done with its mission, it re-enters Earth's atmosphere. As it passes through the atmosphere, the outside of the orbiter heats up to over 1,500°C. The rockets do not fire during re-entry, so the shuttle is more like a glider than a regular airplane. Pilots have to steer the shuttle to the runway very precisely. Space shuttles usually land at Kennedy Space Center in Cape Canaveral, Florida, or at Edwards Air Force Base in California. However, if weather is bad at both these landing sites, a shuttle can land at one of many backup sites around the world. It can later be hauled back to Florida on the back of a jet airplane.

Space Shuttle Disasters

The space shuttle program has been very successful. Space shuttles have made possible many scientific discoveries and other great achievements in space. However, the program has also had some tragic disasters.

From the first flight in 1981 to the end of 1985, space shuttles flew over 20 successful missions, including many satellite launches and missions for scientific research. On January 28, 1986, the space shuttle Challenger launched carrying seven crew members, including Christa McAuliffe, who was to be the first teacher in space. Just 73 seconds after launch, the Challenger started to break apart, and most of it disintegrated in mid-air, as shown in **Figure** 23.32. All seven crew members on board died. Later study showed that the problem was due to an O-ring, a small part in one of the rocket boosters. Because of this disaster, space shuttle missions were put on hold while NASA studied the problem and improved the safety of the shuttles.

Figure 23.32: Plume of smoke from the Challenger disaster. The space shuttle Challenger broke apart 73 seconds after its launch on January 28, 1986. (11)

Shuttle missions started again in 1988, and there were over 87 consecutive missions without a major accident. However, during the takeoff of space shuttle Columbia on January 16, 2003, a small piece of insulating foam broke off the fuel tank. The foam smashed into one wing of the orbiter and damaged a tile on the front edge of the shuttle's wing. These tiles are heat shield tiles that protect the shuttle from extremely high temperatures. When Columbia returned to Earth on February 3, 2003, it could not withstand the high temperature, and broke apart. Pieces of the shuttle were found throughout the southern United States, especially in Texas. As in the Challenger disaster, all seven crew members died.

After the Columbia disaster, shuttle missions were stopped for over two years while NASA worked on the problem. One year after the disaster, President Bush announced that the space shuttle program was to end by the year 2010, and a new Crew Exploration Vehicle would take its place. The Crew Exploration Vehicle, now known as Orion is currently expected to be ready by 2014. All the remaining shuttle missions will be to the International Space Station, except for one repair mission to the Hubble Space Telescope.

Recent Space Missions

Since the 1986 Challenger disaster NASA has focused on missions without a crew, except for the International Space Station missions. These recent missions are less expensive and less dangerous than missions with a crew, yet still provide a great deal of valuable information.

Earth Science Satellites

In recent years, NASA and space agencies from other countries have launched dozens of satellites that collect data on the current state of Earth's systems. For example, NASA's Landsat satellites take detailed images of Earth's continents and coastal areas, such as those in **Figure** 23.33. Other satellites study the oceans, the atmosphere, the polar ice sheets, and other Earth systems. This data helps us to monitor climate change and understand how Earth's systems affect one another.

Figure 23.33: The two images above are from NASA's Landsat 7 satellite. The left shows New Orleans and Lake Pontchartrain on April 26, 2000. The right shows the same area on August 30, 2005, shortly after Hurricane Katrina flooded the city. Dark blue areas in the city are underwater. (6)

Space Telescopes

Some of the greatest astronomical discoveries—and greatest pictures, like the one in **Figure** 23.34, have come from the Hubble Space Telescope. The Hubble was the first telescope in space. It was put into orbit by the space shuttle Discovery in 1990. Since then, four shuttle missions have gone to the Hubble to make repairs and upgrades. A final repair mission to the Hubble is scheduled for 2008.

Figure 23.34: This image taken by the Hubble Space Telescope shows the Cat's Eye Nebula. Hubble has produced thousands of beautiful pictures that are also very valuable for scientific research. (23)

NASA has also put several other telescopes in space, including the Spitzer Space Telescope, the Chandra X-Ray Observatory, and the Compton Gamma Ray Observatory. The biggest and most advanced space telescope yet, the James Webb Telescope, is scheduled to be launched into orbit around 2013. The James Webb will replace the Hubble Space Telescope and will have an even greater ability to view distant objects. Other countries, including Russia, Japan, and several European countries have also put space telescopes in orbit.

Solar System Exploration

We have continued to explore the solar system in recent years. In 1997, the Mars Pathfinder **rover** landed on Mars. A rover is like a spacecraft on wheels (**Figure** 23.35). It can move around on the surface of a moon or planet and collect data from different locations. Two more rovers—Spirit and Opportunity—landed on Mars in 2004, and as of 2008 are still sending data back to Earth. Amazingly, both rovers were only designed to explore Mars for 90 days — they have now worked for more than 15 times their intended lifespan. Several spacecraft are currently in orbit around Mars, studying its surface and thin atmosphere.

Figure 23.35: This artists' painting of one of the two Mars rovers shows the six wheels, as well as a set of instruments being extended forward by a robotic arm. (29)

The Cassini mission has been studying Saturn, including its rings and moons, since 2004. The Huygens probe, built by the European Space Agency, is studying Saturn's moon Titan. Titan has some of the conditions that are needed to support life.

Some missions are studying the smaller objects in our solar system. The Deep Impact probe was sent to collide with a comet, collecting data all the way. When it hit the comet, the impact made a cloud of dust. Space telescopes and telescopes on Earth all collected data after the impact. The Stardust mission collected tiny dust particles from another comet. Missions are currently underway to study some of the larger asteroids and Pluto. Studies of smaller objects in the solar system may help us to understand how the solar system formed.

Future Missions

In 2004, President Bush proposed a "new vision for space exploration." He set the goal of putting humans on the Moon again by 2020. Unlike the Apollo missions, however, Bush proposed that reaching the Moon would only be the beginning. He also proposed building a permanent station on the Moon, which could serve as a base for missions taking humans to Mars and beyond. He announced that the space shuttle program would be retired after the International Space Station was complete (around 2010). A new kind of space vehicle, now called Orion, will be developed to take humans to space.

President Bush also explained we would meet these goals cooperatively, more like the International Space Station than the missions during the Space Race. He said, "We'll invite other nations to share the challenges and opportunities of this new era of discovery. The vision I outline today is a journey, not a race, and I call on other nations to join us on this journey, in a spirit of cooperation and friendship." Meanwhile, China, Russia, and Japan have all said they are planning to send humans to the Moon and establish Moon bases of their own.

Lesson Summary

- The Soviet Union put seven Salyut space stations into orbit between 1971 and 1982.
- The United States' first space station was Skylab. Skylab was in orbit from 1973 to 1979.
- The Soviet (later Russian) space station Mir was the first modular space station. Both Russian and American crews lived on Mir.
- The International Space Station is a huge project that involves many countries. It is still being assembled.
- Space shuttles are reusable vehicles for American astronauts to get into space. A space shuttle takes off like a rocket and lands like a glider plane.
- The space shuttle program has had two major disasters—the Challenger disaster in 1986 and the Columbia disaster in 2003. In each case, the spacecraft was destroyed and a crew of 7 people died.
- Recent space missions have mostly used small spacecraft, such as satellites and space probes, without crews.
- The United States plans to send humans to the Moon again by 2020, build a base on the Moon, then send humans to Mars.

Review Questions

1. Which space station was built and launched by the United States alone?
2. How many years was the Mir space station in orbit?
3. Which space station was the first to involve several countries working together?
4. Describe two ways in which space shuttles were an improvement over the spacecraft used for the Apollo missions?
5. Name the five fully functional space shuttles that the United States built. Which of these were destroyed?
6. Describe the space shuttle Columbia disaster, including its cause.
7. Describe two recent or ongoing space missions.
8. Is the Space Shuttle more like a rocket or a plane? Explain your answer.

Further Reading / Supplemental Links

- http://science.hq.nasa.gov/missions/earth.html
- http://landsat.gsfc.nasa.gov/images/archive/e0004.html
- http://www.whitehouse.gov/news/releases/2004/01/20040114-3.html
- http://www.nytimes.com/2007/09/25/science/space/25china.html?_r=1&ref=world&oref=slogin
- http://en.wikipedia.org

- http://starchild.gsfc.nasa.gov/docs/StarChild/space_level2/skylab.html
- http://spaceflight.nasa.gov/station/; http://www.nasa.gov/mission_pages/station/main/index.html
- http://imagine.gsfc.nasa.gov/docs/features/news/pinksox.html; http://spaceflight.nasa.gov/living/index.html
- http://science.howstuffworks.com/space-shuttle.htm; http://www.nasa.gov/mission_pages/shuttle/main/index.html; http://www.space.com/space-shuttle/
- http://www.nasa.gov/missions/current/index.html; http://www.nasa.gov/mission_pages/exploration/main/index.html; http://en.wikipedia.org/wiki/Orion_%28spacecraft%29

Vocabulary

orbiter The main part of the space shuttle that has wings like an airplane.

space shuttle A reusable spacecraft capable of carrying large pieces of equipment or pieces of a space station.

space station A large spacecraft in space on which humans can live for an extended period of time.

Points to Consider

- To date, a total of 22 people have died on space missions. In the two space shuttle disasters alone, 14 people died. However, space exploration and research have led to many great discoveries and new technologies. Do you think sending people into space is worth the risk? Why or why not?
- In the past several years, private companies have been developing vehicles and launch systems that can take people into space.
- What applications can you think of for such vehicles? What advantages and disadvantages are there to private companies building and launching spacecraft?

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Chapter 24

Earth, Moon, and Sun

24.1 Planet Earth

Lesson Objectives

- Recognize that Earth is a sphere, and describe the evidence for this conclusion.
- Describe what gravity is, and how it affects Earth in the solar system.
- Explain what causes Earth's magnetism, and the effects that magnetism has on the Earth.

Introduction

The Earth and Moon revolve around each other as they orbit the Sun. As planet Earth rotates and revolves, we experience cycles of day and night as well as seasons. Earth has a very large moon for an inner planet. We are the only inner planet that does, so how did the Moon form and what is the surface of the Moon like? We revolve around an average, ordinary star, the Sun. It does not look like any of the other stars we see in the sky. What can we discover about our amazing Sun?

Earth's Shape, Size, and Mass

Every day you walk across some part of Earth's surface, whether that surface is your yard or the sidewalks by your school. For most of us, a walk outside means walking on fairly flat ground. We don't usually stop and realize that the Earth is a **sphere**, an object similar in shape to a ball. How do we know that Earth is a sphere? How could you convince someone that even though the surfaces we walk on look flat, the Earth as a whole is round?

One of the most convincing pieces of evidence for a spherical Earth are the pictures we have of it from Space. Astronauts aboard the Apollo 17 shuttle took one of the most famous photographs in history, called "The Blue Marble" (**Figure** 24.1). This outstanding image shows Earth as it looks from about 29,000 kilometers (18,000 miles) away in Space. The picture shows us that Earth is spherical and looks like a giant blue and white ball. Hundreds of years before humans ever made it into space, we knew the Earth was round. What ways have you been able to see this for yourself?

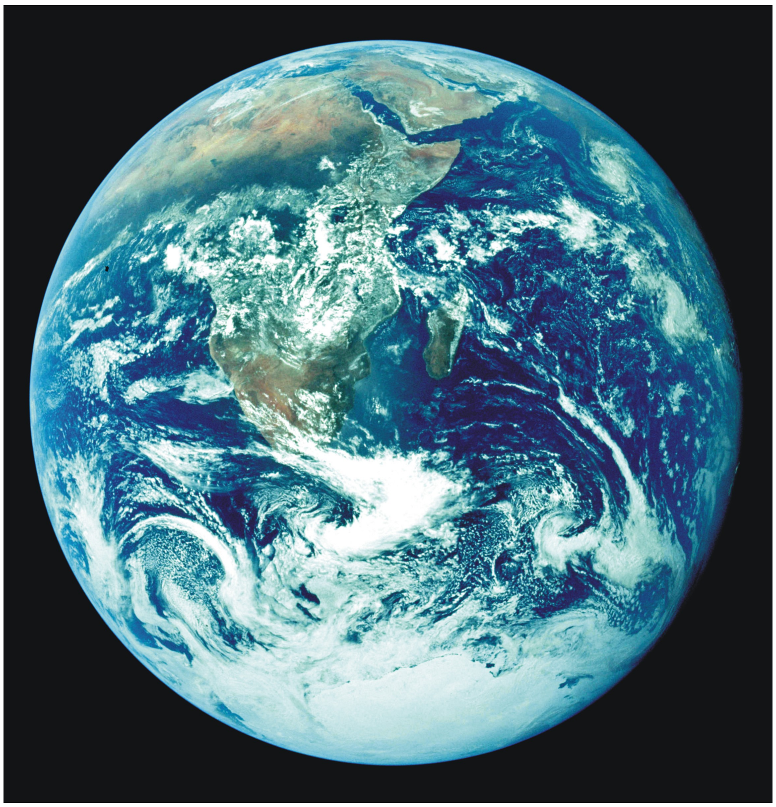

Figure 24.1: Photograph entitled "The Blue Marble" taken by Apollo 17 Crew. (15)

The Sun and the other planets of our Solar System are also spheres. The Sun is found in the center of the solar system, and the planets travel around the Sun in regular paths called **orbits**. Earth is the third planet from the Sun, and its mass is approximately 6.0 x 10^{24} kilograms. In contrast, the volume of planet Jupiter is about 1,000 times greater than Earth's volume, and the Sun's volume is about 1,000 times greater than Jupiter's (**Figure** 24.2).

While the outer planets in the Solar System are giant balls of swirling gas with very low densities, Earth is an inner planet. The inner planets are relatively small, denser, rockier planets than the outer planets. Three-fourths of Earth's rocky surface is covered with water. As far as we know, Earth is also the only planet that carries liquid water, another important requirement for life. The entire planet is also surrounded by a thin layer of air called the

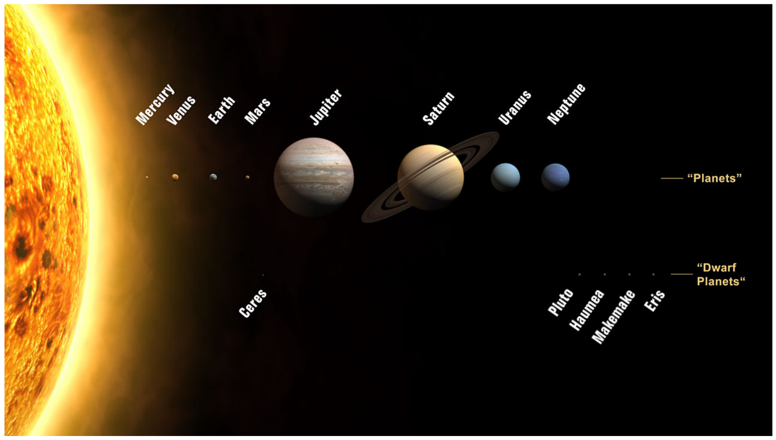

Figure 24.2: Planets and dwarf planets of the solar system. (2)

atmosphere. Earth's atmosphere is unique in the solar system in that it contains just the right amount of oxygen to support animal life. Therefore, Earth is the only planet in the solar system on which life is found. The 'Our Solar System' chapter will discuss the features of other planets in more detail.

When describing Earth, it's useful to name and define the many components of our planet. Since Earth is a sphere, the layers that make it up are also referred to as spheres (**Figure** 24.3).

They are:

- **Atmosphere**—the thin layer of air that surrounds the Earth.
- **Hydrosphere**–the part of Earth's surface that consists of water.
- **Biosphere**—the part of the Earth that supports life. The biosphere includes all the areas where life is found.
- **Lithosphere**–the solid part of Earth. The lithosphere consists of mountains, valleys, continents and all of the land beneath the oceans. Only one-fourth of Earth's surface is land, but solid rock makes up more than 99% of Earth's total mass.

Earth's layers all come into contact with each other and interact. Therefore, Earth's surface is constantly undergoing change.

Earth's Gravity

We know that the Earth orbits the Sun in a regular path (**Figure** 24.4). The Earth's Moon also orbits the Earth in a regular path. **Gravity** is the force of attraction between all objects. Gravity keeps the Earth and Moon in their orbits. Isaac Newton was one of the first scientists to explore the idea of gravity. He understood that the Moon can only circle the Earth because some force is pulling the Moon toward Earth's center. Otherwise, the Moon would continue moving in a straight line off into space. Newton also came to understand

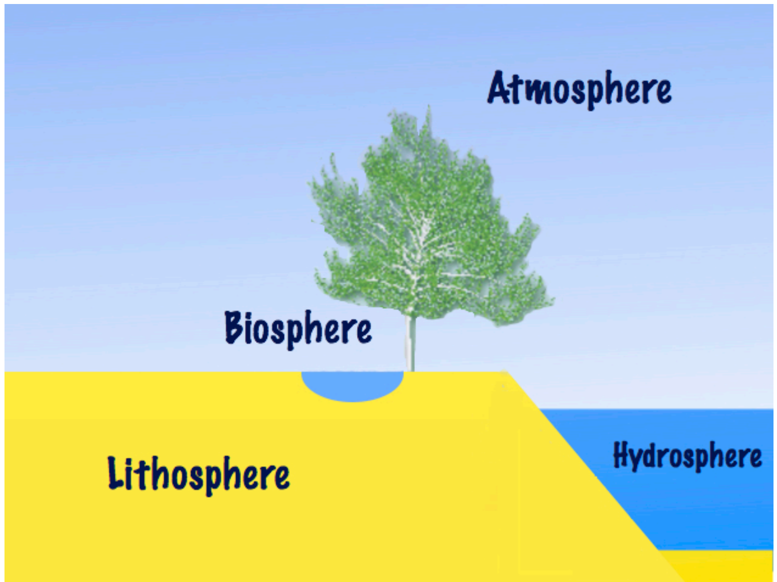

Figure 24.3: Earth has a hydrosphere, lithosphere, atmosphere, and biosphere. (6)

that the same force that keeps the Moon in its orbit is the same force that causes objects on Earth to fall to the ground.

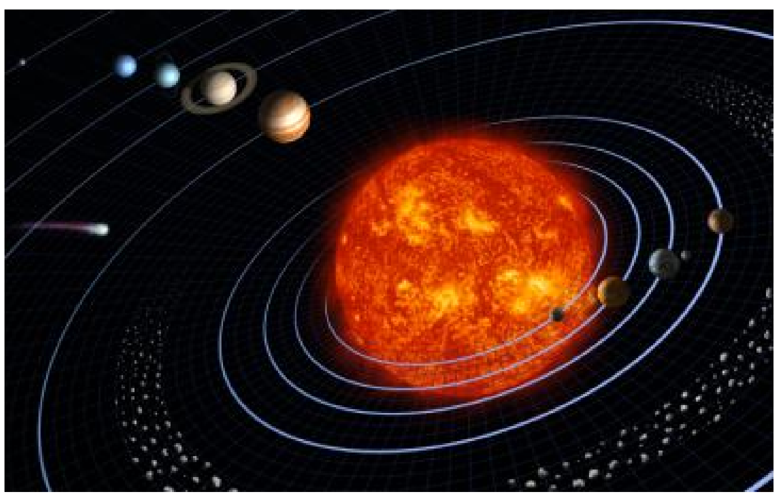

Figure 24.4: The planets orbit the Sun in regular paths. (21)

Newton defined the Universal Law of Gravitation, which states that a force of attraction, called gravity, exists between all objects in the universe (**Figure** 24.5). The strength of the gravitational force depends on how much mass the objects have and how far apart they are from each other. The greater the objects' mass, the greater the force of attraction; in addition, the greater the distance between the objects, the smaller the force of attraction.

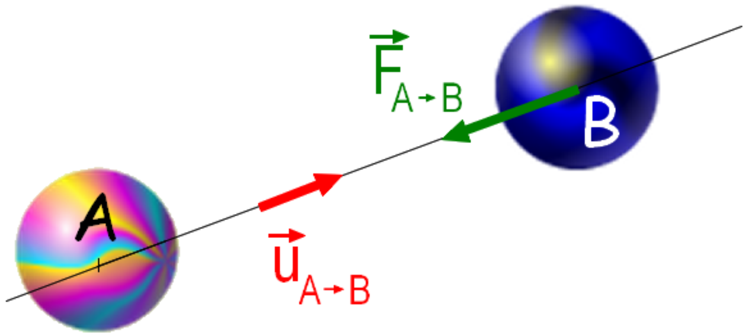

Figure 24.5: The force of gravity exists between all objects in the universe; the strength of the force depends on the mass of the objects and the distance between them. (20)

Earth's Magnetism

Earth has a **magnetic field** (**Figure** 24.6). It may be helpful to imagine that the Earth has a gigantic bar magnet inside of it. A bar magnet has a north and south pole and a magnetic field that extends around it. Earth's magnetic field also has a north and south pole and a magnetic field that surrounds it. Scientists believe Earth's magnetic field arises from the movements of molten metals deep inside Earth's outer liquid iron core. Iron and nickel flow within the Earth's core, and their movement generates Earth's magnetic field. Earth's magnetic field extends several thousand kilometers into space.

Earth's magnetic field serves an important role. It shields the planet from harmful types of radiation from the Sun (**Figure** 24.7). If you have a large bar magnet, you can tie a string to it, hang it from the string, and then watch as it aligns itself in a north-south direction, in response to Earth's magnetic field. This concept allows a compass to work, so that people can navigate by finding magnetic north (**Figure** 24.8).

Lesson Summary

- The Earth and other planets in our solar system are rotating spheres, that also revolve around the Sun in fixed paths called orbits.
- The inner four planets are small, dense rocky planets like Earth. The next four planets are large, gaseous planets like Jupiter.
- The balance between gravity and our motion around the Sun, keep the planets in orbit at fixed distances from the Sun.
- Earth has a magnetic field, created by motion within Earth's outer, liquid iron core that shields us from harmful radiation.

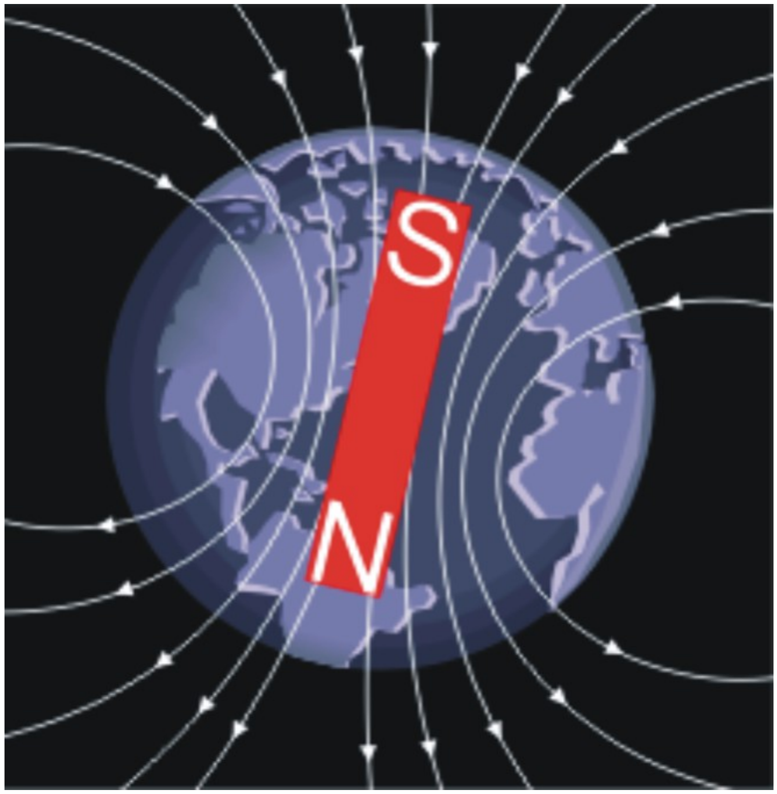

Figure 24.6: Earth's Magnetic Field (25)

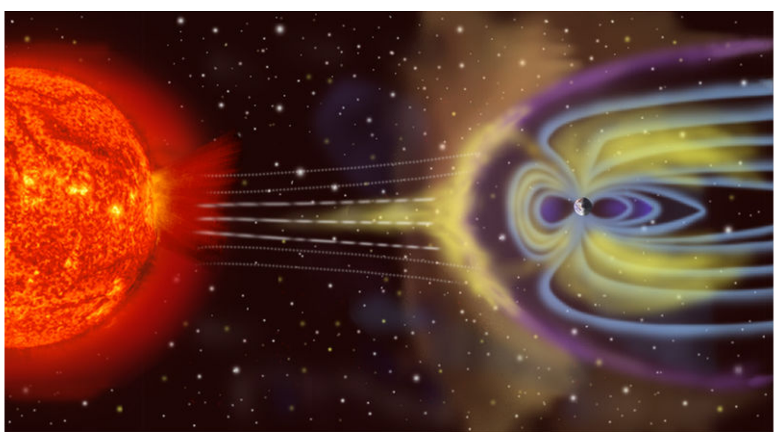

Figure 24.7: Earth's magnetic field protects the Earth from radiation from the sun; Earth, on the right, is tiny by comparison to the Sun. (16)

Figure 24.8: A compass; one end of the needle is pointing to the north. (11)

Review Questions

1. When you watch a tall ship sail over the horizon of the Earth, you see the bottom part of it disappear faster than the top part. With what you have learned about the shape of the Earth, describe why this happens.
2. What are two reasons that Earth is able to support life?
3. The planet Jupiter is gaseous and lacks a solid surface. How does this compare to Earth?
4. Give one example of how Earth's lithosphere and hydrosphere can interact, and can exchange material.
5. How do mass and distance influence the force of gravity?
6. Why are we able to use magnets to determine north-south directions on Earth?

Vocabulary

atmosphere The thin layer of air that surrounds the Earth.

biosphere All parts of the Earth that supports life.

gravity An attractive force that exists between all objects in the universe; gravity is responsible for planets orbiting the Sun, and for moons orbiting those planets.

hydrosphere The layer of Earth consisting of water.

lithosphere The solid layer of Earth, made of rock.

magnetic field A region of space surrounding an object, in which an attractive magnetic force can be detected.

orbit The path of an object, such as a planet or moon, around a larger object such as the Sun.

sphere An object similar in shape to a ball.

Points to Consider

- What would other planets need to have if they were able to support life?
- Would life on Earth be impacted if Earth lost its magnetic field?
- Could a large gas planet like Jupiter or Saturn support life?

24.2 Earth's Motions

Lesson Objectives

- Describe Earth's rotation on its axis.
- Describe Earth's revolution around the Sun.

Introduction

Imagine a line passing through the center of Earth that goes through both the North Pole and the South Pole. This imaginary line is called an *axis*. Earth spins around its axis, just as a top spins around its spindle. This spinning movement is called Earth's **rotation**. At the same time that the Earth spins on its axis, it also orbits, or revolves around the Sun. This movement is called **revolution**.

Earth's Rotation

In 1851, a French scientist named Léon Foucault took an iron sphere and swung it from a wire. He pulled the sphere to one side and then released it, letting it swing back and forth in a straight line. A ball swinging back and forth on a string is called a pendulum. A pendulum set in motion, will not change its motion, so it will not change the direction of the swinging. However, Foucault observed that his pendulum did seem to change direction. He knew that

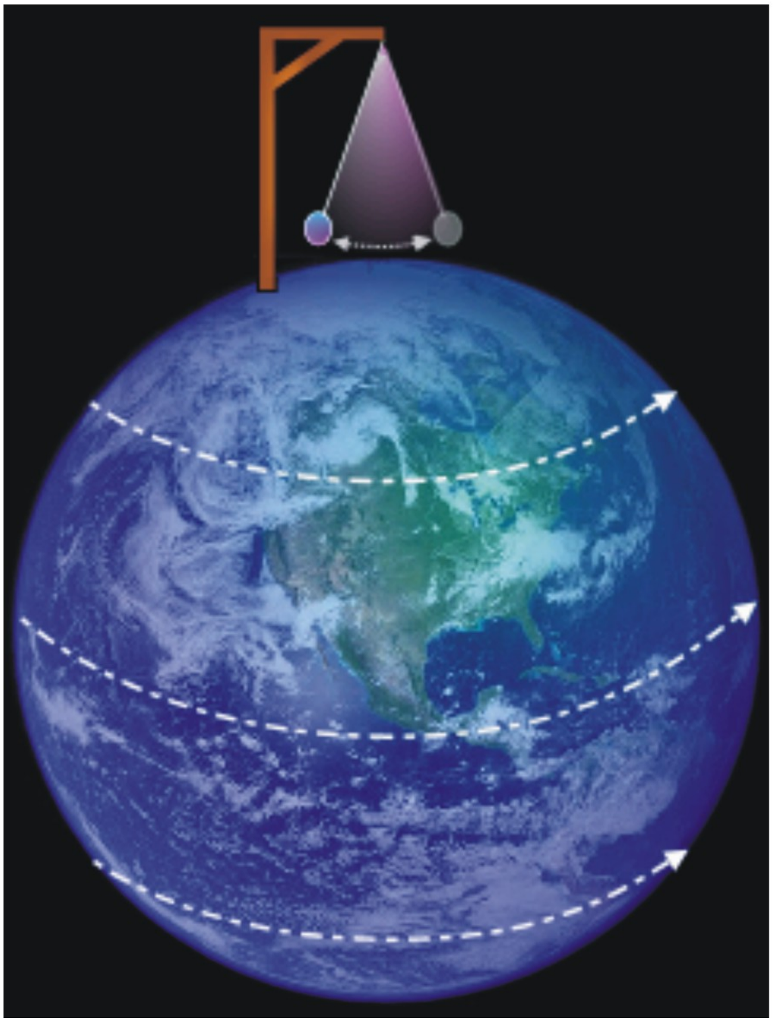

Figure 24.9: Imagine a pendulum at the North Pole. The pendulum always swings in the same direction but because of Earth's rotation; its direction will appear to change to observers on Earth. (14)

the pendulum itself could not change its motion, so he concluded that the Earth, underneath the pendulum was moving. **Figure** 24.9 shows how this might look.

It takes 23 hours, 59 minutes and 4 seconds for the Earth to make one complete rotation on its axis, if we watch Earth spin from out in space. Because Earth is moving around the Sun at the same time that it is rotating, Earth has to turn just a little bit more to reach the same place relative to the Sun, so we experience each day on Earth as 24 hours. At the equator, the Earth rotates at a speed of about 1,700 kilometers per hour. Thankfully, we do not notice this movement, because it would certainly make us dizzy.

Earth's Revolution

Earth's revolution around the Sun takes much longer than its rotation on its axis. One complete revolution takes 365.24 days, or one year. The Earth revolves around the Sun because gravity keeps it in a roughly circular orbit around the Sun. The Earth's orbital path is not a perfect circle, but rather an ellipse, which means that it is like a slight oval in shape (**Figure** 24.10). This creates areas where the Earth is sometimes farther away from the Sun than at other times. We are closer to the Sun at perihelion (147 million kilometers) on about January 3rd and a little further from the Sun (152 million kilometers) at aphelion on July 4th. Students sometimes think our elliptical orbit causes Earth's seasons, but this is not the case. If it were, then the Northern Hemisphere would experience summer in January!

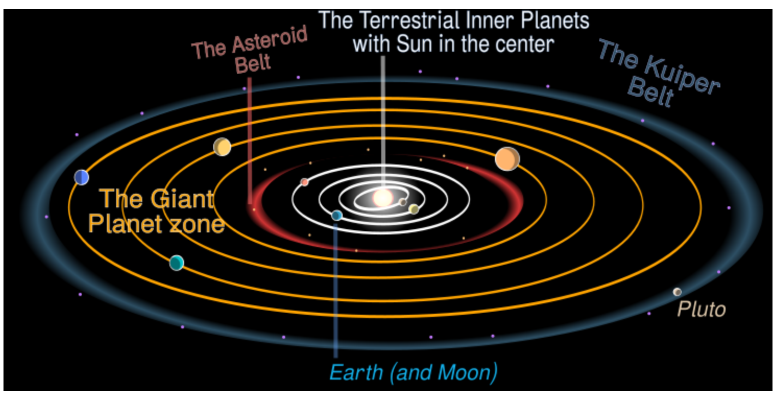

Figure 24.10: Earth and the other planets in the solar system make regular orbits around the Sun; the orbital path is an ellipse and is controlled by gravity. (8)

During one revolution around the Sun, the Earth travels at an average distance of about 150 million kilometers. Mercury and Venus take shorter times to orbit the Sun than the Earth, while all the other planets take progressively longer times depending on their distance from the Sun. Mercury only takes about 88 Earth days to make one trip around the Sun. While Saturn, for example, takes more than 29 Earth years to make one revolution around the Sun.

Earth revolves around the Sun at an average speed of about 27 kilometers (17 miles) per second. Our planet moves slower when it is farther away from the Sun and faster when it is closer to the Sun. The reason the Earth (or any planet) has seasons is that Earth is tilted

23 1/2 ° on its axis. This means that during the Northern **hemisphere** summer the North pole points toward the Sun, and in the Northern hemisphere winter the North Pole is tilted away from the Sun (**Figure** 24.11). The season we experience depends on where the Earth is in its revolutionary orbit around the Sun.

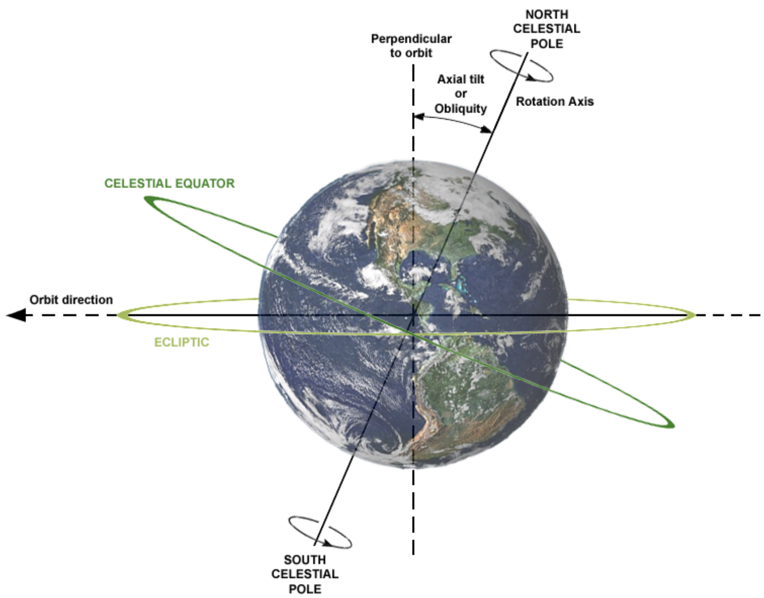

Figure 24.11: The Earth tilts on its axis. (4)

Lesson Summary

- Earth rotates or spins on its axis once each day and revolves around the Sun once every year.
- The tilt of Earth's axis produces seasons.

Review Questions

1. Describe the difference between Earth's rotation and its revolution.
2. What is the force that keeps the Earth and other planets in their orbital paths?
3. The planet Jupiter is about 778,570,000 kilometers from the Sun; Earth is about 150,000,000 kilometers from the Sun. Does Jupiter take more or less time to make one revolution around the sun? Explain your answer.
4. In its elliptical orbit around the Sun, the Earth is closest to the Sun in January. Even though Earth is closest to the Sun in January, people in the Northern hemisphere experience winter weather. Using your understanding of how the Earth is tilted on its axis, why do you think people in the Northern Hemisphere have winter in January?
5. Where on Earth would Foucault's pendulum appear to not be moving? Why?

Vocabulary

axis An imaginary line that runs from the North Pole to South Pole, and includes the center Earth.

ellipse A shape that looks like a slightly squashed circle.

hemisphere One half of a sphere.

revolution The Earth's movement around the Sun in an orbital path.

rotation The motion of the Earth spinning on its axis.

Points to Consider

- What type of experiment could you create to prove that the Earth is rotating on its axis?
- If you lived at the equator, would you experience any effects due to Earth's tilted axis?
- If Earth suddenly increased in mass, what might happen to its orbit around the Sun?

24.3 Earth's Moon

Lesson Objectives

- Explain how scientists believe the Moon formed.
- Describe the features of the Moon.

Introduction

On July 20, 1969 hundreds of millions of people all over the world excitedly sat in front of their televisions and witnessed something that had never happened before in the history of the world. On that day, two American astronauts named Neil Armstrong and Edwin "Buzz" Aldrin landed the *Eagle* on the surface of the Moon (**Figure** 24.12). Neil Armstrong was the commander of the mission, and he was the first human to ever step foot on the Moon. No other place in space, besides Earth, has been touched by humans. Even today, the Moon remains the only other body in space that humans have visited.

Between 1969 and 1972, six piloted spaceships were sent to land on the Moon. They are often referred to as **lunar** expeditions, the word lunar meaning "related to the Moon." On some missions, the astronauts brought back soil and rock samples from the Moon. Once back at Earth, the samples were studied to help scientists learn about the surface features of the Moon. No astronauts have visited the Moon since 1972, but in 2004 the United States President George W. Bush called for a return to Moon exploration by the year 2020. Maybe you can be one of the astronauts to return to the Moon!

This lesson focuses on how the Moon was formed and gives a description of the features and characteristics of the Moon—many of which were investigated and discovered during the major years of lunar exploration in the 1960s and 1970s.

Figure 24.12: Astronaut Buzz Aldrin walks on the Moon on July 20, 1969. (17)

How the Moon Formed

Astronomers have carried out computer simulations showing that the collision of a Mars-sized object with the Earth could have resulted in the formation of the Moon. Additional data shows that the surface of the Moon dates to about 4.5 billion years ago, suggesting that the collision occurred during the heavy bombardment period, about 70 million years after the Earth formed. The Moon also has a relatively small core and appears to be largely comprised of the same basalt material found in the Earth mantle. Such a collision would have been incredibly powerful, producing oceans of liquid magma over much of the surface of the Earth.

The explosive impact that likely led to the formation of the Moon would have produced a huge amount of energy, leaving the surface of the Moon in an initially **molten** state. This means that its surface would have been hot and fluid, like magma inside the Earth today. The magma eventually cooled and hardened so that the Moon now has a solid surface.

Lunar Characteristics

The Moon is Earth's only natural satellite. A **satellite** is a body that moves around a larger body in space. The Moon orbits Earth in the same way that the Earth orbits the Sun, and the Moon remains close to Earth because of the strength of Earth's gravity. The Moon is 3,476 kilometers in diameter, about one-fourth the size of Earth. Because the Moon is not as dense as the Earth, gravity on the Moon is only one-sixth as strong as it is on Earth. You could jump six times as high on the Moon as you can on Earth.

If you watch the Earth and the Moon from space, the Moon makes one complete orbit around the Earth every 27.3 days. The Moon also rotates on its axis once every 27.3 days. Thus, the same side of the Moon always faces Earth. This means from Earth we always see the same side of the Moon. The side of the Moon that faces Earth is called the near side (**Figure** 24.13). The side of the Moon that faces away from Earth is called the far side (**Figure** 24.14). The Moon makes no light of its own, but instead only reflects light from the Sun.

The Lunar Surface

The Moon has no atmosphere. The average surface temperature during the day is approximately 225°F and can reach temperatures as high as 253°F. At night the average temperature drops to -243°F and has been measured as low as -397°F. These extremely cold temperatures occur in craters in the permanently shaded south polar basin and are amongst the coldest temperatures recorded in our entire solar system.

There are no lakes, rivers, or even small puddles anywhere to be found on the Moon's surface. (However, it should be noted that in 2009, NASA scientists believe they discovered that in the top few millimeters of the Moon's surface, there is a large number of water molecules mixed in with dirt and rocks — you can stay up-to-date with their latest findings at `http://www.nasa.gov`). Yet, despite the possible presence of water, with a lack of atmosphere and extreme temperatures, it comes as no surprise to scientists that there has been zero evidence of life naturally occurring on the Moon.

Although there are no "naturally occurring" signs of life on the Moon, there are signs that life has encountered the Moon — that is, there are footprints of astronauts on the Moon's surface. It's likely that these footprints will remain unchanged for thousands of years, because

Figure 24.13: The near side of the Moon, the one that we see, has a thinner crust with many more maria. (1)

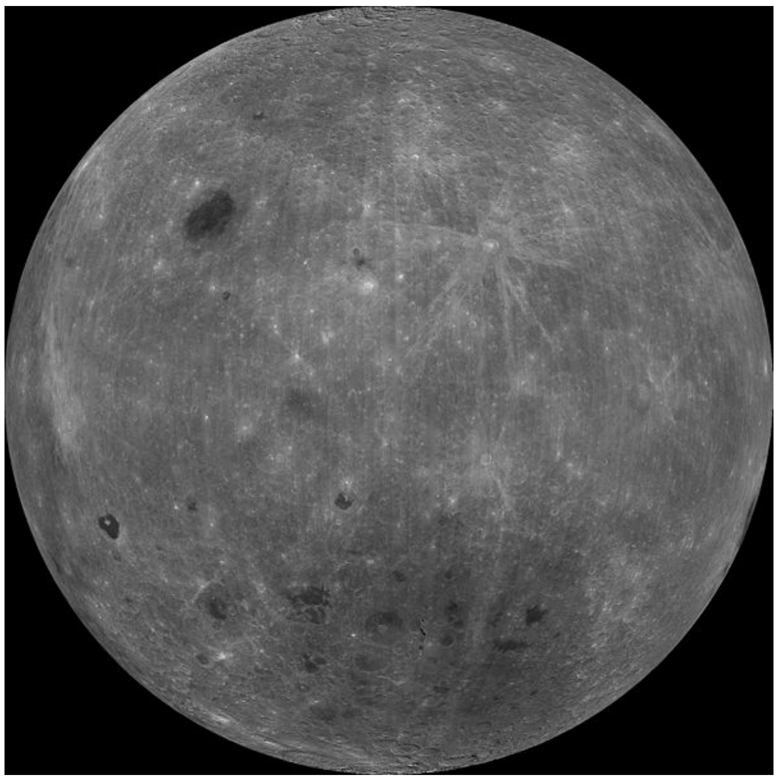

Figure 24.14: The far side of the Moon has a thicker crust and far fewer maria. (7)

there is no wind, rain, or living thing to disturb them. Only a falling **meteorite** or other matter from space could destroy them. A meteorite is a piece of rock that reaches the Moon from space. Meteorites also hit the Earth sometimes.

Earth has mountains, valleys, plains and hills. This combination of all of the surface features of an area of land is called a **landscape**. The landscape of the Moon is very different from that of Earth. The lunar landscape is covered by **craters** caused by the impacts of asteroids and meteorites that crashed into the Moon from space (**Figure** 24.15). The craters are bowl-shaped basins on the Moon's surface. Because the Moon has no water, wind, or weather the craters remain unchanged. If Earth did not have plate tectonics, which continually alters the planet's surface, or an atmosphere, which makes erosion possible, our planet's surface would be at least as covered with meteorite craters as the Moon's. The surfaces of many other moons orbiting other planets have been shaped by asteroid impacts.

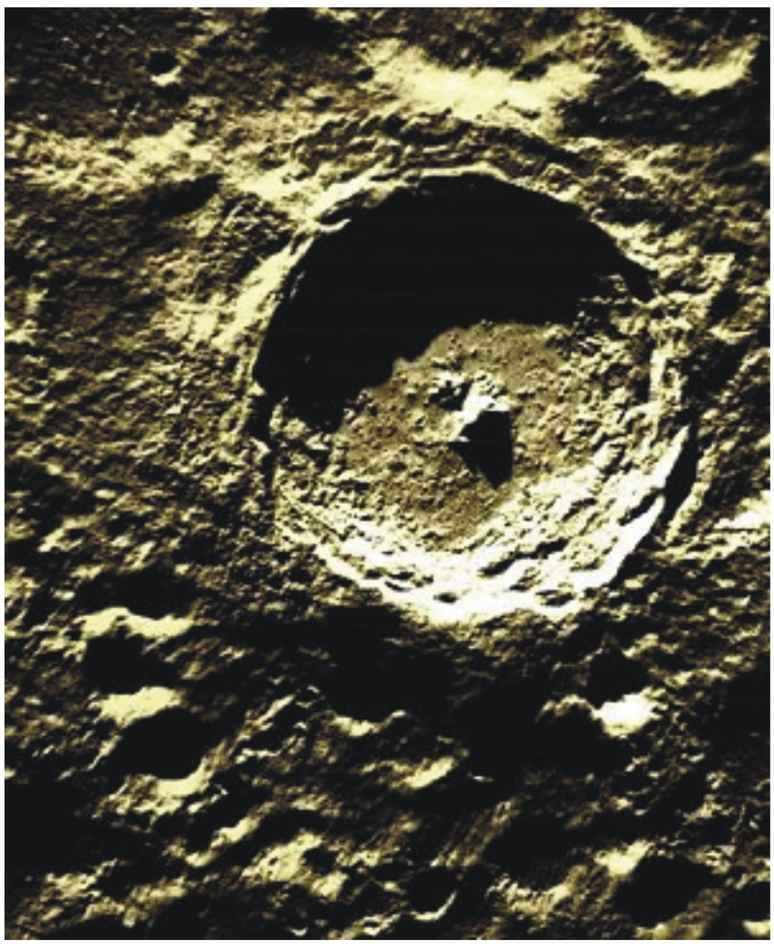

Figure 24.15: A crater on the surface of the Moon. (5)

When you look at the Moon from Earth you notice dark areas and light areas. The dark areas are called **maria**. They are solid, flat areas of basaltic lava. From about 3.0 to 3.5 billion years ago the Moon was continually bombarded by meteorites. Some of these meteorites were so large that they broke through the Moon's newly formed surface, then magma flowed out and filling the craters. Scientists estimate volcanic activity on the Moon ceased about 1.2 billion years ago.

The lighter parts are the Moon is called **terrae** or highlands (**Figure** 24.16). They are higher than the maria and include several high mountain ranges. They are believed to be the rims of ancient impact craters.

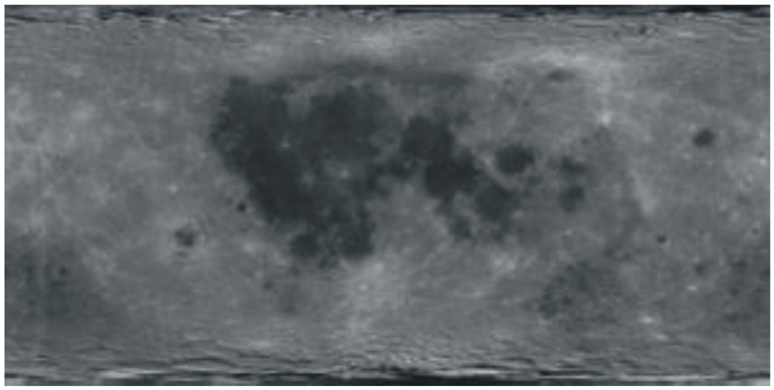

Figure 24.16: A close-up of the Moon, showing maria (the dark areas) and terrae (the light areas); maria covers around 16% of the Moon's surface, mostly on the side of the Moon we see. (12)

Interior of the Moon

Like the Earth, the Moon has a distinct crust, mantle, and core. The crust is composed of igneous rock rich in the elements oxygen, silicon, magnesium, and aluminum. The Moon's crust is about 60 kilometers thick on the near side of the Moon and about 100 kilometers thick on the far side. The mantle is composed of the minerals olivine and orthopyroxene. Analysis of Moon rocks indicates that there may also be high levels of iron and titanium in the lunar mantle. The Moon has a small core, perhaps 600 to 800 kilometers in diameter. The composition of the Moon's core is not known, but it is probably made mostly of iron with some sulfur and nickel. This information is gathered both from rock samples gathered by astronauts and from unpiloted spacecraft sent to the Moon.

Lesson Summary

- Many scientists believe the Moon formed when a Mars sized planet collided with Earth.
- The Moon makes one rotation on its axis in the same number of days it takes for it to orbit the Earth.

- The Moon has dark areas, called maria surrounded by lighter colored highland areas, called terrae.
- Because the Moon is geologically inactive and doesn't have an atmosphere, it has many thousands of craters on its surface.
- The Moon is made of many materials similar to Earth and has a crust, mantle and core, just like the Earth.

Review Questions

1. What is one piece of evidence that supports the idea that the Moon was formed by materials that were once part of the Earth?
2. Why is there no weather on the Moon?
3. Rusting is a process that happens when oxygen reacts chemically with iron, in the presence of water. Can rusting occur on the Moon? Explain your answer.
4. What is the difference between maria and terrea?
5. How much do landscape features on the Moon change over time compared to landscape features on Earth? Explain your answer.
6. Why is the force of gravity on your body weaker on the Moon than on the Earth?

Vocabulary

craters Bowl-shaped depressions on the surface of the Moon caused by impact from meteorites.

giant impact hypothesis The idea that the Moon was formed when a planet sized object from space collided with the Earth about 4.5 billion years ago and sent trillions of tons of material into Earth's orbit; the material eventually came together and formed the Moon.

landscape The surface features of an area.

lunar Related to the Moon.

maria The dark parts of the Moon's surface, made up of ancient basaltic eruptions.

meteorites Pieces of rock that hit the Moon, Earth, or another planet from space.

satellite A body that orbits a larger body in space.

terrae The light parts of the Moon's surface, composed of high crater rims.

Points to Consider

- What things would be different on Earth if Earth did not have a moon?
- If the Moon rotated on its axis once every 14 days, would we see anything different than we do now?
- How do we know that the Moon has been geologically inactive for billions of years?

24.4 The Sun

Lesson Objectives

- Describe the layers of the Sun.
- Describe the surface features of the Sun.

Introduction

Consider the Earth, the Moon, and all the other planets in our solar system. Think about the mass that all those objects must have when they are all added together. Added all together, however, they account for only 0.2% of the total mass of the solar system. The Sun makes up the remaining 99.8% of all the mass in the solar system (**Figure** 24.17)! The Sun is the center of the solar system and the largest object in the solar system. Our Sun is a star that provides light and heat and supports almost all life on Earth.

In this lesson you will learn about the features of the Sun. We will discuss the composition of the Sun, its atmosphere, and some of its surface features.

Layers of the Sun

The Sun is a sphere, but unlike the Earth and the Moon, is not solid. Most atoms in the Sun exist as **plasma**, or a fourth state of matter made up of superheated gas with an electrical charge. Our Sun consists almost entirely of the elements hydrogen and helium. Because the Sun is not solid, it does not have a defined outer boundary. It does, however, have a definite internal structure. There are several identifiable layers of the Sun:

The **core** is the innermost or central layer of the Sun. The core is plasma, but moves similarly to a gas. Its temperature is around 27 million degrees Celsius. In the core, nuclear reactions combine hydrogen atoms to form helium, releasing vast amounts of energy in the process. The energy released then begins to move outward, towards the outer layers of the Sun.

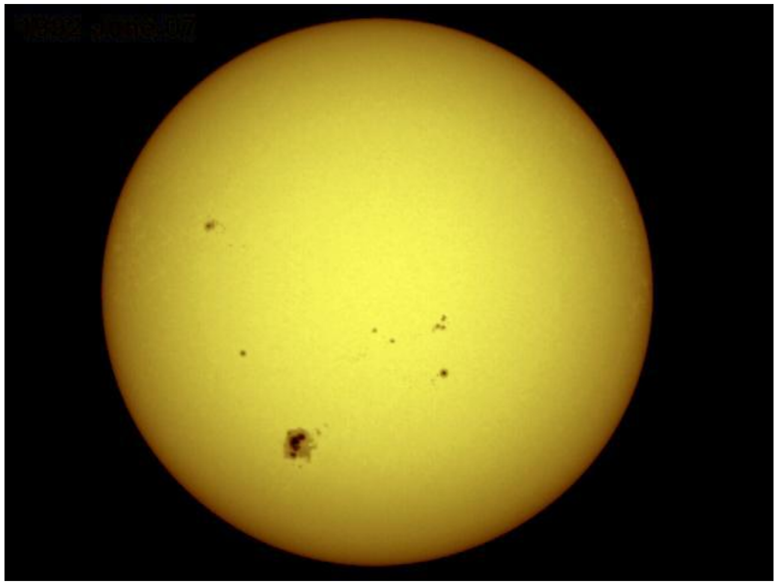

Figure 24.17: The Sun. (9)

The **radiative zone** is just outside the core, which has a temperature of about 7 million degrees Celsius.The energy released in the core travels extremely slowly through the radiative zone. Particles of light called photons can only travel a few millimeters before they hit another particle in the Sun, are absorbed and then released again. It can take a photon as long as 50 million years to travel all the way through the radiative zone.

The **convection zone** surrounds the radiative zone. In the convection zone, hot material from near the Sun's center rises, cools at the surface, and then plunges back downward to receive more heat from the radiative zone. This movement helps to create solar flares and sunspots, which we'll learn more about in a bit. These first three layers make up what we would actually call 'the Sun'. The next three layers make up the Sun's atmosphere. Of course, there are no solid layers to any part of the Sun, so these boundaries are fuzzy and indistinct.

The Sun's 'Atmosphere'

The **photosphere** is the visible surface of the Sun (**Figure** 24.18). This is the region of the Sun that emits sunlight. It's also one of the coolest layers of the Sun — only about 6700 °C. Looking at a photograph of the Sun's surface, you can see that it has several different colors; oranges, yellow and reds, giving it a grainy appearance. We cannot see this when we glance quickly at the Sun. Our eyes can't focus that quickly and the Sun is too bright for us to look at for more than a brief moment. Looking at the Sun for any length of time can cause blindness, so don't try it! Sunlight is emitted from the Sun's photosphere. A fraction of the light that travels from the Sun reaches Earth.

It travels as light in a range of wavelengths, including visible light, ultraviolet and infrared radiation. Visible light is all the light we can see with our eyes. We can't see ultraviolet and infrared radiation, but their effects can still be detected. For example, a sunburn is caused by ultraviolet radiation when you spend too much time in the Sun.

The **chromosphere** is the zone about 2,000 kilometers thick that lies directly above the photosphere. The chromosphere is a thin region of the Sun's atmosphere that glows red as it is heated by energy from the photosphere. Temperatures in the chromosphere range from about 4000°C to about 10,000°C. Jets of gas fire up through the chromosphere at speeds up to 72,000 kilometers per hour, reaching heights as high as 10,000 kilometers.

The **corona** is the outermost layer of the Sun and is the outermost part of its atmosphere. It is the Sun's halo or 'crown.' It has a temperature of 2 to 5 million degrees Celsius and is much hotter than the visible surface of the Sun, or photosphere. The corona extends millions of kilometers into space. If you ever have the chance to see a total solar eclipse, you will be able to see the Sun's corona, shining out into space.

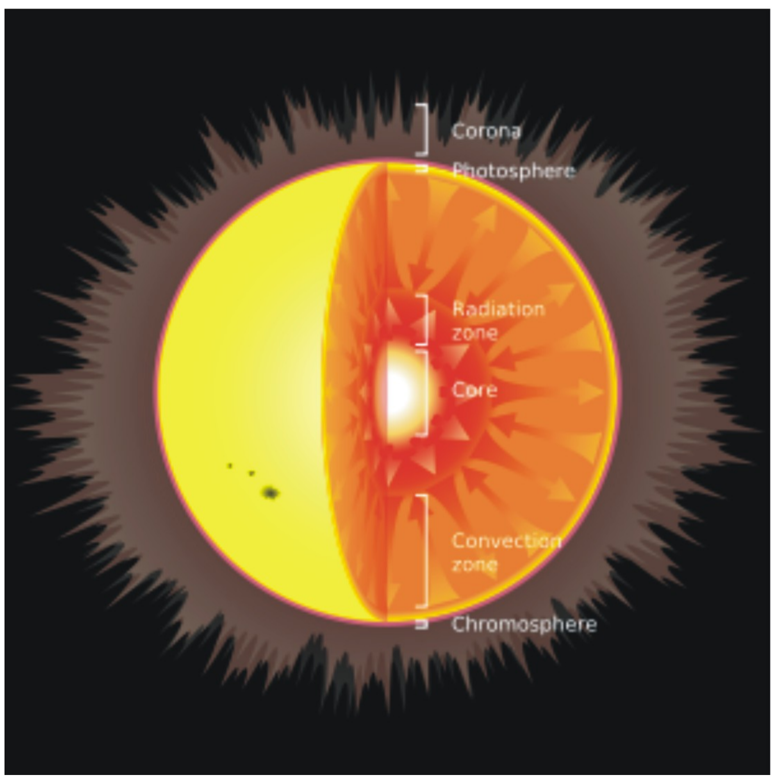

Figure 24.18: The layers of the Sun. (10)

In the Sun's core, **nuclear fusion** reactions generate energy by converting hydrogen to helium. Fusion is a process where the nuclei of atoms join together to form a heavier chemical element. Fusion reactions in the Sun's core produce energy, which we experience as heat and light. The rest of the Sun is heated by movement of heat energy outward from the core. Light energy from the Sun is emitted from the photosphere. It travels through space, and some of it reaches the Earth. The Sun is the source of almost all the energy on Earth and sunlight powers photosynthesis, as well as warming and illuminating our Earth.

Surface Features of the Sun

The most noticeable surface feature of the Sun is the presence of **sunspots**, which are cooler, darker areas on the Sun's surface (**Figure** 24.19). Sunspots are only visible with special light-filtering lenses. They exhibit intense magnetic activity. These areas are cooler and darker because loops of the Sun's magnetic field break through the surface and disrupt the smooth transfer of heat from lower layers. Sunspots usually occur in pairs. When a loop of the Sun's magnetic field breaks through the surface, it usually creates a sunspot both where it comes out and one where it goes back in again. Sunspots usually occur in 11 year cycles, beginning when the number of sunspots is at a minimum, increasing to a maximum number of sunspots and then gradually decreasing to a minimum number of sunspots again.

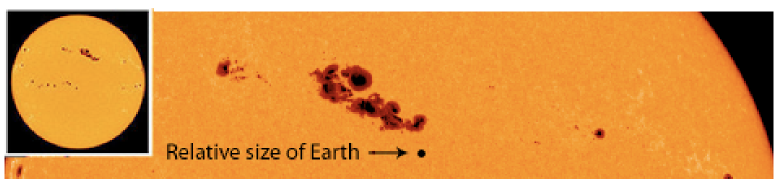

Figure 24.19: Sunspots. (18)

If a loop of the sun's magnetic field snaps and breaks, it creates **solar flares**, which are violent explosions that release huge amounts of energy (**Figure** 24.20). They release streams of highly energetic particles that make up the **solar wind**. The solar wind can be dangerous to spacecraft and astronauts. It sends out large amounts of radiation, which can harm the human body. Solar flares have knocked out entire power grids and can disturb radio, satellite and cell phone communications.

Another highly visible feature on the Sun are solar prominences. If plasma flows along a loop of the Sun's magnetic field from sunspot to sunspot, it forms a glowing arch that reaches thousands of kilometers into the Sun's atmosphere. Prominences can last for a day to several months. Prominences are also visible during a total solar eclipse.

A beautiful and mysterious effect of the Sun's electrically charged particles are auroras, which form around the polar regions high in Earth's atmosphere. Gases in Earth's atmosphere are excited by the electrically charged particles of the solar wind and glow producing curtains of light, which bend and change as you watch.

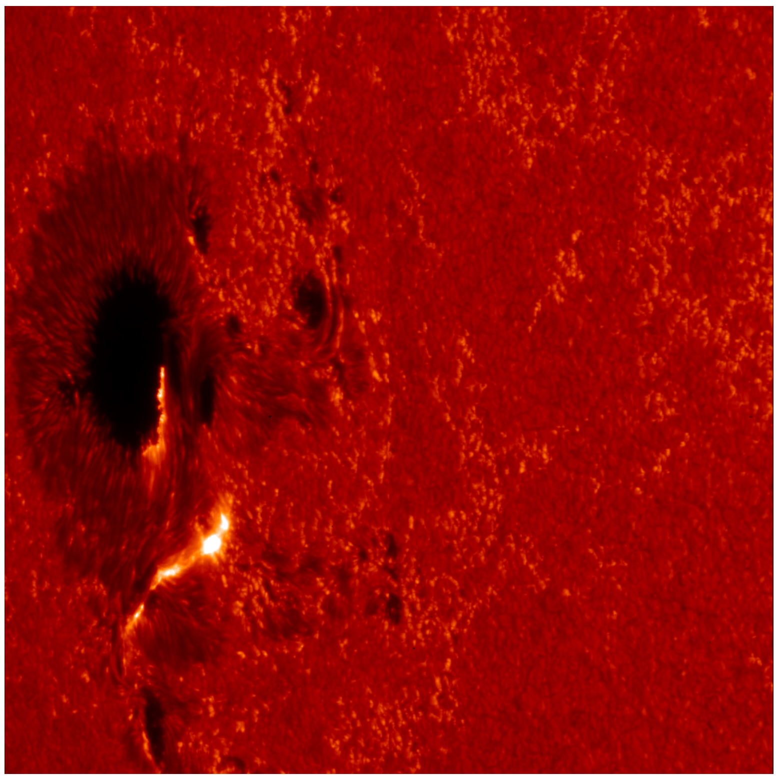

Figure 24.20: A Solar Flare. (22)

Lesson Summary

- The mass of the Sun is tremendous. It makes up 99.8% of the mass of our solar system.
- The Sun is mostly made of hydrogen with smaller amounts of helium in the form of plasma.
- The main part of the Sun has three layers: the core, the radiative zone and the convection zone.
- The Sun's atmosphere also has three layers: the photosphere, the chromosphere and the corona.
- Nuclear fusion of hydrogen in the core of the Sun produces tremendous amounts of energy that radiate out from the Sun.
- Some features of the Sun's surface include sunspots, solar flares, and prominences.

Review Questions

1. In what way does the Sun support all life on Earth?
2. Which two elements make up the Sun almost in entirety?
3. Which process is the source of heat in the Sun and where does it take place?
4. Some scientists would like to plan a trip to take humans to Mars. One of the things standing in the way of our ability to do this is solar wind. Why will we have to be concerned with solar wind?
5. Describe how movements in the convection zone contribute to solar flares.
6. Do you think fusion reactions in the Sun's core will continue forever and go on with no end? Explain your answer.

Vocabulary

chromosphere Thin layer of the Sun's atmosphere that lies directly above the Photosphere; glows red.

convection zone Layer of the Sun that surrounds the Radiative Zone; energy moves as flowing cells of gas.

core Innermost or central layer of the Sun.

corona Outermost layer of the Sun; a plasma that extends millions of kilometers into space.

nuclear fusion The merging together of the nuclei of atoms to form new, heavier chemical elements; huge amounts of nuclear energy are released in the process.

photosphere Layer of the Sun that we see; the visible surface of the Sun.

photosynthesis The process that green plants use to convert sunlight to energy.

plasma A high energy, high temperature form of matter. Electrons are removed from atoms, leaving each atom with an electrical charge.

radiation Electromagnetic energy; photons.

radiative zone Layer of the Sun immediately surrounding the core; energy moves atom to atom as electromagnetic waves.

solar flare A violent explosion on the Sun's surface.

solar wind A stream of radiation emitted by a solar flare. The solar wind extends millions of kilometers out into space and can even reach the Earth.

sunspots Cooler, darker areas on the Sun's surface that have lower temperatures than surrounding areas; sunspots usually occur in pairs.

Points to Consider

- If something were to suddenly cause nuclear fusion to stop in the Sun, how would we know?
- Are there any types of dangerous energy from the Sun? What might be affected by them?
- If the Sun is all made of gases like hydrogen and helium, how can it have layers?

Going Further - Applying Math

Have you ever wondered how to measure something that you cannot reach or touch? The answer is that you can use simple geometry. We can measure the diameter of the Sun, even though we cannot go to the Sun and even though the Sun is much too large for a human being to measure. We can do this using the rules of similar triangles. The sides of similar triangles are proportional to each other. By setting up one very small triangle that is proportional to another, very large triangle, we can find an unknown distance or measurement as long as we know three out of four of the parts of the equation. If you make a pinhole in an index card and project an image of the Sun onto a clipboard held 1 meter from the index card, the diameter of our projected image of the Sun will be proportional to the true diameter of the Sun. Here's the equation: $s / d = S / D$ where s = diameter of the projected image of the Sun, S = true diameter of the Sun. We also need to know the true distance between the Earth and the Sun, $D = 1.496 \times 10^{8}$ km and the distance (d

= 1 meter) between the clipboard and the index card. Before you can correctly solve this equation, you will need to change all of your measurements to the same unit - in this case, change all your measurements to km. Try this out and see how accurately you can measure the true diameter of the Sun.

24.5 The Sun and the Earth-Moon System

Lesson Objectives

- Describe how Earth's movements affect seasons and cause day and night.
- Explain solar and lunar eclipses.
- Describe the phases of the Moon and explain why they occur.
- Explain how movements of the Earth and Moon affect Earth's tides.

Introduction

The solar system is made up of the Sun, the planets that orbit the Sun, their satellites, dwarf planets and many, many small objects, like asteroids and comets. All of these objects move and we can see these movements. We notice the Sun rises in the eastern sky in the morning and sets in the western sky in the evening. We observe different stars in the sky at different times of the year. When ancient people made these observations, they imagined that the sky was actually moving while the Earth stood still. In 1543, Nicolaus Copernicus (**Figure** 24.21) proposed a radically different idea: the Earth and the other planets make regular revolutions around the Sun. He also suggested that the Earth rotates once a day on its axis. Copernicus' idea slowly gained acceptance and today we base our view of motions in the solar system on his work. We also now know that everything in the universe is moving.

In this lesson you will learn about how the movements of the Earth, Moon, and Sun affect different phenomena on Earth, including day and night, the seasons, tides, and phases of the Moon.

Positions and Movements

Earlier we discussed Earth's rotation and revolution. The Earth rotates once on its axis about every 24 hours. If you were to look at Earth from the North Pole, it would be spinning counterclockwise. As the Earth rotates, observers on Earth see the Sun moving across the sky from east to west with the beginning of each new day. We often say that the Sun is "rising" or "setting," but actually it is the Earth's rotation that gives us the perception of the Sun rising up or setting over the horizon. When we look at the Moon or the stars at night, they also seem to rise in the east and set in the west. Earth's rotation is

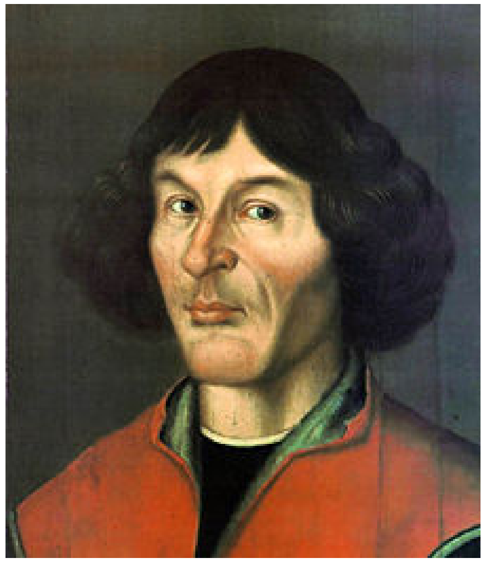

Figure 24.21: Nicholas Copernicus. (13)

also responsible for this. As Earth turns, the Moon and stars change position in our sky.

Earth's Day and Night

Another effect of Earth's rotation is that we have a cycle of daylight and darkness approximately every 24 hours. This is called a day. As Earth rotates, the side of Earth facing the Sun experiences daylight, and the opposite side (facing away from the Sun) experiences darkness or nighttime. Since the Earth completes one rotation in about 24 hours, this is the time it takes to complete one day-night cycle. As the Earth rotates, different places on Earth experience sunset and sunrise at a different time. As you move towards the poles, summer and winter days have different amounts of daylight hours in a day. For example, in the Northern hemisphere, we begin summer on June 21. At this point, the Earth's North Pole is pointed directly toward the Sun. Therefore, areas north of the equator experience longer days and shorter nights because the northern half of the Earth is pointed toward the Sun. Since the southern half of the Earth is pointed away from the Sun at that point, they have the opposite effect—longer nights and shorter days.

For people in the Northern hemisphere, winter begins on December 21. At this point, it is Earth's South Pole that is tilted toward the Sun, and so there are shorter days and longer nights for those who are north of the equator.

Earth's Seasons

It is a common *misconception* that summer is warm and winter and cold because the Sun is closer to Earth in the summer and farther away from it during the winter. Remember that seasons are caused by the 23 1/2 ° tilt of Earth's axis of rotation and Earth's yearly revolution around the Sun (**Figure** 24.22). This results in one part of the Earth being more directly exposed to rays from the Sun than the other part. The part tilted away from the Sun experiences a cool season, while the part tilted toward the Sun experiences a warm season. Seasons change as the Earth continues its revolution, causing the hemisphere tilted away from or towards the Sun to change accordingly. When it is winter in the Northern hemisphere, it is summer in the Southern hemisphere, and vice versa.

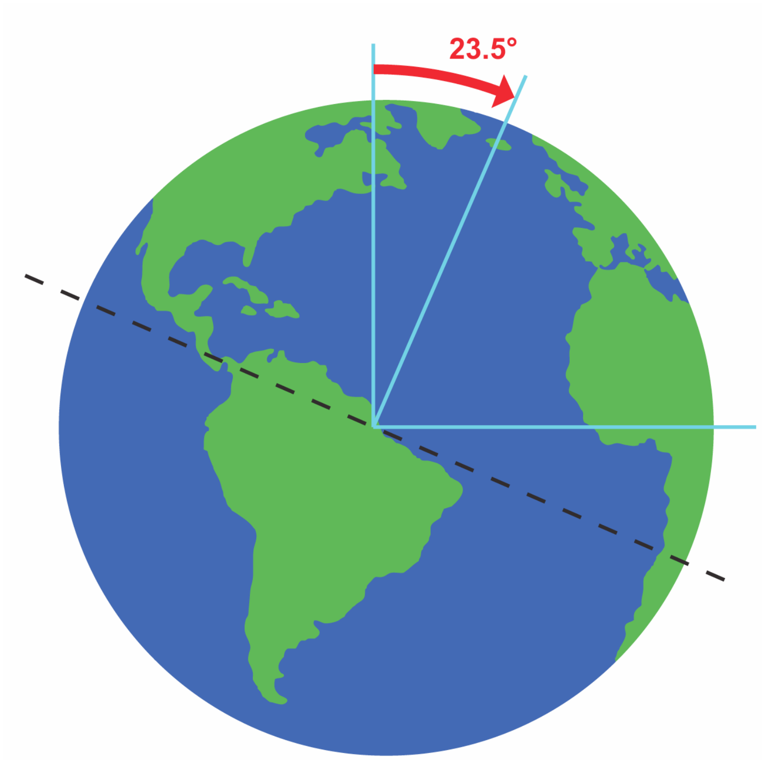

Figure 24.22: The Earth's tilt on its axis leads to one hemisphere facing the Sun more than the other hemisphere and gives rise to seasons. (19)

Solar Eclipses

A **solar eclipse** occurs when the new moon passes directly between the Earth and the Sun (**Figure** 24.23). This casts a shadow on the Earth and blocks our view of the Sun. A total solar eclipse occurs when the Moon's shadow completely blocks the Sun (**Figure** 24.24). When only a portion of the Sun is out of view, it is called a partial solar eclipse. Solar eclipses are rare events that usually only last a few minutes. That is because the Moon's shadow only covers a very small area on Earth and Earth is turning very rapidly. As the Sun is covered by the moon's shadow, it will actually get cooler outside. Birds may begin to sing, and stars will become visible in the sky. During a solar eclipse, the corona and solar prominences can be seen.

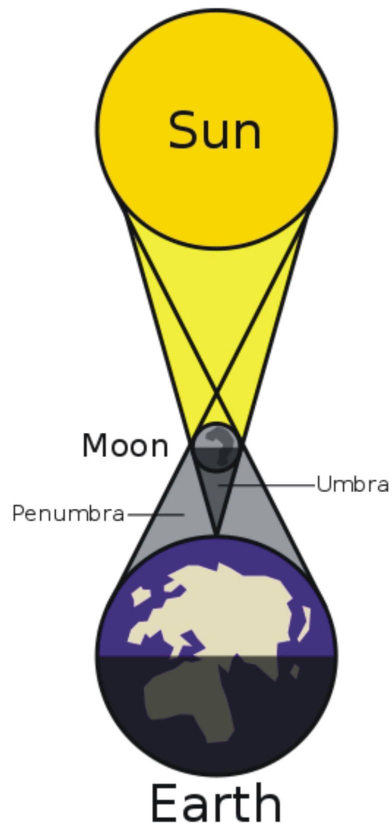

Figure 24.23: A Solar Eclipse. (26)

A Lunar Eclipse

A **lunar eclipse** occurs when the full moon moves through the shadow of the Earth (**Figure** 24.25). This can only happen when the Earth is between the Moon and the Sun and all three are lined up in the same plane, called the ecliptic. The ecliptic is the plane of Earth's orbit around the Sun. The Earth's shadow has two distinct parts: the umbra and the penumbra. The **umbra** is the inner, cone shaped part of the shadow, in which all of the light has been blocked. The outer part of Earth's shadow is the **penumbra** where only part of the light is blocked. In the penumbra, the light is dimmed but not totally absent. A total lunar eclipse occurs when the Moon travels completely in Earth's umbra. During a partial lunar

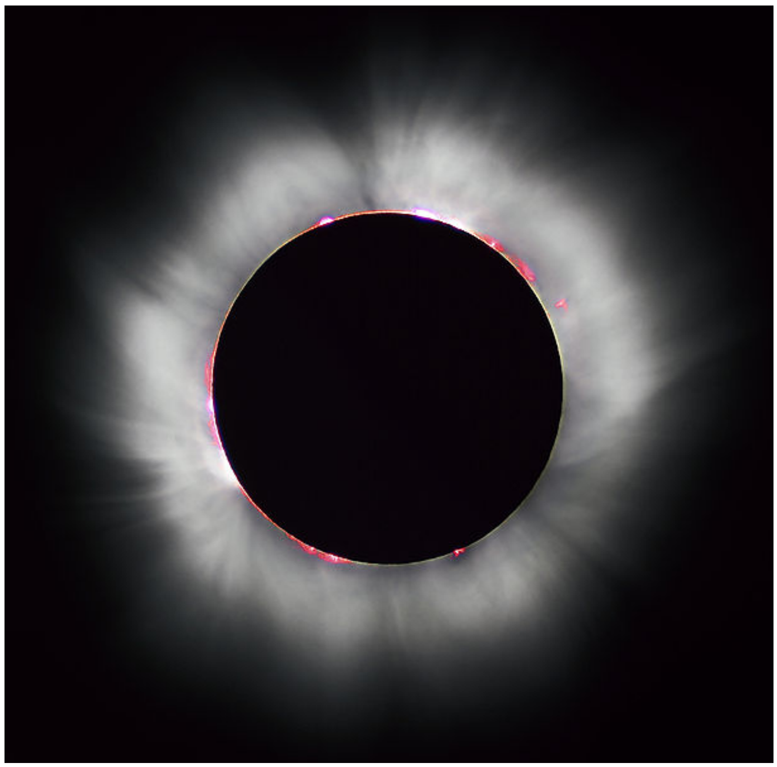

Figure 24.24: Photo of a Total Solar Eclipse. (28)

eclipse, only a portion of the Moon enters Earth's umbra. A penumbral eclipse happens when the Moon passes through Earth's penumbra. The Earth's shadow is quite large, so a lunar eclipse lasts for hours and can be seen by anyone with a view of the Moon at the time of the eclipse.

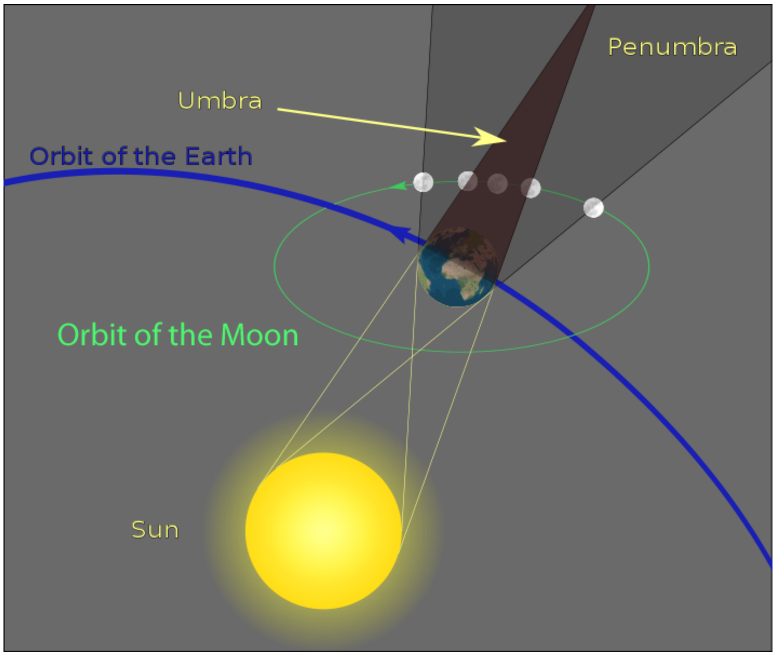

Figure 24.25: The Formation of a Lunar Eclipse. (3)

Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common. The next total lunar eclipse will occur December 21, 2010. The moon glows with a dull red coloring during a total lunar eclipse.

The Phases of the Moon

The Moon does not produce any light of its own — it only reflects light from the Sun. As the Moon moves around the Earth, we see different parts of the near side of the Moon illuminated by the Sun. This causes the changes in the shape of the Moon that we notice on a regular basis, called the phases of the Moon. As the Moon revolves around Earth, the illuminated portion of the near side of the Moon will change from fully lit to completely dark and back again.

A full moon is the lunar phase seen when the whole of the Moon's lit side is facing Earth. This phase happens when Earth is between the Moon and the Sun. About one week later, the Moon enters the quarter-moon phase. At this point, the Moon appears as a half-circle, since only half of the Moon's lit surface is visible from Earth. When the Moon moves between Earth and the Sun, the side facing Earth is completely dark. This is called the new moon phase, and we do not usually see the Moon at this point. Sometimes you can just barely make out the outline of the new moon in the sky. This is because some sunlight reflects off the Earth and hits the moon. Before and after the quarter-moon phases are the gibbous and crescent phases. During the gibbous moon phase, the moon is more than half lit but not full. During the crescent moon phase, the moon is less than half lit and is seen as only a sliver or crescent shape. It takes about 29.5 days for the Moon to revolve around Earth and go through all the phases (**Figure** 24.26).

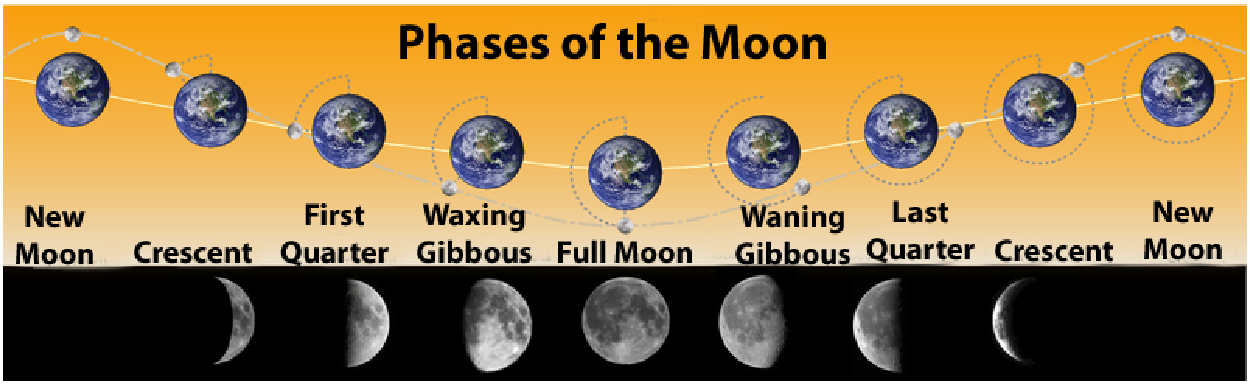

Figure 24.26: The Phases of the Moon. Note that the Sun would be above the top of this picture, and thus, the Sun's rays would be directed downward. (27)

The Tides

Tides are the regular rising and falling of Earth's surface water in response to gravitational attraction from the Moon and Sun. The Moon's gravity causes the oceans to bulge out in the direction of the Moon. In other words, the Moon's gravity is pulling upwards on Earth's water, producing a high tide. On the other side of the Earth, there is another high tide area, produced where the Moon's pull is weakest. As the Earth rotates on its axis, the areas directly in line with the Moon will experience high tides. Each place on Earth experiences changes in the height of the water throughout the day as it changes from high tide to low tide. There are two high tides and two low tides each tidal day. **Figure** 24.27 and **Figure** 24.28 will help you better understand how tides work.

The first picture shows what is called a **spring tide**. Confusingly, this tide has nothing to do with the season 'Spring', but means that the tide waters seem to spring forth. During a spring tide, the Sun and Moon are in line. This happens at both the new moon and the full moon. The Sun's gravity pulls on Earth's water, while the Moon's gravity pulls on the water in the same places. The high tide produced by Sun adds to the high tide produced by the Moon. So spring tides have higher than normal high tides. This water is shown on the picture as the gray bulges on opposite sides of the Earth. Notice that perpendicular to the gray areas, the water is at a relatively low level. The places where the water is being pulled

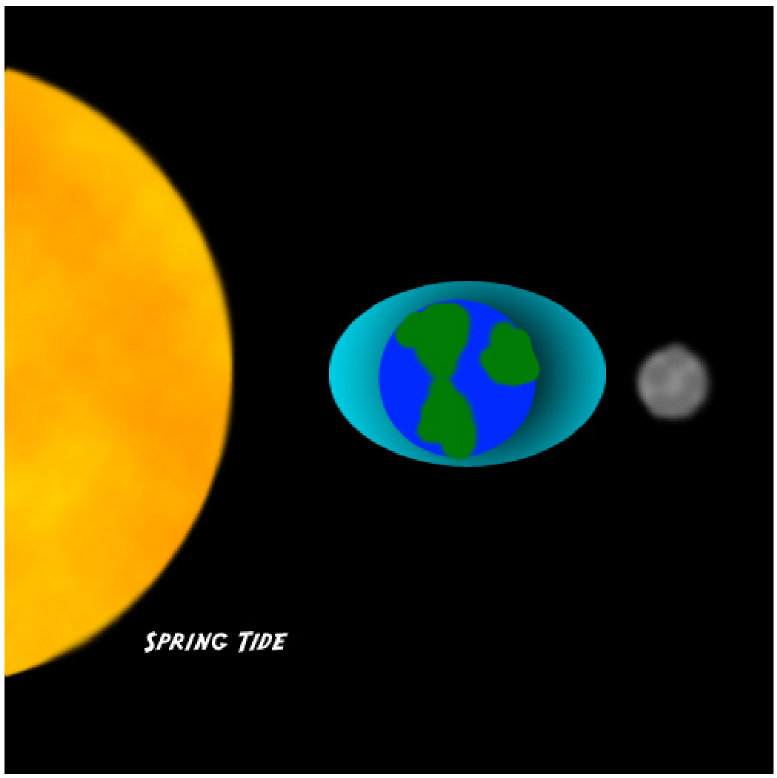

Figure 24.27: A Spring Tide. (23)

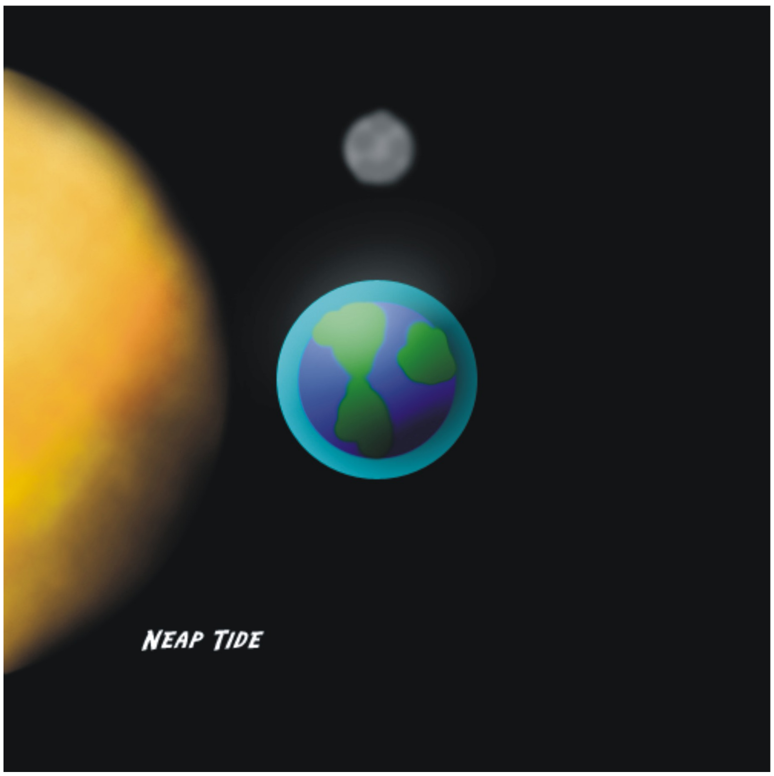

Figure 24.28: A Neap Tide. (24)

out experience high tides, while the areas perpendicular to them experience low tides. Since the Earth is rotating on its axis, the high-low tide cycle moves around the globe in a 24-hour period.

The second picture shows a **neap tide**. A neap tide occurs when the Earth and Sun are in line but the Moon is perpendicular to the Earth. This happens when the moon is at first or last quarter moon phase. In this case, the pull of gravity from the Sun partially cancels out the pull of gravity from the Moon, and the tides are less pronounced. Neap tides produce less extreme tides than the normal tides. This is because the high tide produced by the Sun adds to the low tide area of the Moon and vice versa. So high tide is not as high and low tide is not as low as it usually might be.

Lesson Summary

- As the Earth rotates on its axis and revolves around the Sun, several different effects are produced.
- When the new moon comes between the Earth and the Sun along the ecliptic, a solar eclipse is produced.
- When the Earth comes between the full moon and the Sun along the ecliptic, a lunar eclipse occurs.
- Observing the Moon from Earth, we see a sequence of phases as the side facing us goes from completely darkened to completely illuminated and back again once every 29.5 days.
- Also as the Moon orbits Earth, it produces tides aligned with the gravitational pull of the Moon.
- The Sun also produces a smaller solar tide. When the solar and lunar tide align, at new and full moons, we experience higher than normal tidal ranges, called spring tides.
- At first and last quarter moons, the solar tide and lunar tide interfere with each other, producing lower than normal tidal ranges called neap tides.

Review Questions

1. The globe is divided into time zones, so that any given hour of the day in one time zone occurs at a different time in other time zones. For example, New York City is in one time zone and Los Angeles is in another time zone. When it is 8 am in New York City, it is only 5 am in Los Angeles. Explain how Earth's motions cause this difference in times.
2. Explain how Earth's tilt on its axis accounts for seasons on Earth.
3. Explain how the positions of the Earth, Moon, and Sun vary during a solar eclipse and a lunar eclipse.
4. Draw a picture that shows how the Earth, Moon, and Sun are lined up during the new moon phase.

5. Why are neap tides less extreme than spring tides?

Further Reading / Supplemental Links

- Demonstration of Why Earth has Seasons http://www.youtube.com/watch?v=DuiQvPLWziQ&feature=related
- Solar and Lunar Eclipses hhttp://www.youtube.com/watch?v=tIE1MTGz4eI&feature=related

Vocabulary

crescent Phase of the moon when it is less than half full but still slightly lit.

gibbous Phase of the moon when it is more than half lit but not completely full.

lunar eclipse An eclipse that occurs when the Moon moves through the shadow of the Earth and is blocked from view.

neap tide Type of tide event when the Sun and Earth are in line and the Moon is perpendicular to the Earth.

penumbra Outer part of shadow that remains partially lit during an eclipse.

solar eclipse Occurs when moon passes directly between the Earth and Sun; the Moon's shadow blocks the Sun from view.

spring tide An extreme tide event that happens when the Earth, Moon, and the Sun are aligned; happens at full and new moon phases.

tide The regular rising and falling of Earth's surface waters twice a tidal day as a result of the Moon's and Sun's gravitational attraction.

umbra Inner cone shaped part of a shadow when all light is blocked during an eclipse.

Points to Consider

- Why don't eclipses occur every single month at the full and new moons?
- The planet Mars has a tilt that is very similar to Earth's. What does this produce on Mars?
- Venus comes between the Earth and the Sun. Why don't we see an eclipse when this happens?

Image Sources

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(28) *Photo of a Total Solar Eclipse.*. GNU-FDL.

Chapter 25

The Solar System

25.1 Introduction to the Solar System

Lesson Objectives

- Describe historical views of the solar system.
- Name the planets, and describe their motion around the sun.
- Explain how the solar system formed.

Changing Views of the Solar System

People have not always known about all the objects in our solar system. The ancient Greeks were aware of five of the planets. They did not know what these objects were; they just noticed that they moved differently than the stars did. They seemed to wander around in the sky, changing their position against the background of stars. In fact, the word "planet" comes from a Greek word meaning "wanderer." They named these objects after gods from their mythology. The names we use now for the planets are the Roman equivalents of these Greek names: Mercury, Venus, Mars, Jupiter, and Saturn.

The Geocentric Universe

The ancient Greeks believed that Earth was at the center of the universe, as shown in **Figure** 25.1. This view is called the **geocentric model** of the universe. *Geocentric* means "Earth-centered." The geocentric model also described the sky, or *heavens,* as having a set of spheres layered on top of one another. Each object in the sky was attached to one of these spheres, and moved around Earth as that sphere rotated. From Earth outward, these spheres contained the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and an outer sphere which contained all the stars. The planets appear to move much faster than the stars and so the Greeks placed them closer to Earth.

Today, powerful telescopes can actually see the surfaces of planets in our solar system. Even though the closest stars have diameters that are hundreds of times larger than the Earth, the distant stars appear as tiny dots that cannot be resolved.

Figure 25.1: Model of a geocentric universe. This diagram of the universe from the Middle Ages shows Earth at the center, with the Moon, the Sun, and the planets orbiting Earth. (34)

The geocentric model may seem strange to us now, but at the time, it worked quite well. It explained why all the stars appear to rotate around Earth once per day. It also explained why the planets move differently from the stars, and from each other. One problem with the geocentric model was resolved around 150 A.D. by the astronomer Ptolemy. At times, some planets seemed to move backwards (in retrograde) instead of in their usual forward motion around the Earth. Ptolemy resolved this problem by using a system of circles to describe the motion of planets (**Figure** 25.2). In Ptolemy's system, a planet moved in a small circle, called an *epicycle.* This circle in turn moved around Earth in a larger circle, called a *deferent.* Ptolemy's version of the geocentric model worked so well that it remained the accepted model of the universe for more than a thousand years.

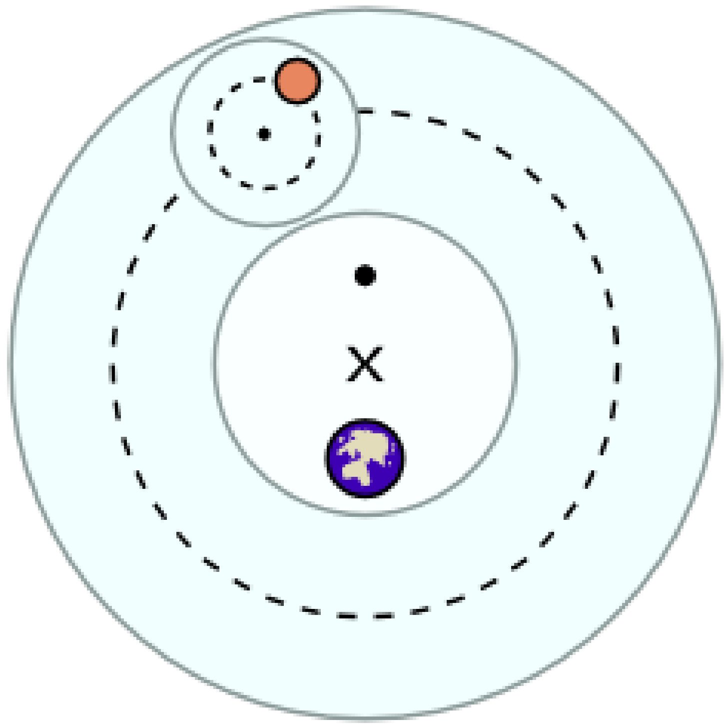

Figure 25.2: Diagram of an epicycle and deferent. According to Ptolemy, a planet moves on a small circle that in turn moves on a larger circle around Earth. (26)

The Heliocentric Universe

Ptolemy's geocentric model worked pretty well, but it was complicated and occasionally made errors in predicting the movement of planets. At the beginning of the 16^{th} century A.D., Nicolaus Copernicus proposed a different model in which Earth and all the other planets orbited the Sun. Because this model put the Sun at the center, it is called the **heliocentric model** of the universe. *Heliocentric* means "sun-centered." **Figure** 25.3 shows the heliocentric model compared to the geocentric model. Copernicus' model explained the motion of the planets about as well as Ptolemy's model, but it did not require complicated additions like epicycles and deferents.

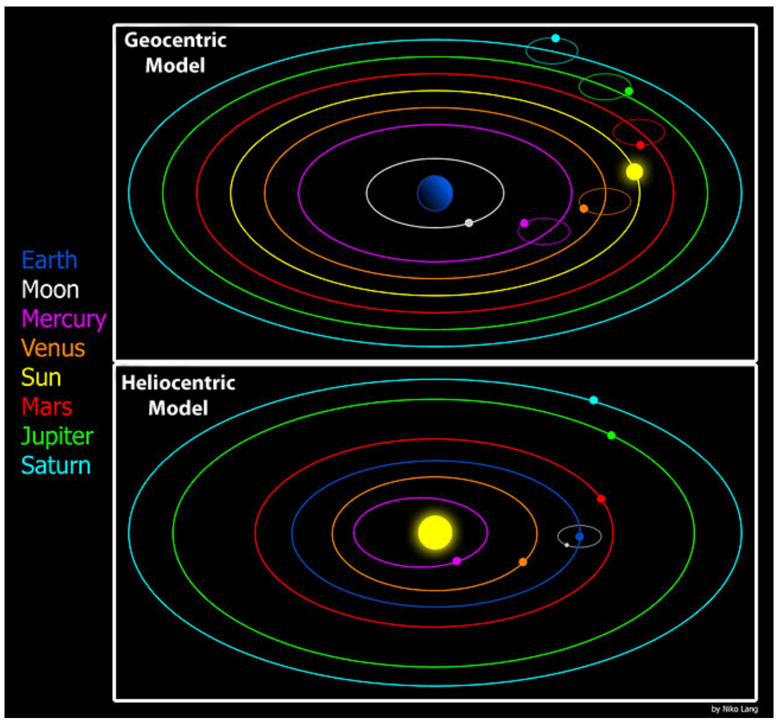

Figure 25.3: Unlike the geocentric model (top image), the heliocentric model (lower image), had the Sun at the center, and did not require epicycles. (5)

Although Copernicus' model worked more simply than Ptolemy's, it still did not perfectly describe the motion of the planets. The problem was that, like Ptolemy, Copernicus still thought planets moved in perfect circles. Not long after Copernicus, Johannes Kepler refined the heliocentric model. He proposed that planets move around the Sun in ellipses (ovals), not circles. This model matched observations perfectly.

Because people were so used to thinking of Earth at the center of the universe, the heliocentric model was not widely accepted at first. However, when Galileo Galilei first turned a telescope to the heavens in 1610, he made several striking discoveries. He found that the planet Jupiter has moons orbiting around it. This was the first evidence that objects could orbit something besides Earth. He also discovered that Venus has phases like our moon does. The phases of Venus provided direct evidence that Venus orbits the Sun. Galileo's discoveries caused many more people to accept the heliocentric model of the universe. The shift from an Earth-centered view to a Sun-centered view of the universe is referred to as the *Copernican Revolution.*

The Modern Solar System

Today, we know that our solar system is just one tiny part of the universe as a whole. Neither Earth nor the Sun are at the center of the universe —in fact, the universe has no true center. However, the heliocentric model does accurately describe our solar system. In our modern view of the solar system, the Sun is at the center, and planets move in elliptical orbits around the Sun. The planets do not emit their own light, but instead reflect light from the Sun.

Extrasolar Planets or Exoplanets

Since the early 1990s, astronomers have discovered other solar systems, with planets orbiting stars other than our own Sun (called "extrasolar planets" or simply "exoplanets"). Although a handful of exoplanets have now been directly imaged, the vast majority have been discovered by indirect methods. One technique involves detecting the very slight motion of a star periodically moving toward and away from us along our line-of-sight (also known as a star's "radial velocity"). This periodic motion can be attributed to the gravitational pull of a planet (or, sometimes, another star) orbiting the star. Another technique involves measuring a star's brightness over time. A temporary, periodic decrease in light emitted from a star can occur when a planet crosses in front of (or "transits") the star it is orbiting, momentarily blocking out some of the starlight. As of February 2010, over 420 exoplanets have been confirmed with more being discovered at an ever-increasing rate.

Planets and Their Motions

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

Figure 4 shows the Sun and the major objects that orbit the Sun. There are eight planets. From the Sun outward, they are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The Sun is just an average star compared to other stars, but it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! **Table** 25.1 gives more exact data on the sizes of the sun and planets relative to Earth.

Table 25.1:

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth masses	109.2 Earth diameters
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth mass	1.00 Earth diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth masses	11.21 Earth diameters
Saturn	95.2 Earth masses	9.41 Earth diameters
Uranus	14.6 Earth masses	3.98 Earth diameters
Neptune	17.2 Earth masses	3.81 Earth diameters

(*Sources:* http://en.wikipedia.org/wiki/Planets, http://en.wikipedia.org/wiki/Sun, *License:* GNU-FDL)

What Is (and Isn't) a Planet?

So what exactly is a planet? Simply put, a **planet** is a massive, round body orbiting a star. For our solar system, this star is the Sun. A **moon** is an object that orbits a planet.

"Isn't Pluto a planet?" you may wonder. When it was discovered in 1930, Pluto was considered a ninth planet. When we first saw Pluto, our telescopes actually saw Pluto and its moon, Charon as one much larger object. With better telescopes, we realized that Pluto had a moon and Pluto was much smaller than we thought! With the discovery of many objects like Pluto, and one of them, Eris, even larger than Pluto, in 2006, astronomers refined the definition of a planet. According to the new definition, a planet must:

- orbit a star
- be big enough that its own gravity causes it to be shaped like a sphere
- be small enough that it isn't a star itself
- have cleared the area of its orbit of smaller objects

Objects that meet the first three criteria but not the fourth are called **dwarf planets**. Most astronomers now consider Pluto to be a dwarf planet, along with the objects Ceres and Eris. Even before astronomers decided to change the definition of a planet, there were many aspects of Pluto that did not fit with the other planets in our solar system.

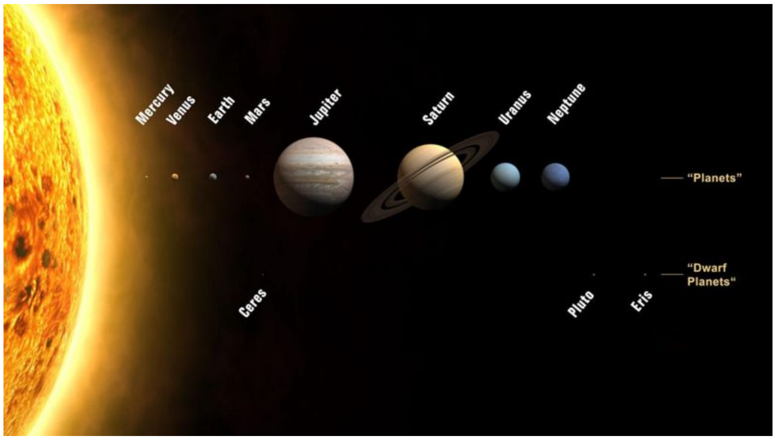

Figure 25.4: Relative sizes of the Sun, planets & dwarf planets. The largest objects in the solar system are the Sun, the eight planets, and the three known dwarf planets. In this figure, the relative sizes are correct but the relative distances are not correct. (30)

The Size and Shape of Orbits

Figure 25.4 shows the Sun and planets in the correct relative sizes. However, the relative distances are not correct. **Figure** 25.5 shows the relative sizes of the orbits. The image in the upper left shows the orbits of the inner planets. The upper left image also shows the *asteroid belt*, a collection of many small objects between the orbits of Mars and Jupiter. The image in the upper right shows the orbits of the outer planets. This upper right image also shows the *Kuiper belt*, another group of objects beyond the orbit of Neptune. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next.

In **Figure 5**, you can see that the orbits of the planets are nearly circular. In fact, the orbits are not quite circular, but are slightly elliptical. The orbit of Pluto is a much longer ellipse. Some astronomers think Pluto was dragged into its current orbit by Neptune.

Something else Kepler discovered was a relationship between the time it takes a planet to make one complete orbit around the Sun (this is also called an "orbital period") and the distance from the Sun to the planet. So, if the orbital period of a planet is known, then it is possible to determine how far away from the Sun the planet orbits. This is how we can measure the distances to other planets within our own solar system.

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km, or 93 million miles. **Table** 25.2 shows the distances to the planets (the average radius of orbits) in AU. The table also shows how long it takes each planet to spin on its axis (the length of a day) and how long it takes each planet to complete an orbit (the length of a year); in particular, notice how slowly Venus rotates relative to Earth.

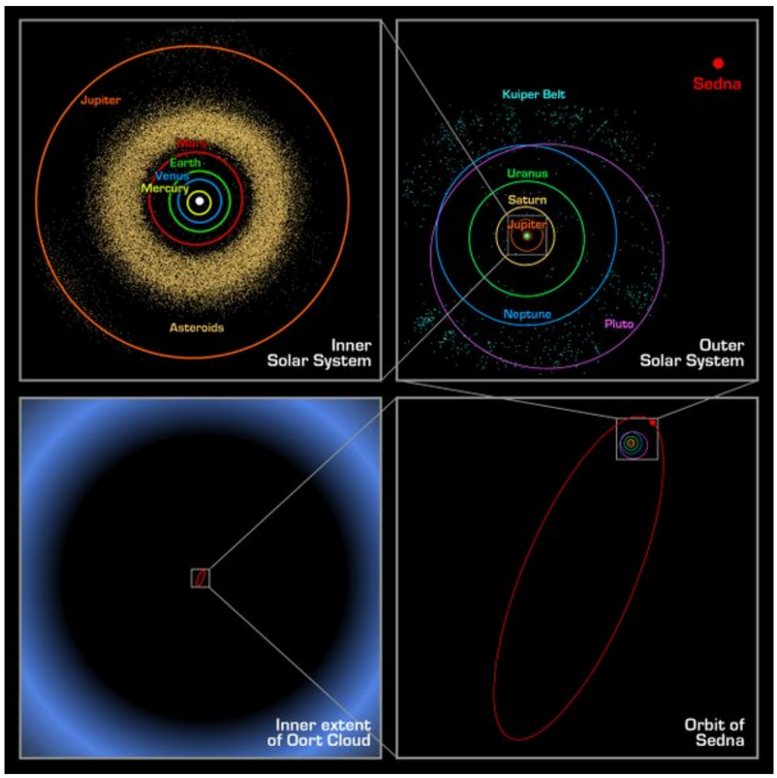

Figure 25.5: This figure shows the relative sizes of the orbits of planets in the solar system. The inner solar system is on the upper left. The upper right shows the outer planets of our solar system. (28)

Table 25.2: **Distances to the Planets and Properties of Orbits Relative to Earth's Orbit**

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

(*Source:* http://en.wikipedia.org/wiki/Planets, *License:* GNU-FDL)

The Role of Gravity

Planets are held in their orbits by the force of gravity. Imagine swinging a ball on a string in a circular motion. If you were to let go of the string, the ball would go flying out in a straight line. But the force of the string pulling on the ball keeps the ball moving in a circle. The motion of a planet is very similar, except the force pulling the planet is the attractive force of gravity between the planet and the Sun.

Every object is attracted to every other object by gravity. The force of gravity between two objects depends on how much mass the objects have and on how far apart they are. When you are sitting next to a friend, there is a gravitational force between you and your friend, but it is far too weak for you to detect. In order for the force of gravity to be strong enough to detect, at least one of the objects has to have a lot of mass. You can feel the force of gravity between you and Earth because Earth has a lot of mass. This force of gravity is what keeps you from floating off the ground. The distances from the Sun to the planets are very large. But the force of gravity between the Sun and each planet is very large because the Sun and the planets are very large objects. The force of gravity also holds moons in orbit around planets.

The moon orbits the Earth, and the Earth-moon system orbits the Sun. But Earth and its moon are not the only things that orbit the Sun. There are also other planets and smaller objects, such as asteroids, meteoroids, and comets that also orbit the Sun. The **solar system** consists of the Sun and all the objects that revolve around the sun as a result of gravity.

Formation of the Solar System

There are two key features of the solar system we haven't mentioned yet. First, all the planets lie in nearly the same plane, or flat disk like region. Second, all the planets orbit in the same direction around the Sun. These two features are clues to how the solar system formed.

A Giant Nebula

The most widely accepted explanation of how the solar system formed is called the **nebular hypothesis**. According to this hypothesis, the solar system formed about 4.6 billion years ago from the collapse of a giant cloud of gas and dust, called a **nebula**. The nebula was made mostly of hydrogen and helium, but there were heavier elements as well.

The nebula was drawn together by gravity. As the nebula collapsed, it started to spin. As it collapsed further, the spinning got faster, much as an ice skater spins faster when he pulls his arms to his sides during a spin move. This effect, called "conservation of angular momentum," along with complex effects of gravity, pressure, and radiation, caused the nebula to form into a disk shape, as shown in **Figure** 25.6. This is why all the planets are found in the same plane.

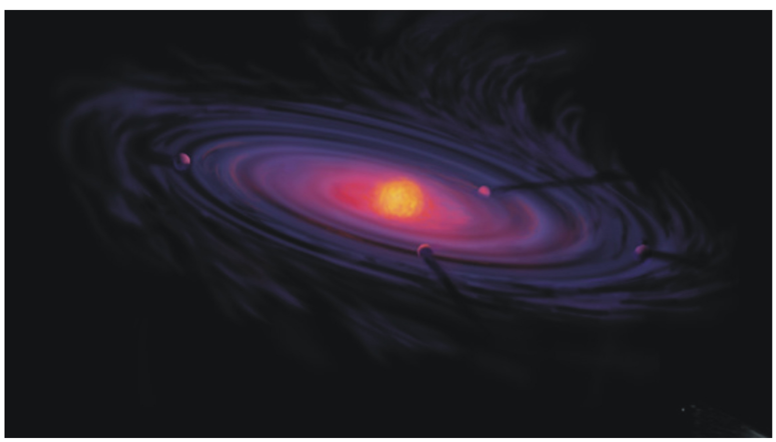

Figure 25.6: The nebular hypothesis describes how the solar system formed from a cloud of gas and dust into a disk with the Sun at the center. This painting was made by an artist; it's not an actual photograph of a protoplanetary disk. (9)

Formation of the Sun and Planets

As gravity pulled matter into the center of the disk, the density and pressure increased at the center. When the pressure in the center was high enough that nuclear fusion reactions started in the center, a star was born—the Sun.

Meanwhile, the outer parts of the disk were cooling off. Small pieces of dust in the disk started clumping together. These clumps collided and combined with other clumps. Larger clumps, called *planetesimals*, attracted smaller clumps with their gravity. Eventually, the planetesimals formed the planets and moons that we find in our solar system today.

The outer planets—Jupiter, Saturn, Uranus and Neptune—condensed farther from the Sun from lighter materials such as hydrogen, helium, water, ammonia, and methane. Out by Jupiter and beyond, where it's very cold, these materials can form solid particles. But in closer to the Sun, these same materials are gases. As a result, the inner planets—Mercury, Venus, Earth, and Mars—formed from dense rock, which is solid even when close to the Sun.

Lesson Summary

- The **solar system** consists of the Sun and all the objects that are bound to the Sun by gravity.
- There are eight planets in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Neptune. Ceres, Makemake, Pluto and Eris are considered dwarf planets.
- The ancient Greeks believed in a geocentric model of the universe, with Earth at the center and everything else orbiting Earth.
- Copernicus, Kepler, and Galileo promoted a heliocentric model of the universe, with the sun at the center and Earth and the other planets orbiting the Sun.
- Planets are held by the force of gravity in elliptical orbits around the Sun.
- The nebular hypothesis describes how the solar system formed from a giant cloud of gas and dust about 4.6 billion years ago.
- The nebular hypothesis explains why the planets all lie in one plane and orbit in the same direction around the Sun.

Review Questions

1. What does *geocentric* mean?
2. Describe the geocentric model and heliocentric model of the universe.
3. How was Kepler's version of the heliocentric model different from Copernicus'?
4. Name the eight planets in order from the Sun outward.
5. What object used to be considered a planet, but is now considered a dwarf planet?
6. What keeps planets and moons in their orbits?
7. How old is the solar system?
8. Use the nebular hypothesis to explain why the planets all orbit the Sun in the same direction.

Further Reading / Supplemental Links

- http://www.youtube.com/watch?v=FHSWVLwbbNw&NR=1
- http://sse.jpl.nasa.gov/planets/index.cfm
- http://www.iau.org/iau0602.423.0.html
- http://starchild.gsfc.nasa.gov/docs/StarChild/solar_system_level2/solar_system.html; http://sse.jpl.nasa.gov/planets/index.cfm
- http://www.solarviews.com/eng/homepage.htm
- http://www.nineplanets.org/
- http://www.teachingideas.co.uk/science/orderingplanets.htm
- http://www.classzone.com/books/earth_science/terc/content/visualizations/es2701/es2701page01.cfm?chapter_no=27
- http://www.windows.ucar.edu/tour/link=/our_solar_system/formation.html
- http://www.solarviews.com/cap/misc/ssanim.htm
- http://en.wikipedia.org/

Vocabulary

geocentric model Model used by the ancient Greeks that puts the Earth at the center of the universe.

heliocentric model Model proposed by Copernicus that put the Sun at the center of the universe.

moon A celestial object that orbits a larger celestial object.

nebula An interstellar cloud of gas and dust.

nebular hypothesis The hypothesis that our solar system developed from a spinning cloud of gas and dust, or a nebula.

planet Around, celestial object that orbits a star and has cleared its orbit of smaller objects.

solar system The Sun and all the objects that revolve around the Sun as a result of gravity.

Points to Consider

- Would you expect all the planets in the solar system to be made of similar materials? Why or why not?

- The planets are often divided into two groups: the inner planets and the outer planets. Which planets do you think are in each of these two groups? What do members of each group have in common?

25.2 Inner Planets

Lesson Objectives

- Describe key features of each of the inner planets.
- Compare each of the inner planets to Earth and to one another.

The Inner Planets

The four planets closest to the sun - Mercury, Venus, Earth and Mars are the inner planets, also called the terrestrial planets because they are similar to Earth. **Figure** 25.7 shows the relative sizes of these four planets. All of the inner planets are small, relative to the outer planets. All of the inner planets are solid, dense, rocky planets. The inner planets either do not have moons or have just one (Earth) or two (Mars). None of the inner planets has rings. Compared to the outer planets, the inner planets have shorter orbits around the Sun, but all the inner planets spin more slowly. Venus spins the slowest of all the planets. At one time, all the inner planets have been geologically active. They are all made of cooled igneous rock with inner iron cores.

Mercury

Mercury, shown in **Figure** 25.7, is the planet closest to the Sun. Mercury is the smallest planet, and it has no moon. As **Figure** 25.7 shows, the surface of Mercury is covered with craters, like Earth's moon. The presence of impact craters that are so old means that Mercury hasn't changed much geologically for billions of years and, with only a trace of an atmosphere, has no weather to wear down the ancient craters.

Because Mercury is so close to the Sun, it is difficult to observe from Earth, even with a telescope. However, the Mariner 10 spacecraft, shown in **Figure** 25.8, visited Mercury in 1974–1975. In January 2008, the Messenger mission returned to Mercury and took much more detailed pictures. One of these images can be seen in **Figure** 25.9.

Short Year, Long Days

Mercury is named for the Roman messenger god, who could run extremely fast. Likewise, Mercury moves very fast in its orbit around the Sun. A **year** on Mercury—the length of

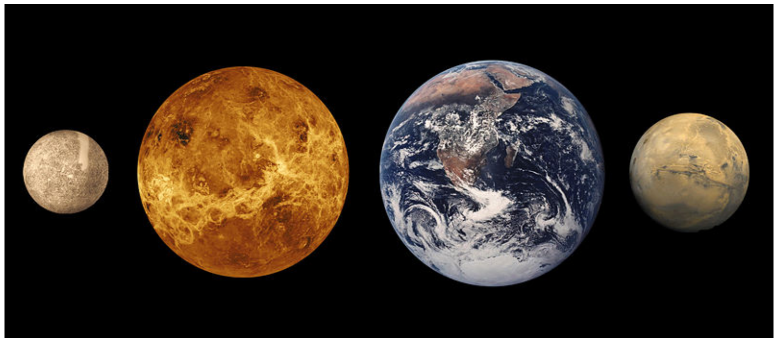

Figure 25.7: This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars. (35)

Figure 25.8: Mariner 10 made three flybys of Mercury in 1974 and 1975. (32)

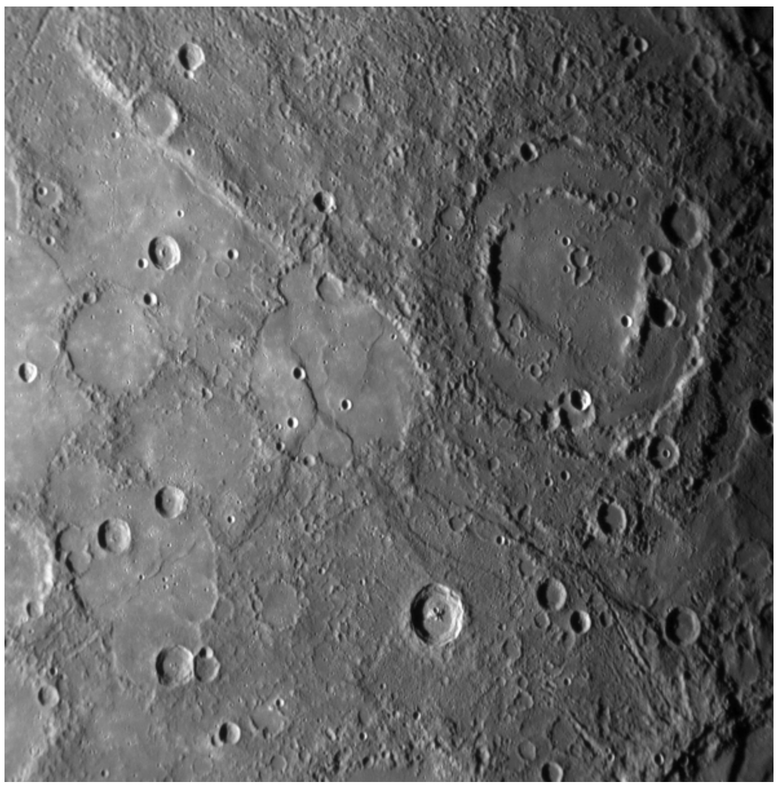

Figure 25.9: Mercury is covered with craters, like Earth's moon. (4)

time it takes to orbit the Sun—is just 88 Earth days.

Mercury has a very short year, but very long days. A **day** is defined as the time it takes a planet to turn on its axis. Mercury rotates slowly on its axis, turning exactly three times for every two times it orbits the Sun. Therefore, each day on Mercury is 58 Earth days long. In other words, on Mercury, a year is only a Mercury day and a half long!

Extreme Temperatures

Mercury is very close to the Sun, so it can get very hot. However, Mercury has virtually no atmosphere and it rotates very slowly. Because there is no atmosphere and no water to insulate the surface, temperatures on the surface of Mercury vary widely. In direct sunlight, the surface can be as hot as 427 °C (801 °F). On the dark side, or in the shadows inside craters, the surface can be as cold as –183 °C (–297 °F)! Although most of Mercury is extremely dry, scientists believe there may be a small amount of water in the form of ice at the poles of Mercury, in areas which never receive direct sunlight.

A Liquid Metal Core

Figure 25.10 shows a diagram of Mercury's interior. Mercury is one of the densest planets. Scientists believe the interior contains a relatively large, liquid core made mostly of melted iron. Mercury's core takes up about 42% of the planet's volume. Mercury's highly cratered surface is evidence that Mercury is not geologically active.

Venus

The second planet out from the Sun, Venus, is our nearest neighbor. Not only is it closer to Earth than any other planet, but it also is the most similar to Earth in size. Named after the Roman goddess of love, it is the only planet named after a female. Venus is sometimes called Earth's "sister planet." But just how similar is Venus to Earth?

A Harsh Environment

Viewed through a telescope, Venus looks smooth and featureless. That's because Venus is covered by a thick layer of clouds, as shown in pictures of Venus taken at ultraviolet wavelengths, such as **Figure** 25.11. Because of the thick, cloudy atmosphere, we cannot take ordinary photos of the surface of Venus, even from spacecraft orbiting the planet. However, we can make maps of the surface using radar. **Figure** 25.12 shows a topographical map of Venus produced by the Magellan probe using radar.

Unlike clouds on Earth, Venus's clouds are not made of water vapor. They are made of

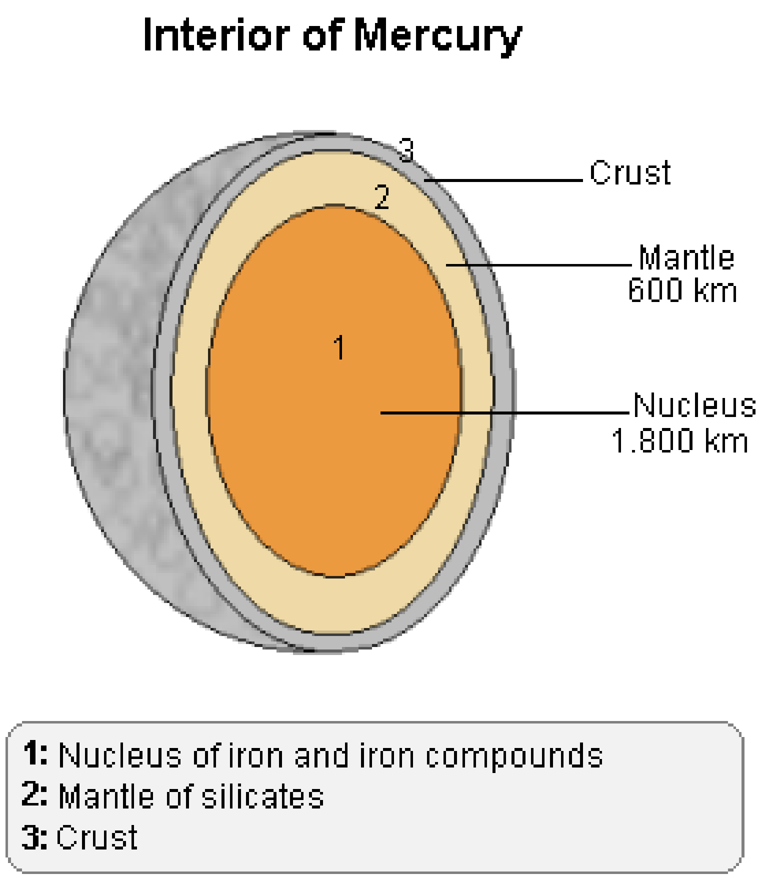

Figure 25.10: Mercury contains a thin crust, a mantle, and a large, liquid core that is rich in iron. (17)

carbon dioxide and sulfur dioxide—and they also contain large amounts of corrosive sulfuric acid!

Figure 25.11: This ultraviolet image from the Pioneer Venus Orbiter shows thick layers of clouds in the atmosphere of Venus. (2)

The atmosphere of Venus is so thick that the atmospheric pressure on the surface of Venus is 90 times greater than the atmospheric pressure on Earth's surface. The thick atmosphere also causes a strong greenhouse effect, which traps heat from the Sun. As a result, Venus is the hottest planet, even hotter than Mercury. Temperatures at the surface reach 465°C (860 °F). That's hot enough to melt lead!

Volcanoes

Venus has more volcanoes than any other planet. Planetary scientists have estimated that Venus has up to 100,000 or even a million volcanoes. Although these volcanoes contributed carbon dioxide in the past, most of the volcanoes are now dead. Venus doesn't seem to have tectonic plates like the Earth's. It's surface is covered with dead volcanoes and ancient craters.

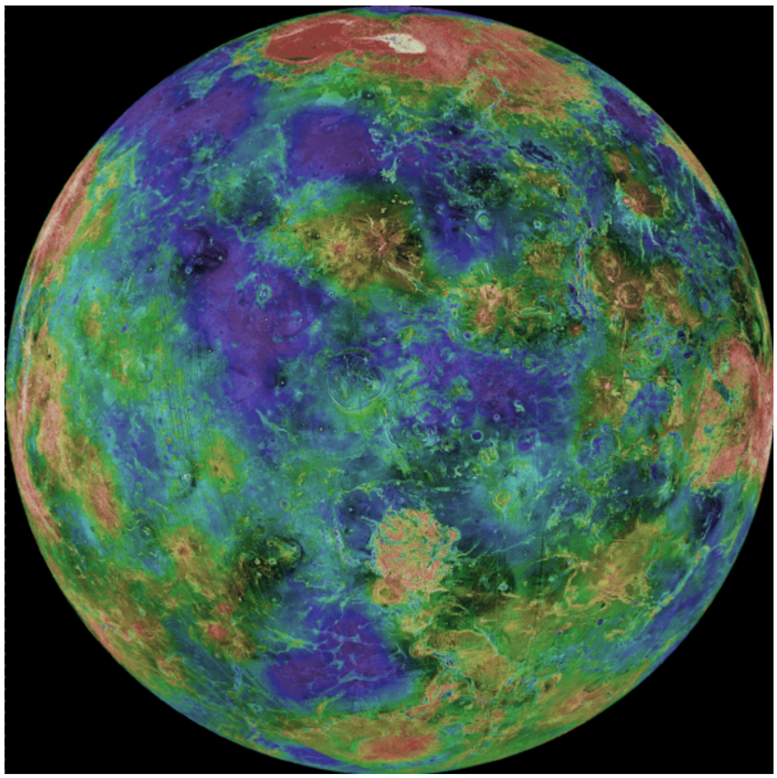

Figure 25.12: This topographic map of Venus was made from radar data collected by the Magellan probe between 1990 and 1994. (1)

Orbiting spacecraft have used radar to reveal mountains, valleys, and canyons on Venus. Most of the surface, however, has large areas of volcanoes surrounded by plains of lava. **Figure** 25.13 is an image made by a computer using radar data. It shows a volcano called Maat Mons, with lava beds in the foreground. The reddish-orange color is close to what scientists think the color of sunlight would look like on the surface of Venus.

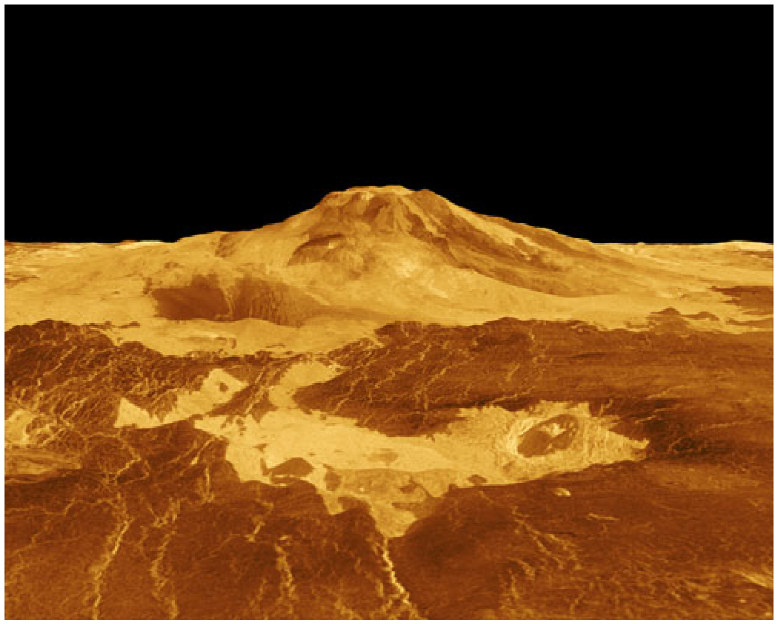

Figure 25.13: This image of Maat Mons was generated from radar data. The surface of Venus has many mountains, volcanoes, and plains of lava. (10)

Motion and Appearance

Venus is the only planet that rotates clockwise as viewed from its North pole, in a direction opposite to the direction it orbits the Sun. It turns slowly in the reverse direction, making one turn every 243 days. This is longer than a year on Venus—it takes Venus only 224 days to orbit the Sun.

Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. When Venus rises early in the morning, just before the Sun rises, it is sometimes called "the morning star." When it sets in the evening, just after the Sun sets, it may be called "the evening star." Venus' clouds reflect sunlight very well. As a result, Venus is very bright. When it is visible, Venus is the brightest object in the sky besides the sun and the Moon.

Like Mercury, Venus has no moon.

Earth

The third planet out from the Sun is shown in **Figure** 25.14. Does it look familiar? It's Earth! Because it is our home planet, we know a lot more about Earth than we do about any other planet. But what are key features of Earth when viewed as a member of our solar system?

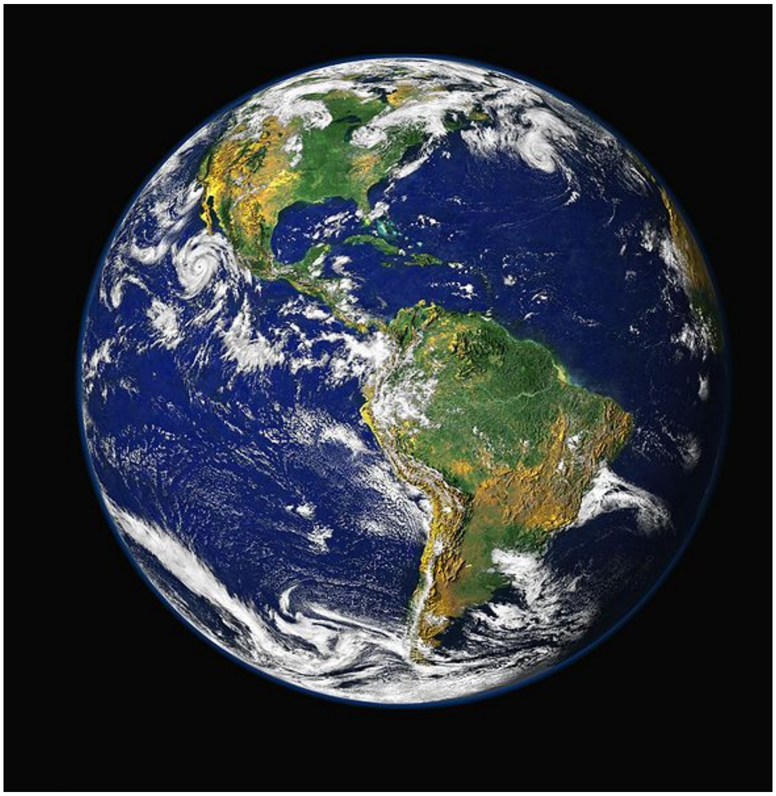

Figure 25.14: This famous image of Earth was taken during the Apollo 17 mission to the moon. (21)

Oceans and Atmosphere

As you can see in **Figure** 25.14, Earth has vast oceans of liquid water, large masses of land, ice covering the poles, and a dynamic atmosphere with clouds of water vapor. Earth's average surface temperature is 14°C (57°F). As you know, water is a liquid at this temperature. The oceans and the atmosphere help keep Earth's surface temperatures fairly steady.

Earth is the only planet known to have life. The conditions on Earth, especially the presence of liquid water, are ideal for life as we know it. The atmosphere filters out radiation that would be harmful to life, such as ultraviolet radiation and X rays. The presence of life has changed Earth's atmosphere, so it has much more oxygen than the atmospheres of other planets.

Plate Tectonics

The top layer of Earth's interior—the crust—contains numerous plates, known as tectonic plates. These plates move on the convecting mantle below, so they slowly move around on the surface. Movement of the plates causes other geological activity, such as earthquakes, volcanoes, and the formation of mountains. Earth is the only planet known to have plate tectonics.

Earth's Motions and Moon

Earth rotates on its axis once per day. In fact, the time of this rotation is how people have defined a day. Earth orbits the Sun once every 365.24 days, which is also how we have defined a year. Earth has one large moon, which orbits Earth once every 29.5 days, a period known as a month.

Earth's moon is the only large moon around a terrestrial planet in the solar system. The Moon is covered with craters, and also has large plains of lava. There is evidence that the Moon formed when a very large object—perhaps as large as the planet Mars—struck Earth in the distant past.

Mars

Mars, shown in **Figure** 25.15, is the fourth planet from the Sun, and the first planet beyond Earth's orbit. The Martian atmosphere is thin relative to Earth's and with much lower atmospheric pressure. Unlike Earth's neighbor on the side nearer the sun, Mars has only a weak greenhouse effect, which raises its temperature only slightly above what it would be if the planet did not have an atmosphere.

Although Mars is not the closest planet to Earth, it is the easiest to observe. Therefore, Mars has been studied more thoroughly than any other planet besides Earth. Humans have sent many space probes to Mars. Currently, there are three scientific satellites in orbit around Mars, and two functioning rovers on the surface. No humans have ever set foot on Mars. However, both NASA and the European Space Agency have set goals of sending people to Mars sometime between 2030 and 2040.

Figure 25.15: This image of Mars, taken by the Hubble Space Telescope in August, 2003, shows the planets reddish color and a prominent polar ice cap. (33)

A Red Planet

Viewed from Earth, Mars is reddish in color. The ancient Greeks and Romans named the planet after the god of war. They may have associated the planet with war because its red color reminded them of blood. Mars appears red because the surface of the planet really is a reddish-orange rust color, due to large amounts of iron in the soil. Mars has only a very thin atmosphere, made up mostly of carbon dioxide.

Surface Features

Mars is home to the largest mountain in the solar system—Olympus Mons, shown in **Figure** 25.16. Olympus Mons is a shield volcano, similar to the volcanoes that make up the Hawaiian islands on Earth. Olympus Mons is about 27 km (16.7 miles/88,580 ft) above the normal Martian surface level. That makes it more than three times taller than Mount Everest. At its base, Olympus Mons is about the size of the entire state of Arizona!

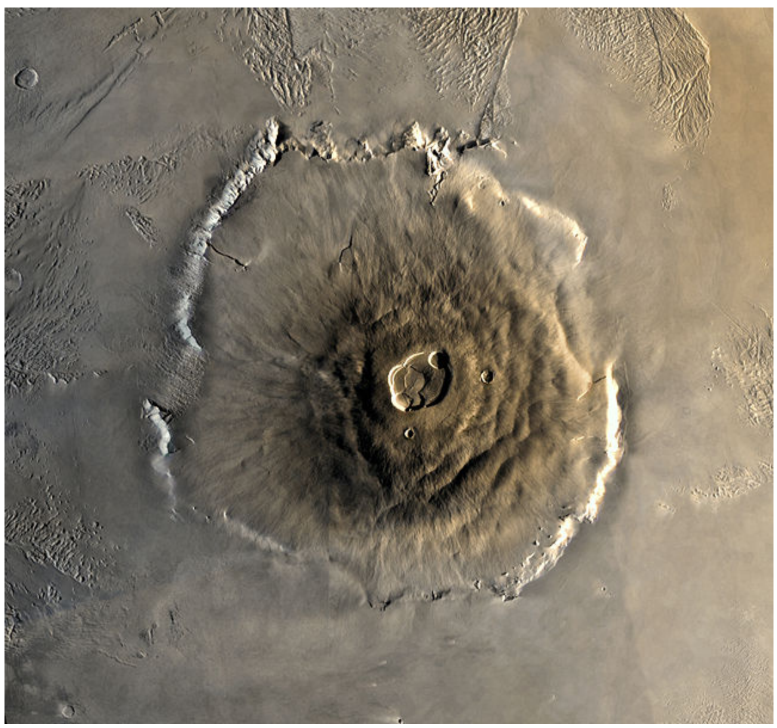

Figure 25.16: The Martian volcano Olympus Mons is the largest mountain in the solar system. (29)

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** 25.17). This canyon is 4,000 km (2,500 miles) long, as long as Europe is wide, and one-fifth the circumference of Mars. The canyon is 7 km (4.3 miles) deep. By comparison, the Grand Canyon on Earth is only 446 km (277 miles) long and about 2 km (1.2 miles) deep.

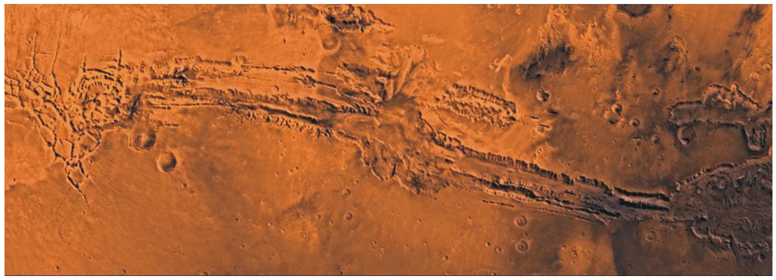

Figure 25.17: The Martian canyon Valles Marineris is the largest canyon in the solar system. (19)

Although Mars has mountains, canyons, and other features similar to Earth, it doesn't have as much geological activity as Earth. There is no evidence of plate tectonics on Mars. There are also more craters on Mars than on Earth, though fewer than on the Moon.

Is There Water on Mars?

Water cannot stay in liquid form on Mars because the pressure of the atmosphere is too low. However, there is a lot of water in the form of ice. **Figure** 25.15 shows a prominent ice cap at the south pole of Mars. Scientists also believe there is also a lot of ice water present just under the Martian surface. This ice can melt when volcanoes erupt, and water can flow across the surface temporarily.

Scientists have reason to think that water once flowed over the surface of Mars because they can see surface features that look like water-eroded canyons, and the Mars rover collected round clumps of crystals that, on Earth, usually form in water. The presence of water on Mars, even though it is now frozen as ice, suggests that it might have been possible for life to exist on Mars in the past.

Two Martian Moons

Mars has two very small moons, Phobos and Deimos. As you can see in **Figure** 25.18, these moons are not spherical in shape, but instead just look like irregular rocks. Phobos and Deimos were discovered in 1877. They are named after characters in Greek mythology—the two sons of Ares, who followed their father into war. Ares is equivalent to the Roman god Mars.

Lesson Summary

- The four inner planets, or terrestrial planets, have solid, rocky surfaces.

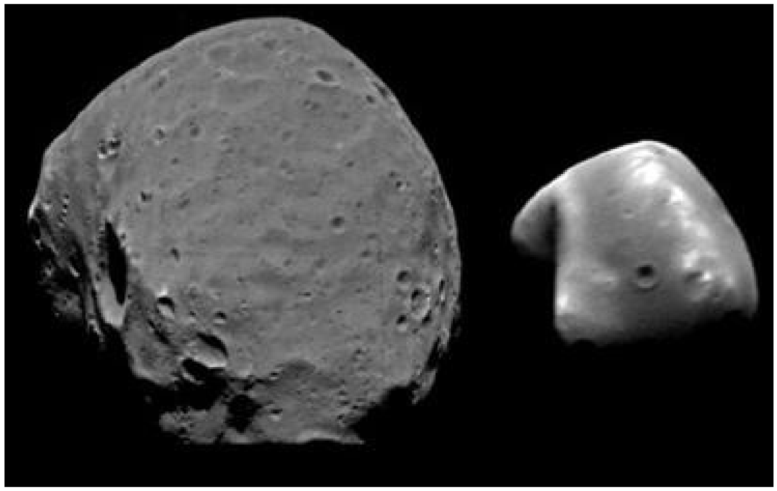

Figure 25.18: Mars has two small moons, Phobos (left) and Deimos (right). (8)

- Mercury is the smallest planet and the closest to the Sun. It has an extremely thin atmosphere, with surface temperatures ranging from very hot to very cold. Like the Moon, it is covered with craters.
- Venus is the second planet from the Sun and the closest planet to Earth, in distance and in size. It has a very thick, corrosive atmosphere, and the surface temperature is extremely high.
- Radar maps of Venus show that it has mountainous areas, as well as volcanoes surrounded by plains of lava.
- Venus rotates slowly in a direction opposite to the direction of its orbit.
- Earth is the third planet from the Sun. It is the only planet with large amounts of liquid water, and the only planet known to support life. Earth has a large moon, the only large moon around a terrestrial planet.
- Mars is the fourth planet from the Sun. It has two small moons. Mars is reddish in color because of oxidized iron (rust) in its soil. Mars has the largest mountain and the largest canyon in the solar system.
- There is a lot of water ice in the polar ice caps and under the surface of Mars.

Review Questions

1. Name the inner planets in order from the Sun outward. Then name them from smallest to largest.
2. Why do the temperatures on Mercury vary widely?
3. Venus is farther from the Sun than Mercury. Why does Venus have higher temperatures than Mercury?
4. How are maps of Venus made?
5. Name two major ways in which Earth is unlike any other planets.

6. Why does Mars appear to be red?
7. Suppose you are planning a mission to Mars. Identify two places where you might be able to get water on the planet.

Further Reading / Supplemental Links

- http://www.nasa.gov/worldbook/venus_worldbook.html
- http://solarsystem.nasa.gov/planetselector.cfm?Object=Mercury
- http://solarsystem.jpl.nasa.gov/planets/profile.cfm?Object=Mercury&Display=Kids
- http://mars.jpl.nasa.gov/extreme/
- http://www.google.com/mars/
- http://www.youtube.com/watch?v=U8-DTJpygyk
- http://www.youtube.com/watch?v=U8-DTJpygyk
- http://www.youtube.com/watch?v=HqFVxWfVtoo&feature=related
- http://www.youtube.com/watch?v=M-KfYEQUg2s

Vocabulary

day

The time it takes a planet to rotate once on its axis.

inner planets

The four planets inside the asteroid belt of our solar system; Mercury, Venus, Earth and Mars.

terrestrial planets

The solid, dense, rocky planets that are like Earth.

year

The time it takes for a planet to orbit the Sun.

Points to Consider

- We are planning to send humans to Mars sometime in the next few decades. What do you think it would be like to be on Mars? Why do you think we are going to Mars instead of Mercury or Venus?
- Why do you think the four inner planets are also called terrestrial planets? What might a planet be like if it weren't a terrestrial planet?

25.3 Outer Planets

Lesson Objectives

- Describe key features of the outer planets and their moons.
- Compare the outer planets to each other and to Earth.

Introduction

The four planets farthest from the sun—Jupiter, Saturn, Uranus, and Neptune—are called the **outer planets** of our solar system. **Figure** 25.19 shows the relative sizes of the outer planets and the Sun. Because they are much larger than Earth and the other inner planets, and because they are made primarily of gases and liquids rather than solid matter, the outer planets are also called **gas giants**.

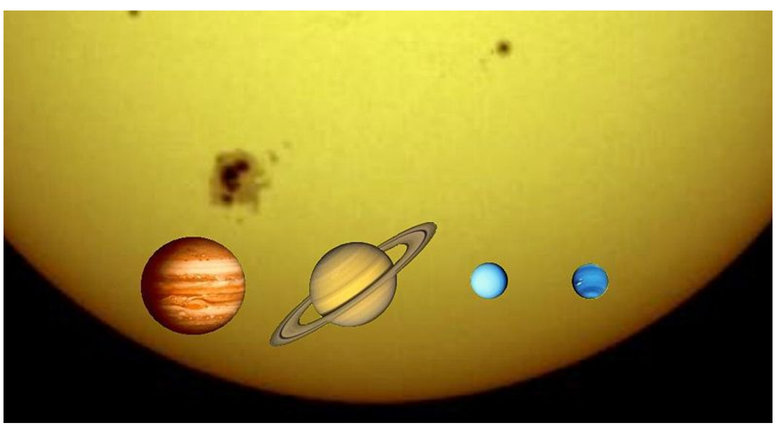

Figure 25.19: This image shows the four outer planets and the Sun, with sizes to scale. From left to right, the outer planets are Jupiter, Saturn, Uranus, and Neptune. (18)

The gas giants are made up primarily of hydrogen and helium, the same elements that make up most of the Sun. Astronomers believe that hydrogen and helium gases were found in large amounts throughout the solar system when it first formed. However, the inner planets didn't have enough mass to hold on to these very light gases. As a result, the hydrogen and helium initially on these inner planets floated away into space. Only the Sun and the massive outer planets had enough gravity to keep hydrogen and helium from drifting away.

All of the outer planets have numerous moons. All of the outer planets also have **planetary rings**, which are rings of dust and other small particles encircling a planet in a thin plane. Only the rings of Saturn can be easily seen from Earth.

Jupiter

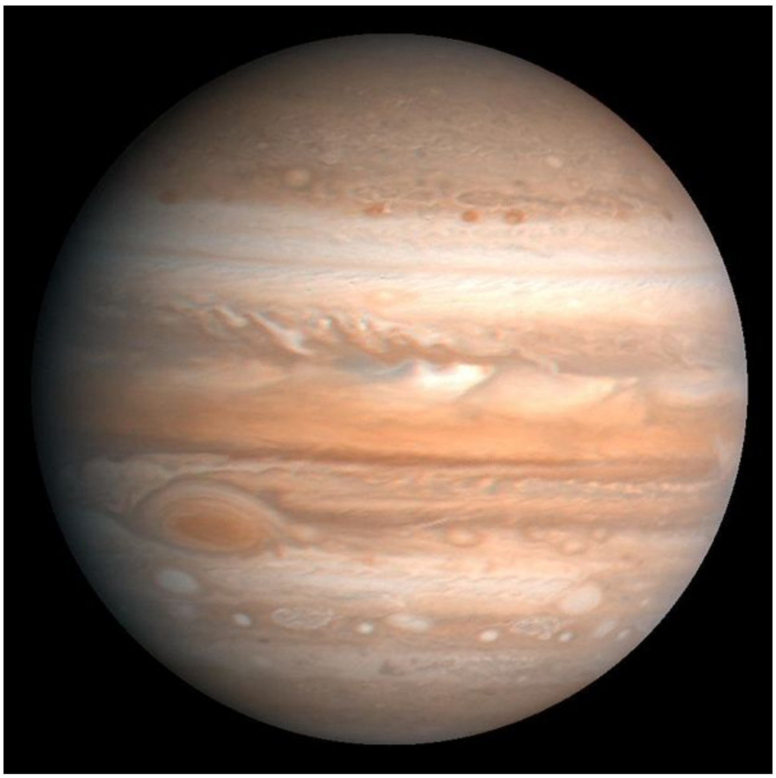

Figure 25.20: This image of Jupiter was taken by Voyager 2 in 1979. The colors were later enhanced to bring out more details. (3)

Jupiter, shown in **Figure** 25.20, is the largest planet in our solar system, and the largest object in the solar system besides the Sun. Jupiter is named for the king of the gods in Roman mythology. Jupiter is truly a giant! It is much less dense than Earth—it has 318 times the mass of Earth, but over 1,300 times Earth's volume. Because Jupiter is so large, it reflects a lot of sunlight. When it is visible, it is the brightest object in the night sky besides the Moon and Venus. This brightness is all the more impressive, since Jupiter is quite far from the Earth — 5.20 AUs away. It takes Jupiter about 12 Earth years to orbit once around the Sun.

A Ball of Gas and Liquid

If a spaceship were to try to land on the surface of Jupiter, the astronauts would find that there is no solid surface at all! Jupiter is made mostly of hydrogen, with some helium, and small amounts of other elements. The outer layers of the planet are gas. Deeper within the planet, pressure compresses the gases into a liquid. Some evidence suggests that Jupiter may have a small rocky core at its center.

A Stormy Atmosphere

The upper layer of Jupiter's atmosphere contains clouds of ammonia (NH_3) in bands of different colors. These bands rotate around the planet, but also swirl around in turbulent storms. The **Great Red Spot,** shown in **Figure** 25.21, is an enormous, oval-shaped storm found south of Jupiter's equator. It is more than three times as wide as the entire Earth! Clouds in the storm rotate in a counterclockwise direction, making one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years. It is possible, but not certain, that this storm is a permanent feature on Jupiter.

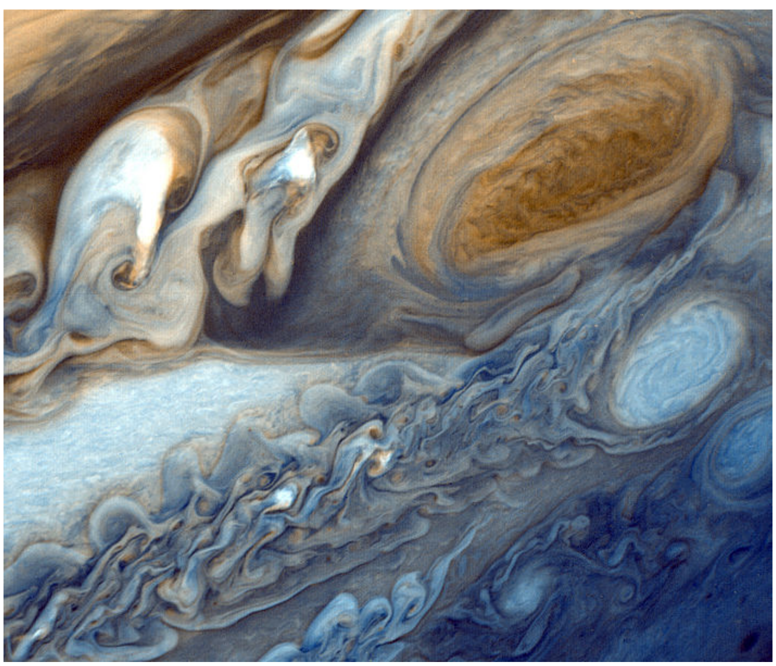

Figure 25.21: This image of Jupiter's Great Red Spot (upper right of image) was taken by the Voyager 1 spacecraft. The white storm just below the Great Red Spot is about the same diameter as Earth. (7)

Jupiter's Moons and Rings

Jupiter has a very large number of moons. As of 2008, we have discovered over 60 natural satellites of Jupiter. Of these, four are big enough and bright enough to be seen from Earth, using no more than a pair of binoculars. These four moons—named Io, Europa, Ganymede, and Callisto—were first discovered by Galileo in 1610, so they are sometimes referred to as the **Galilean moons**.

Figure 25.22 shows the four Galilean moons and their sizes relative to the Great Red Spot. The Galilean moons are larger than the dwarf planets Pluto, Ceres, and Eris. In fact, Ganymede, which is the biggest moon in the solar system, is even larger than the planet Mercury!

Scientists are particularly interested in Europa, the smallest of the Galilean moons, because it may be a likely place to find extraterrestrial life. The surface of Europa is a smooth layer of ice. Evidence suggests that there is an ocean of liquid water under the ice. Europa also has a continual source of energy—it is heated as it is stretched and squashed by tidal forces from Jupiter. Because it has liquid water and a continual heat source, astrobiologists surmise that life might have formed on Europa much as it did on Earth. Numerous missions have been planned to explore Europa, including plans to drill through the ice and send a probe into the ocean. However, no such mission has yet been attempted.

In 1979, two spacecrafts—Voyager 1 and Voyager 2—visited Jupiter and its moons. Photos from the Voyager missions showed that Jupiter has a ring system. This ring system is very faint, so it is very difficult to observe from Earth.

Saturn

Saturn, shown in **Figure** 25.23, is famous for its beautiful rings. Saturn's mass is about 95 times the mass of Earth, and its volume is 755 times Earth's volume, making it the second largest planet in the solar system. Despite its large size, Saturn is the least dense planet in our solar system. It is less dense than water, which means if there could be a bathtub big enough, Saturn would float. In Roman mythology, Saturn was the father of Jupiter. So, it is an appropriate name for the next planet beyond Jupiter. Saturn orbits the Sun once about every 30 Earth years.

Saturn's composition is similar to Jupiter. It is made mostly of hydrogen and helium, which are gases in the outer layers and liquids at deeper layers. It may also have a small solid core. The upper atmosphere has clouds in bands of different colors. These rotate rapidly around the planet, but there seems to be less turbulence and fewer storms on Saturn than on Jupiter.

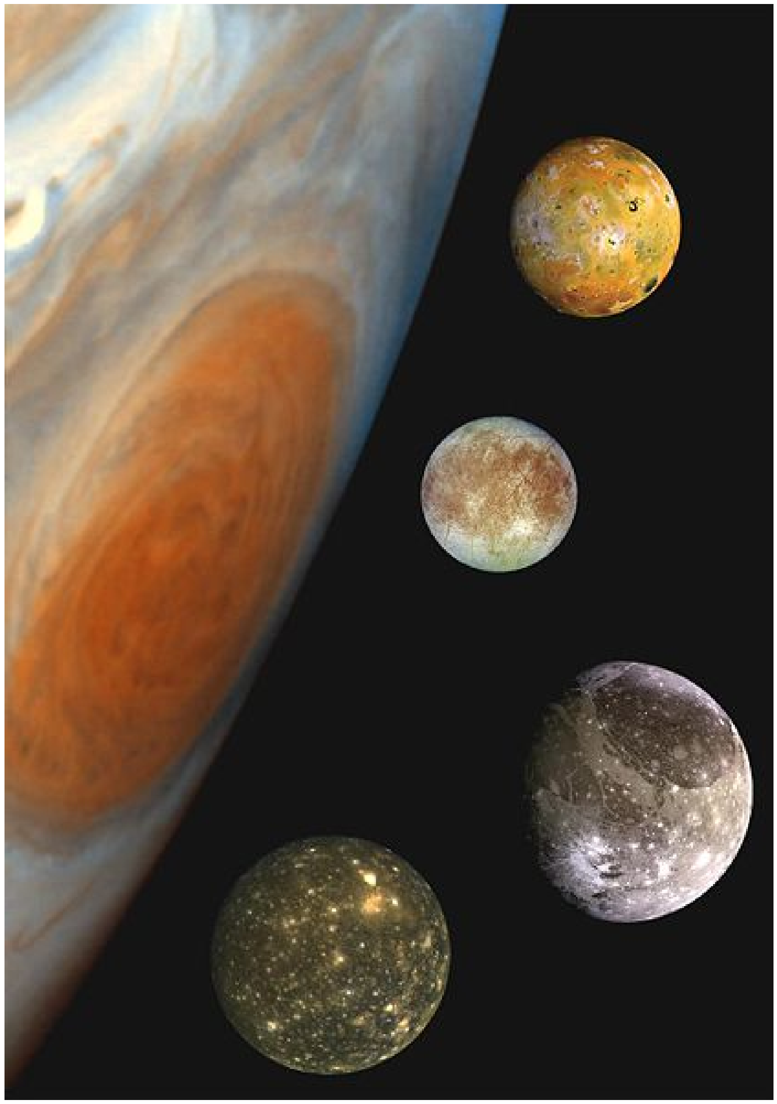

Figure 25.22: This composite image shows the the four Galilean moons and Jupiter. From top to bottom, the moons are Io, Europa, Ganymede and Callisto. Jupiter's Great Red Spot is in the background. Sizes are to scale. (37)

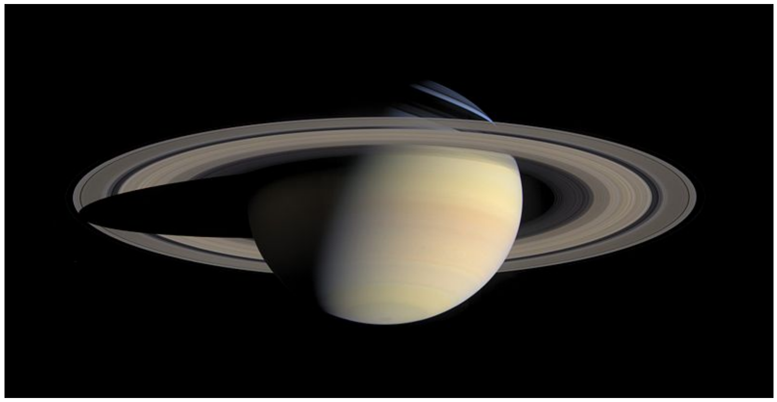

Figure 25.23: This image of Saturn and its rings is a composite of pictures taken by the Cassini orbiter in 2004. (16)

A Weird Hexagon

There is a strange feature at Saturn's north pole—the clouds form a hexagonal pattern, as shown in the infrared image in **Figure** 25.24. This hexagon was viewed by Voyager 1 in the 1980's, and again by the Cassini Orbiter in 2006, so it seems to be a long-lasting feature. Though astronomers have hypothesized and speculated about what causes these hexagonal cloud, no one has yet come up with a convincing explanation.

Saturn's Rings

The rings of Saturn were first observed by Galileo in 1610. However, he could not see them clearly enough to realize they were rings; he thought they might be two large moons, one on either side of Saturn. In 1659, the Dutch astronomer Christiaan Huygens was the first to realize that the rings were in fact rings. The rings circle Saturn's equator. They appear tilted because Saturn itself is tilted about 27 degrees to the side. The rings do not touch the planet.

The Voyager 1 spacecraft visited Saturn in 1980, followed by Voyager 2 in 1981. The Voyager probes sent back detailed pictures of Saturn, its rings, and some of its moons. From the Voyager data, we learned that Saturn's rings are made of particles of water and ice, with a little bit of dust as well. There are several gaps in the rings. Some of the gaps have been cleared out by moons that are within the rings. Scientists believe the moons' gravity caused ring dust and gas to fall towards the moon, leaving a gap in the rings. Other gaps in the rings are caused by the competing gravitational forces of Saturn and of moons outside the rings.

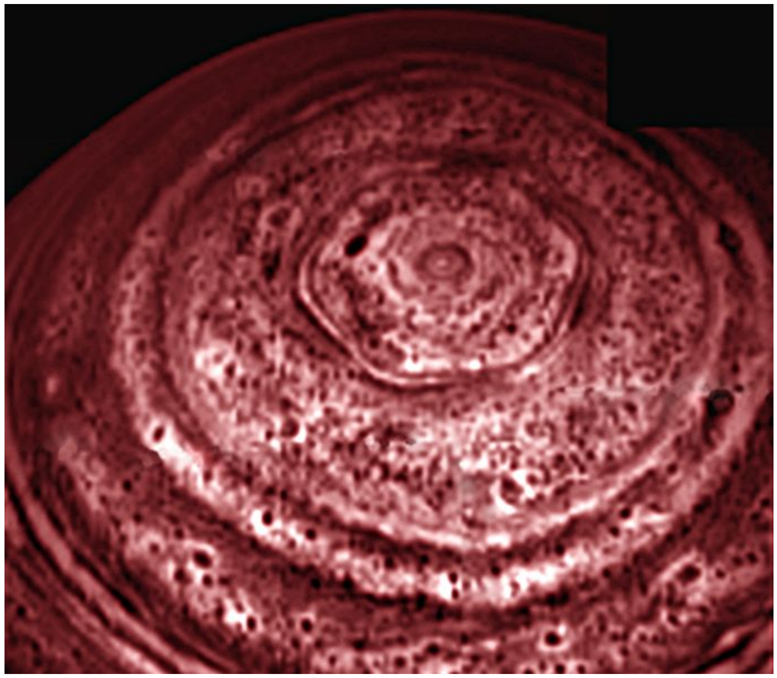

Figure 25.24: This infrared image taken of Saturn's north pole shows that the clouds are in a hexagon (six-sided) shape. (11)

Saturn's Moons

As of 2008, over 60 moons have been identified around Saturn. Most of them are very small. Some are even found within the rings. In a sense, all the particles in the rings are like little moons, too, because they orbit around Saturn. Only seven of Saturn's moons are large enough for gravity to have made them spherical, and all but one are smaller than Earth's moon.

Saturn's largest moon, Titan, is about one and a half times the size of Earth's Moon and is also larger than the planet Mercury. **Figure** 25.25 compares the size of Titan to Earth. Scientists are very interested in Titan because it has an atmosphere that is similar to what Earth's atmosphere might have been like before life developed on Earth. Titan may have a layer of liquid water under a layer of ice on the surface. Scientists now believe there are also lakes on the surface of Titan, but these lakes contain liquid methane (CH_4) and ethane (C_2H_6) instead of water! Methane and ethane are compounds found in natural gas, a mixture of gases found naturally on Earth and often used as fuel.

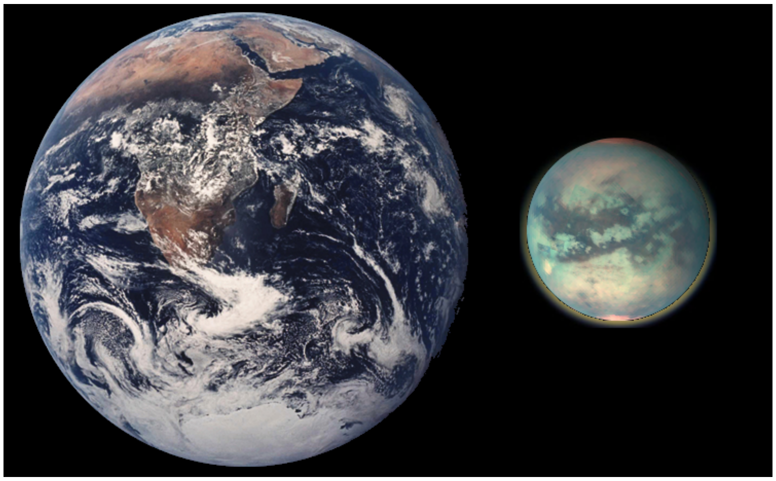

Figure 25.25: This composite image compares Saturn's largest moon, Titan (right) to Earth (left). Titan has an atmosphere similar to what Earth's might have been like before life formed on Earth. (24)

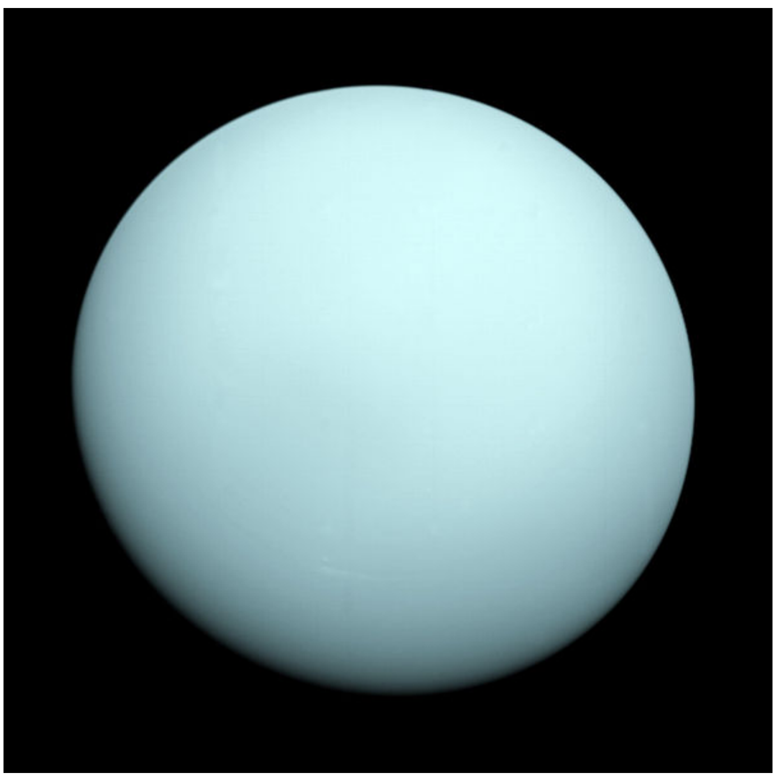

Figure 25.26: This image of Uranus was taken by Voyager 2 in 1986. (23)

Uranus

Uranus, shown in **Figure** 25.26, is named for the Greek god of the sky. In Greek mythology, Uranus was the father of Cronos, the Greek equivalent of the Roman god Saturn. By the way, astronomers pronounce the name "YOOR-uh-nuhs."

Uranus was not known to ancient observers. It was first discovered by the astronomer William Herschel in 1781. Uranus can be seen from Earth with the unaided eye, but it was overlooked for centuries because it is very faint. Uranus is faint because it is very far away, not because it is small. It is about 2.8 billion kilometers (1.8 billion miles) from the Sun. Light from the Sun takes about 2 hours and 40 minutes to reach Uranus. Uranus orbits the Sun once about every 84 Earth years.

An Icy Blue-Green Ball

Like Jupiter and Saturn, Uranus is composed mainly of hydrogen and helium. It has a thick layer of gas on the outside, then liquid further on the inside. However, Uranus has a higher percentage of icy materials, such as water, ammonia (NH_3), and methane (CH_4), than Jupiter and Saturn do. When sunlight reflects off Uranus, clouds of methane filter out red light, giving the planet a blue-green color. There are bands of clouds in the atmosphere of Uranus, but they are hard to see in normal light, so the planet looks like a plain blue ball.

Uranus is the lightest of the outer planets, with a mass about 14 times the mass of Earth. Even though it has much more mass than Earth, it is much less dense than Earth. At the "surface" of Uranus, the gravity is actually weaker than on Earth's surface. If you were at the top of the clouds on Uranus, you would weigh about 10% less than what you weigh on Earth.

The Sideways Planet

Most of the planets in the solar system rotate on their axes in the same direction that they move around the Sun. Uranus, though, is tilted on its side so its axis is almost parallel to its orbit. In other words, it rotates like a top that was turned so that it was spinning parallel to the floor. Scientists think that Uranus was probably knocked over by a collision with another planet-sized object billions of years ago.

Rings and Moons of Uranus

Uranus has a faint system of rings, as shown in **Figure** 25.27. The rings circle the planet's equator, but because Uranus is tilted on its side, the rings are almost perpendicular to the planet's orbit.

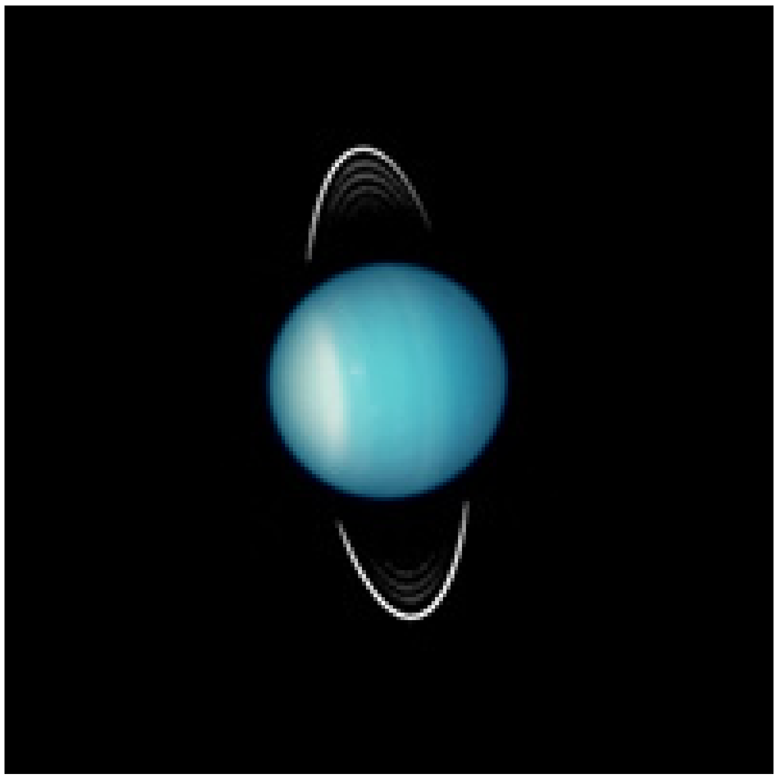

Figure 25.27: This image from the Hubble Space Telescope shows the faint rings of Uranus. The planet is tilted on its side, so the rings are nearly vertical. (12)

Uranus has 27 moons that we know of. All but a few of them are named for characters from the plays of William Shakespeare. The five biggest moons of Uranus—Miranda, Ariel, Umbriel, Titania and Oberon—are shown in **Figure** 25.28.

Figure 25.28: These Voyager 2 photos have been resized to show the relative sizes of the five main moons of Uranus. (14)

Neptune

Neptune, shown in **Figure** 25.29, is the eighth planet from the Sun. It is the only major planet that can't be seen from Earth without a telescope. Scientists predicted the existence of Neptune before it was actually discovered. They noticed that Uranus did not always appear exactly where it should appear. They knew there must be another planet beyond Uranus whose gravity was affecting Uranus' orbit. This planet was discovered in 1846, in the position that had been predicted, and it was named Neptune for the Roman god of the sea due to its blush color.

Neptune has slightly more mass than Uranus, but it is slightly smaller in size. In many respects, it is similar to Uranus. Uranus and Neptune are often considered "sister planets." Neptune, which is nearly 4.5 billion kilometers (2.8 billion miles) from the Sun, is much farther from the Sun than even distant Uranus. It moves very slowly in its orbit, taking 165 Earth years to complete one orbit around the Sun.

Extremes of Cold and Wind

Neptune is blue in color, with a few darker and lighter spots. The blue color is caused by atmospheric gases, including methane (CH_4). When Voyager 2 visited Neptune in 1986, there was a large dark-blue spot south of the equator. This spot was called the Great Dark Spot. However, when the Hubble Space Telescope took pictures of Neptune in 1994, the Great Dark Spot had disappeared. Instead, another dark spot had appeared north of the equator. Astronomers believe both of these spots represent gaps in the methane clouds on Neptune.

The changing appearance of Neptune is due to its turbulent atmosphere. The winds on Neptune are stronger than on any other planet in the solar system, reaching speeds of 1,100

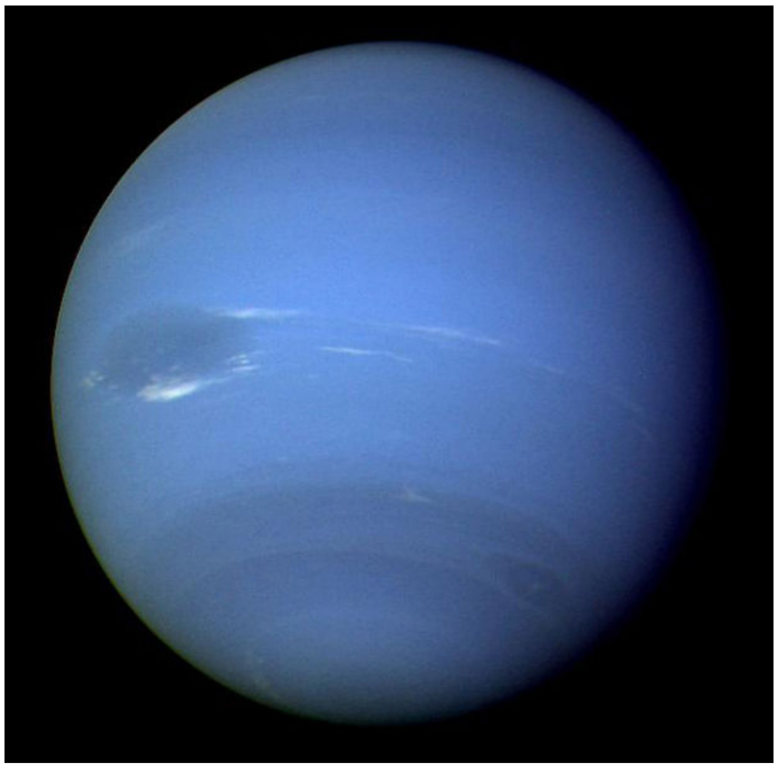

Figure 25.29: This image of Neptune was taken by Voyager 2 in 1989. The Great Dark Spot seen on the left center in the picture has since disappeared, but a similar dark spot has appeared on another part of the planet. (22)

km/h (700 mi/h), close to the speed of sound. This extreme weather surprised astronomers, since the planet receives little energy from the Sun to power weather systems. Neptune is also one of the coldest places in the solar system. Temperatures at the top of the clouds are about –218$_o$C (–360$_o$F).

Neptune's Rings and Moons

Like the other outer planets, Neptune has rings of ice and dust. These rings are much thinner and fainter than those of Saturn. Some evidence suggests that the rings of Neptune may be unstable, and may change or disappear in a relatively short time.

Neptune has 13 known moons. Triton, shown in **Figure** 25.30, is the only one of them that has enough mass to be spherical in shape. Triton orbits in the direction opposite to the orbit of Neptune. Scientists think Triton did not form around Neptune, but instead was captured by Neptune's gravity as it passed by.

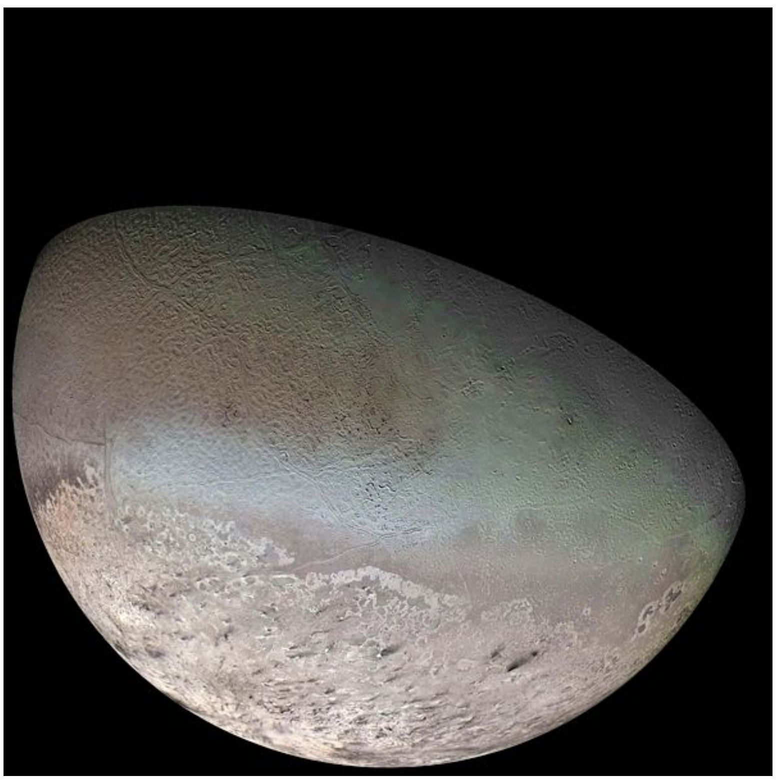

Figure 25.30: This image Triton, Neptune's largest moon, was taken by Voyager 2 in 1989. (15)

Pluto

Pluto was once considered one of the outer planets, but when the definition of a planet was changed in 2006, Pluto became one of the leaders of the dwarf planets. It is one of the largest and brightest objects that make up this group. Look for Pluto in the next section in the discussion of dwarf planets.

Lesson Summary

- The four outer planets—Jupiter, Saturn, Uranus, and Neptune—are all gas giants made primarily of hydrogen and helium. They have thick gaseous outer layers and liquid interiors.
- All of the outer planets have numerous moons, as well as planetary rings made of dust and other particles.
- Jupiter is by far the largest planet in the solar system. It has bands of different colored clouds, and a long-lasting storm called the Great Red Spot.
- Jupiter has over 60 moons. The four biggest were discovered by Galileo, and are called the Galilean moons.
- One of the Galilean moons, Europa, may have an ocean of liquid water under a layer of ice. The conditions in this ocean might be right for life to have developed.
- Saturn is smaller than Jupiter, but similar in composition and structure.
- Saturn has a large system of beautiful rings. Saturn's largest moon, Titan, has an atmosphere similar to Earth's atmosphere before life formed.
- Uranus and Neptune were discovered in modern times. They are similar to each other in size and composition. They are both smaller than Jupiter and Saturn, and also have more icy materials.
- Uranus is tilted on its side, probably due to a collision with a large object in the past.
- Neptune is very cold and has very strong winds. It had a large dark spot that disappeared, then another dark spot appeared on another part of the planet. These dark spots are storms in Neptune's atmosphere.
- Pluto is no longer considered one of the outer planets. It is now considered a dwarf planet.

Review Questions

1. Name the outer planets a) in order from the Sun outward, b) from largest to smallest by mass, and c) from largest to smallest by size.
2. Why are the outer planets called gas giants?
3. How do the Great Red Spot and Great Dark Spot differ?
4. Name the Galilean moons, and explain why they are called that.
5. Why might Europa be a likely place to find extraterrestrial life?

6. What causes gaps in Saturn's rings?
7. Why are scientists interested in the atmosphere of Saturn's moon Titan?
8. What liquid is found on the surface of Titan?
9. Why is Uranus blue-green in color?
10. What is the name of Neptune's largest moon?

Further Reading / Supplemental Links

- http://www.nasa.gov/worldbook/jupiter_worldbook.html
- http://solarsystem.nasa.gov/planetselector.cfm?Object=Jupiter
- http://www.youtube.com/watch?v=5iVw72sX3Bg
- http://www.youtube.com/watch?v=iLXeUVCNoX8
- http://www.youtube.com/watch?v=29wfzotaBIg
- http://www.youtube.com/watch?v=FqX2YdnwtRc

Vocabulary

Galilean moons The four largest moons of Jupiter discovered by Galileo.

gas giants The four large outer planets composed of the gases hydrogen and helium.

Great Red Spot An enormous, oval shaped storm on Jupiter.

outer planets The four large planets beyond the asteroid belt in our solar system.

planetary rings Rings of dust and rock encircling a planet in a thin plane.

Points to Consider

- The inner planets are small and rocky, while the outer planets are large and gaseous. Why might the planets have formed into two groups like they are?
- We have discussed the Sun, the planets, and the moons of the planets. What other objects can you think of that can be found in our solar system?

25.4 Other Objects in the Solar System

Lesson Objectives

- Locate and describe the asteroid belt.

- Explain where comets come from and what causes their tails.
- Differentiate between meteors, meteoroids, and meteorites.

Introduction

When our solar system formed, most of the matter ended up in the Sun, the star at the center of the system. Material spinning in a disk around the Sun clumped together into larger and larger pieces, forming the eight planets and their moons. But some of the smaller pieces of matter in the solar system never joined one of these larger bodies. In this lesson, we will talk about some of these other objects in the solar system.

Asteroids

Asteroids are very small, rocky bodies that orbit the Sun. "Asteroid" means "star-like," and in a telescope, asteroids look like points of light, just like stars. Asteroids are also sometimes called *planetoids or minor planets,* because in some ways they are similar to miniature planets. Unlike planets, though, asteroids are irregularly shaped because they do not have enough gravity to become round like planets. They do not have atmospheres, and they are not geologically active. The only geological changes to an asteroid are due to collisions, which may break up the asteroid or create craters on the asteroid's surface. **Figure** 25.31 shows a typical asteroid.

The Asteroid Belt

Hundreds of thousands of asteroids have been discovered in our solar system. They are still being discovered at a rate of about 5,000 new asteroids per month! The majority of the asteroids are found in between the orbits of Mars and Jupiter, in a region called the **asteroid belt**, as shown in **Figure** 25.32. Although there are many thousands of asteroids in the asteroid belt, their total mass adds up to only about 4% of Earth's moon.

Scientists believe that the bodies in the asteroid belt formed there during the formation of the solar system. However, they have never been able to form into a single planet because the gravity of Jupiter, which is very massive, continually disrupts the asteroids.

Near-Earth Asteroids

Near-Earth asteroids are asteroids whose orbits cross Earth's orbit. Any object whose orbit crosses Earth can collide with Earth. There are over 4,500 known near-Earth asteroids; between 500 and 1,000 of these are over 1 kilometer in diameter. Small asteroids do in fact collide with Earth on a regular basis—asteroids 5–10 m in diameter hit Earth on average about once per year. Evidence suggests that large asteroids hitting Earth in the past have

Figure 25.31: Asteroid 951 Gaspra was the first asteroid photographed at close range. This picture was taken in 1991 by the Galileo probe on its way to Jupiter. 951 Gaspra is a medium-sized asteroid, measuring about 19 by 12 by 11 kilometers (12 by 7.5 by 7 miles). (6)

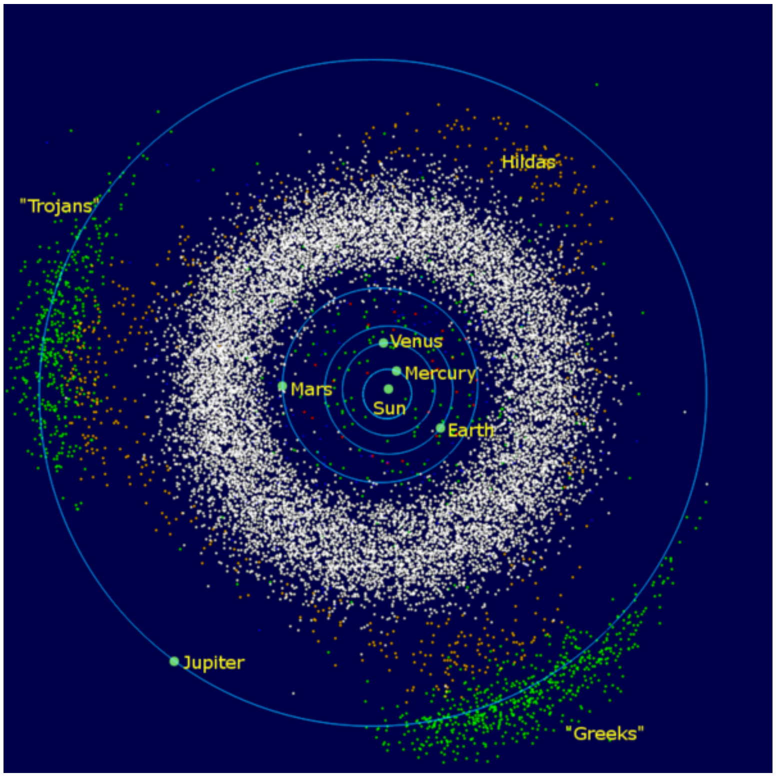

Figure 25.32: The asteroid belt is a ring of many asteroids between the orbits of Mars and Jupiter. The white dots in the figure are asteroids in the main asteroid belt. Other groups of asteroids closer to Jupiter are called the Hildas (orange), the Trojans (green), and the Greeks (also green). (25)

caused many organisms to die and many species to go extinct. Astronomers are always on the lookout for new asteroids, and follow the known near-Earth asteroids closely, so they can predict a possible collision as early as possible.

Asteroid Missions

Scientists are interested in asteroids in part because knowing more about what they are made of can tell us about our solar system and how it might have formed. They may also eventually be mined for rare minerals or for construction projects in space. Some asteroids have been photographed as spacecraft have flown by on their way to the outer planets. A few missions have been sent out to study asteroids directly. In 1997, the NEAR Shoemaker probe went into orbit around an asteroid called 433 Eros, and finally landed on its surface in 2001. The Japanese Hayabusa probe is currently studying an asteroid and may return samples of its surface to Earth. In 2007, NASA launched the Dawn mission, which is scheduled to visit some of the largest asteroids in 2011-2015.

Meteors

If you have spent much time looking at the sky on a dark night, you have probably seen a 'shooting star', like in **Figure** 25.33. A shooting star is a streak of light across the sky. The proper scientific name for a shooting star is a **meteor**. Meteors are not stars at all. Rather, they are small pieces of matter burning up as they enter Earth's atmosphere from space.

Meteoroids

Before these small pieces of matter enter Earth's atmosphere, they are called **meteoroids**. Meteoroids are like asteroids, only smaller. Meteoroids range from the size of boulders down to the size of tiny sand grains. Objects larger than meteoroids are considered asteroids, and objects smaller than meteoroids are considered *interplanetary dust.* Meteoroids are sometimes found clustered together in long trails. These are remnants left behind by comets. When Earth passes through one of these clusters, there is a **meteor shower**, an increase in the number of bright meteors in a particular region of the sky for a period of time.

Meteorites

Suppose a small rocky object—a meteoroid—enters Earth's atmosphere. Friction in the atmosphere heats the object quickly so it starts to vaporize, leaving a trail of glowing gases. At this point, it has become a meteor. Most meteoroids vaporize completely before they ever reach Earth's surface, but larger meteoroids may have a small core of material that travels

Figure 25.33: This photo captures a meteor - also called a 'shooting star,' streaking across the sky to the right of the Milky Way. (13)

all the way through the atmosphere and hits the Earth's surface. The solid remains of a meteoroid found on Earth's surface is called a **meteorite**.

Meteorites provide clues about our solar system. Many meteorites come from meteoroids that formed when the solar system formed (**Figure** 25.34). Some are from the insides of asteroids that have split apart. A few meteorites are made of materials more like the rocks on Mars. Scientists believe the material in these meteorites was actually knocked off the surface of Mars by an asteroid impact, and then entered Earth's atmosphere as a meteor.

Comets

Comets are small, icy objects that orbit the Sun in very elliptical orbits. Their orbits carry them from the outer solar system to the inner solar system, close to the Sun. When a comet gets close to the Sun, the outer layers of ice melt and evaporate. The gas and dust released in this way forms an atmosphere—called a *coma*—around the comet. Radiation and particles streaming from the Sun also push some of this gas and dust into a long *tail*, which always points away from the Sun no matter which way the comet is moving. **Figure** 25.35 shows Comet Hale-Bopp, which shone brightly for several months in 1997.

Gases in the coma and tail of a comet glow, and also reflect light from the Sun. Comets are very hard to see except when they have their comas and tails. For this reason, comets appear for only a short time when they are near the Sun, then seem to disappear again as

Figure 25.34: A lunar meteorite (27)

they move back to the outer solar system. The time between one appearance of a comet and the next is called the comet's *period*. For example, the first comet whose period was known, Halley's comet, has a period of 75 years. It last traveled through the inner solar system in 1986, and will appear again in 2061.

Where Comets Come From

Comets that have periods of about 200 years or less are considered short period comets. Most short-period comets come from a region beyond the orbit of Neptune. This area, which contains not only comets but also asteroids and at least two dwarf planets, is called the *Kuiper belt.* (Kuiper is pronounced "KI-per," rhyming with "viper.")

Some comets have much longer periods, as long as thousands or even millions of years. Most long-period comets come from a very distant region of the solar system called the *Oort cloud*, which is about 50,000–100,000 AU from the Sun (50,000–100,000 times the distance from the Sun to Earth). Comets carry materials from the outer solar system to the inner solar system. Comets may have brought water and other substances to Earth during collisions early in Earth's history.

Figure 25.35: Comet Hale-Bopp, also called the Great Comet of 1997, shone brightly for several months in 1997. The comet has two visible tails: a bright, curved dust tail and a fainter, straight tail of ions (charged atoms) pointing directly away from the Sun. (20)

Dwarf Planets

The **dwarf planets** of our solar system are exciting proof of how much we are learning about our solar system. With the discovery of many new objects in our solar system, in 2006, astronomers refined the definition of a planet. According to the new definition, a planet must:

1. orbit a star
2. be big enough that its own gravity causes it to be shaped like a sphere
3. be small enough that it isn't a star itself
4. have cleared the area of its orbit of smaller objects

At the same time, astronomers defined a new type of object: dwarf planets. A dwarf planet is an object that meets numbers 1–3 above, but not number 4. There are four dwarf planets in our solar system: Ceres, Pluto, Makemake and Eris.

Figure 25.36 shows Ceres, a rocky, spherical body that is by far the largest object in the asteroid belt. Before 2006, Ceres was considered the largest of the asteroids. Ceres has enough mass that its gravity causes it to be shaped like a sphere. Still, Ceres only has about 1.3% of the mass of the Earth's Moon. Ceres orbits the Sun, is round and is not a star but the area of its orbit is full of other smaller bodies, so Ceres fails the fourth criterion for being a planet, and is now considered a dwarf planet.

Figure 25.36: This composite image compares the size of the dwarf planet Ceres to Earth and the Moon. (31)

Pluto

From the time it was discovered in 1930 until 2006, Pluto was considered the ninth planet of the solar system. However, it was always thought of as an oddball planet. Unlike the other outer planets in the solar system, which are all gas giants, it is small, icy and rocky. Its diameter is about 2400 kilometers. It is only about 1/5 the mass of Earth's Moon. Its orbit is tilted relative to the other planets and is shaped like a long, narrow ellipse, sometimes even passing inside the orbit of Neptune.

Starting in 1992, many objects have been discovered in the same area as Pluto's orbit, an area now known as the Kuiper belt. The Kuiper belt begins outside the orbit of Neptune and continues out at least 500 AU. We have discovered more than 200 million Kuiper belt objects. Pluto orbits within this region. When the definition of a planet was changed in 2006, Pluto failed the test of clearing out its orbit of other bodies, so it is now considered a dwarf planet.

Pluto has 3 moons of its own. The largest, Charon, is big enough that the Pluto-Charon system is sometimes considered to be a double dwarf planet (**Figure** 25.37). Two smaller moons, Nix and Hydra, were discovered in 2005.

Makemake

Makemake is the third largest and second brightest dwarf planet we have discovered so far (**Figure** 25.37). It is about three quarters the size of Pluto. Its diameter is estimated to be between 1300 and 1900 kilometers. Makemake is named after the deity that created humanity in the mythology of the people of Easter Island. It orbits the Sun in 310 years at a distance between 38.5 to 53 AU. It is believed to be made of methane, ethane and nitrogen ices.

Eris

Eris is the largest known dwarf planet in the solar system — about 27% more massive than Pluto (**Figure** 25.37). It was not discovered until 2003 because it is extremely far away from the Sun. Although Pluto, Makemake and Eris are in the Kuiper belt, Eris is about 3 times farther from the Sun than Pluto is, and almost 100 times farther from the Sun than Earth is. When it was first discovered, it was considered for a short time to be the "tenth planet" in the solar system. The discovery of Eris helped prompt the new definition of planets and dwarf planets in 2006. Eris also has a small moon, Dysnomia that orbits it once about every 16 days.

Astronomers already know there may be other dwarf planets in the outer reaches of the solar system. Look for Haumea, Quaoar, Varuna and Orcus to be possibly added to the list of dwarf planets in the future. We still have a lot to discover and explore!

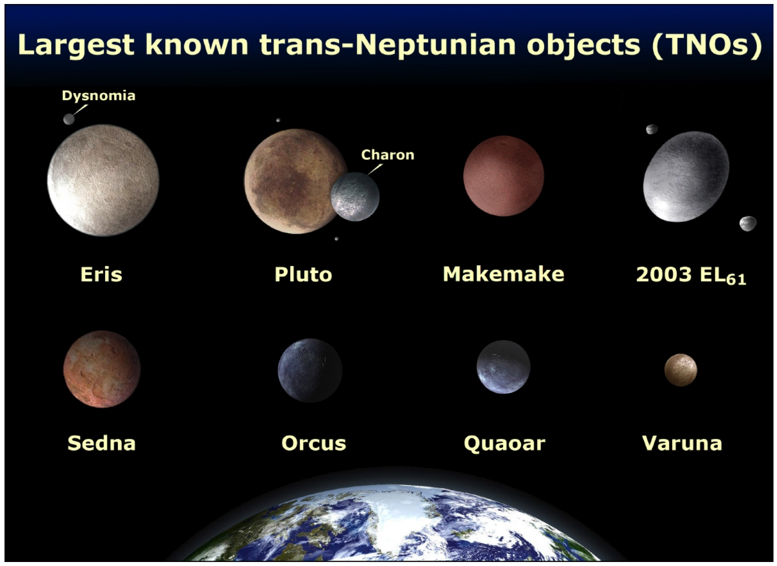

Figure 25.37: Largest Known Trans-Neptunian Objects. (36)

Lesson Summary

- Asteroids are irregularly-shaped, rocky bodies that orbit the Sun. Most of them are found in the asteroid belt, between the orbits of Mars and Jupiter.
- Meteoroids are smaller than asteroids, ranging from the size of boulders to the size of sand grains. When meteoroids enter Earth's atmosphere, they vaporize, creating a trail of glowing gas called a meteor. If any of the meteoroid reaches Earth, the remaining object is called a meteorite.
- Comets are small, icy objects that orbit the Sun in very elliptical orbits. When they are close to the Sun, they form comas and tails, which glow and make the comet more visible.
- Short-period comets come from the Kuiper belt, beyond Neptune. Long-period comets come from the very distant Oort cloud.
- Dwarf planets are spherical bodies that orbit the Sun, but that have not cleared their orbit of smaller bodies. Ceres is a dwarf planet in the asteroid belt. Pluto, Makemake and Eris are dwarf planets in the Kuiper belt.

Review Questions

1. Arrange the following from smallest to largest: asteroid, star, meteoroid, planet, dwarf planet.
2. Where are most asteroids found?
3. What is the difference between a meteor, a meteoroid, and a meteorite?
4. What kind of objects would scientists study to learn about the composition of the Oort

cloud?

5. Why is Pluto no longer considered a planet?
6. Name the four known dwarf planets in our solar system.

Further Reading / Supplemental Links

- http://www.nasa.gov/worldbook/asteroid_worldbook.html
- http://www.iau.org/iau0602.423.0.html
- http://en.wikipedia.org/

Vocabulary

asteroid

Rocky objects larger than a few hundred meters that orbit the Sun in the region known as the asteroid belt.

asteroid belt

Region between the orbits of Mars and Jupiter where many asteroids are found.

comet

Asmall, icy, dusty object in orbit around the Sun.

dwarf planet

Around celestial object orbiting the Sun that has not cleared its orbit of other objects.

Kuiper belt

Aregion of space around the Sun beyond the orbit of Neptune that contains millions of frozen objects.

meteor

Material from outer space that burns up as it enters Earth's atmosphere.

meteorite

The solid portion of a meteor that hits Earth's surface.

meteoroid

Asmall rock in interplanetary space that has not yet entered Earth's atmosphere.

meteor shower

An area of frequent meteors appearing to originate in a particular part of the sky.

Points to Consider

- In 2006, astronomers changed the definition of a planet and created a new category of dwarf planets. Do you think planets, dwarf planets, moons, asteroids, and meteoroids are clearly separate groups?
- What defines each of these groups, and what do objects in these different groups have in common? Could an object change from being in one group to another? How?
- We have learned about many different kinds of objects that are found within our solar system. What objects or systems of objects can you think of that are found outside our solar system?

Image Sources

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Chapter 26

Stars, Galaxies, and the Universe

26.1 Stars

Lesson Objectives

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

Introduction

When you look at the sky on a clear night, you can see dozens, perhaps even hundreds, of tiny points of light. Almost every one of these points of light is a star, a giant ball of glowing gas at a very, very high temperature. Some of these stars are smaller than our Sun, and some are larger. Except for our own Sun, all stars are so far away that they only look like single points, even through a telescope.

Constellations

For centuries, people have seen the same stars you can see in the night sky. People of many different cultures have identified **constellations,** which are apparent patterns of stars in the sky. **Figure** 26.1 shows one of the most easily recognized constellations. The ancient Greeks thought this group of stars looked like a hunter from one of their myths, so they named it Orion after him. The line of three stars at the center of the picture is ”Orion’s Belt”.

Figure 26.1: The constellation Orion is a familiar pattern of stars in the sky. (13)

The patterns in constellations and in groups or clusters of stars, called asterisms, stay the same night after night. However, in a single night, the stars move across the sky, keeping the same patterns. This apparent nightly motion of the stars is actually due to the rotation of Earth on its axis. It isn't the stars that are moving; it is actually Earth spinning that makes the stars seem to move. The patterns shift slightly with the seasons, too, as Earth revolves around the Sun. As a result, you can see different constellations in the winter than in the summer. For example, Orion is a prominent constellation in the winter sky, but not in the summer sky.

Apparent Versus Real Distances

Although the stars in a constellation appear close together as we see them in our night sky, they are usually at very different distances from us, and therefore they are not at all close together out in space. For example, in the constellation Orion, the stars visible to the naked eye are at distances ranging from just 26 light-years (which is relatively close to Earth) to several thousand light-years away. A light-year is the distance that light can travel in one year; it is a large unit of distance used to measure the distance between objects in space.

Energy of Stars

Only a small portion of the light from the Sun reaches Earth; yet that light is enough to keep the entire planet warm and to provide energy for all the living things on Earth. The Sun is a fairly average star. The reason the Sun appears so much bigger and brighter than any of the other stars is that it is very close to us. Some other stars produce much more energy than the Sun. How do stars generate so much energy?

Nuclear Fusion

Stars are made mostly of hydrogen and helium. These are both very lightweight gases. However, there is so much hydrogen and helium in a star that the weight of these gases is enormous. In the center of a star, the pressure is great enough to heat the gases and cause **nuclear fusion reactions**. In a nuclear fusion reaction, the nuclei, or centers of two atoms join together and create a new atom from two original atoms. In the core of a star, the most common reaction turns two hydrogen atoms into a helium atom. Nuclear fusion reactions require a lot of energy to get started, but once they are started, they produce even more energy.

The energy from nuclear reactions in the core pushes outward, balancing the inward pull of gravity on all the gas in the star. This energy slowly moves outward through the layers of the star until it finally reaches the outer surface of the star. The outer layer of the star glows brightly, sending the energy out into space as electromagnetic radiation, including visible light, heat, ultraviolet light, and radio waves.

Scientists have built machines called accelerators that can propel subatomic particles until they have attained almost the same amount of energy as found in the core of a star. When these particles collide with each other head-on, new particles are created. This process simulates the nuclear fusion that takes place in the cores of stars. It also simulates the conditions that allowed for the first Helium atom to be produced from the collision of two hydrogen atoms when the Universe was only a few minutes old. Two well-known accelerators are SLAC in California, USA and CERN in Switzerland.

How Stars Are Classified

Stars come in many different colors. If you look at the stars in Orion (as shown in **Figure** 26.1), you will notice that there is a bright, red star in the upper left and a bright, and a blue star in the lower right. The red star is named Betelgeuse (pronounced BET-ul-juice), and the blue star is named Rigel.

Color and Temperature

If you watch a piece of metal, such as a coil of an electric stove as it heats up, you can see how color is related to temperature. When you first turn on the heat, the coil looks black, but you can feel the heat with your hand held several inches from the coil. As the coil gets hotter, it starts to glow a dull red. As it gets hotter still, it becomes a brighter red, then orange. If it gets extremely hot, it might look yellow-white, or even blue-white. Like a coil on a stove, a star's color is determined by the temperature of the star's surface. Relatively cool stars are red, warmer stars are orange or yellow, and extremely hot stars are blue or blue-white.

Classifying Stars by Color

The most common way of classifying stars is by color. **Table** 26.1 shows how this classification system works. The class of a star is given by a letter. Each letter corresponds to a color, and also to a range of temperatures. Note that these letters don't match the color names; they are left over from an older system that is no longer used.

Table 26.1: **Classification of Stars By Color and Temperature**

Class	Color	Temperature range	Sample Star
O	Blue	30,000 K or more	Zeta Ophiuchi
B	Blue-white	10,000–30,000 K	Rigel
A	White	7,500–10,000 K	Altair

Table 26.1: (continued)

Class	Color	Temperature range	Sample Star
F	Yellowish-white	6,000–7,500 K	Procyon A
G	Yellow	5,500–6,000 K	Sun
K	Orange	3,500–5,000 K	Epsilon Indi
M	Red	2,000–3,500 K	Betelgeuse, Proxima Centauri

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

For most stars, surface temperature is also related to size. Bigger stars produce more energy, so their surfaces are hotter. **Figure** 26.2 shows a typical star of each class, with the colors about the same as you would see in the sky.

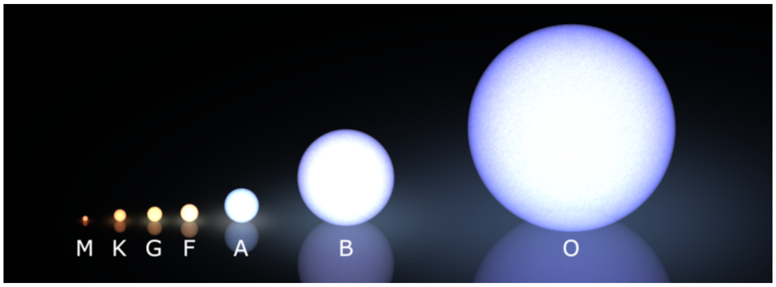

Figure 26.2: Typical stars by class, color and size. For most stars, size is related to class and to color. This image shows a typical star of each class. The colors are approximately the same as you would see in the sky. (6)

Lifetime of Stars

As a way of describing the stages in a star's development, we could say that stars are born, grow, change over time, and eventually die. Most stars change in size, color, and class at least once during this journey.

Formation of Stars

Stars are born in clouds of gas and dust called **nebulas**, like the one shown in **Figure** 26.3. In **Figure** 26.1, the fuzzy area beneath the central three stars across the constellation Orion, often called Orion's sword, contains another nebula called the Orion nebula.

Star formation starts when gravity starts to pull gas and dust in the nebula together. As the gas and dust falls together, it forms into one or more spheres. As one of these spheres collapses further, the pressure inside increases. As the pressure increases, the temperature of the gas also increases. Eventually, the pressure and temperature become great enough to cause nuclear fusion to start in the center. At this point, the ball of gas has become a star.

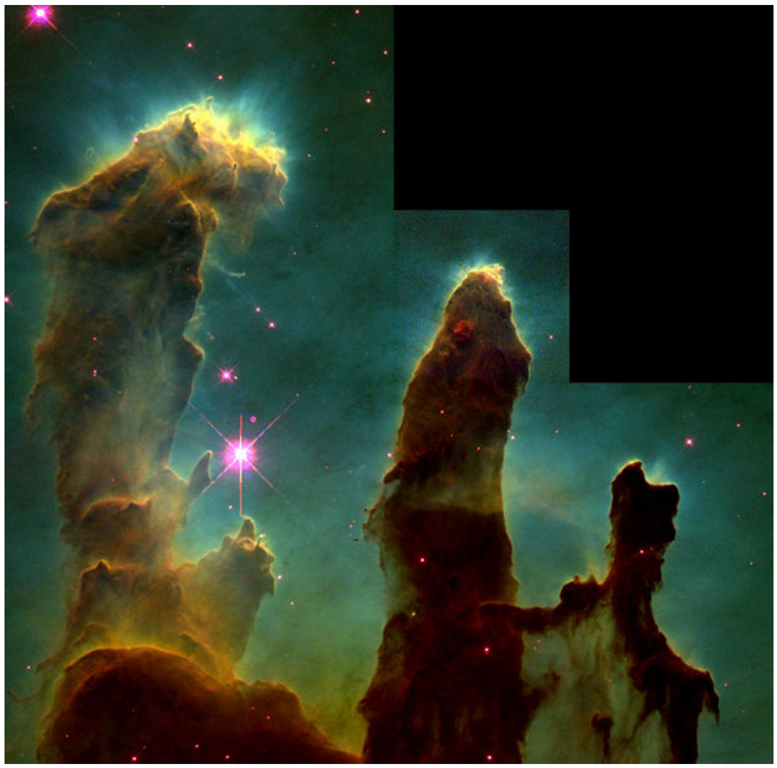

Figure 26.3: The Eagle Nebula and the Pillars of Creation. The pillars of gas and dust shown here are in the Eagle Nebula. (16)

The Main Sequence

For most of a star's life, the nuclear fusion in the core combines hydrogen atoms to form helium atoms. A star in this stage is said to be a **main sequence star**, or to be on the main sequence. This term comes from the Hertzsprung-Russell diagram, that plots a star's surface temperature against its true brightness or magnitude. For stars on the main sequence, the hotter they are, the brighter they are. The length of time a star is on the main sequence depends on how long a star is able to balance the inward force of gravity with the outward force provided by the nuclear fusion going on in its core. More massive stars have higher pressure in the core, so they have to burn more of their hydrogen "fuel" to prevent gravitational collapse. Because of this, more massive stars have higher temperatures, and also run out of hydrogen sooner than smaller stars do.

Our Sun, which is a medium-sized star, has been a main sequence star for about 5 billion years. It will continue to shine without changing for about 5 billion more years. Very large stars may be on the main sequence for "only" 10 million years or so. Very small stars may be main sequence stars for tens to hundreds of billions of years.

Red Giants and White Dwarfs

As a star begins to use up its hydrogen, it then begins to fuse helium atoms together into heavier atoms like carbon. Eventually, stars contain fewer light elements to fuse. The star can no longer hold up against gravity and it starts to collapse inward. Meanwhile, the outer layers spread out and cool. The star becomes larger, but cooler on the surface and red in color. Stars in this stage are called **red giants**.

Eventually, a red giant burns up all of the helium in its core. What happens next depends on how massive the star is. A typical star like the Sun, stops fusion completely at this point. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth. A star at this point is called a **white dwarf**. Eventually, a white dwarf cools down and its light fades out.

Supergiants and Supernovas

A star that has much more mass than the Sun will end its life in a more dramatic way. When very massive stars leave the main sequence, they become *red supergiants*. The red star Betelgeuse in Orion is a red supergiant.

Unlike red giants, when all the helium in a red supergiant is gone, fusion does not stop. The star continues fusing atoms into heavier atoms, until eventually its nuclear fusion reactions produce iron atoms. Producing elements heavier than iron through fusion takes more energy than it produces. Therefore, stars will ordinarily not form any elements heavier than iron. When a star exhausts the elements that it is fusing together, the core succumbs to gravity and collapses violently, creating a violent explosion called a **supernova**. A supernova explosion contains so much energy that some of this energy can actually fuse heavy atoms together, producing heavier elements such as gold, silver, and uranium. A supernova can shine as brightly as an entire galaxy for a short time, as shown in **Figure** 26.4.

Neutron Stars and Black Holes

After a large star explodes in a supernova, the leftover material in the core is extremely dense. If the core is less than about four times the mass of the Sun, the star will be a **neutron star**, as shown in **Figure** 26.5. A neutron star is made almost entirely of neutrons. Even though it is more massive than the sun, it is only a few kilometers in diameter.

Figure 26.4: Supernova 1994D: When very large stars stop nuclear fusion, they explode as supernovas. A bright supernova, like the one in the bottom left of the figure, can shine as brightly as an entire galaxy for a short time. (18)

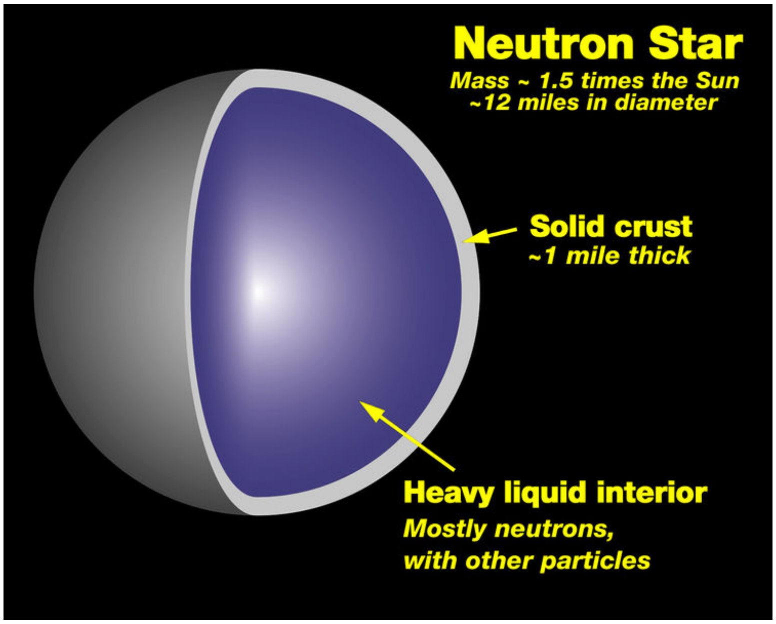

Figure 26.5: After a supernova, the remaining core may end up as a neutron star. (20)

If the core remaining after a supernova is more than about 5 times the mass of the Sun, the core will collapse so far that it becomes a **black hole**. Black holes are so dense that not even light can escape their gravity. For that reason, black holes cannot be observed directly. But we can identify a black hole by the effect that it has on objects around it, and by radiation that leaks out around its edges.

Measuring Star Distances

The Sun is much closer to Earth than any other star. Light from the Sun takes about 8 minutes to reach Earth. Light from the next nearest star, Proxima Centauri, takes more than 4 years to reach Earth. Traveling to Proxima Centauri in spacecraft similar to those we have today would take tens of thousands of years.

Light-years

Because astronomical distances are so large, it helps to use units of distance that are large as well. A **light-year** is defined the distance that light travels in one year. One light-year is 9,500,000,000,000 (9.5 trillion) kilometers, or 5,900,000,000,000 (5.9 trillion) miles. Proxima Centauri is 4.22 light-years away, which means that its light takes 4.22 years to reach us.

One light-year is approximately equal to 60,000 AU and 4.22 light-years is almost 267,000 AU. Recalling that Neptune, the farthest planet from the Sun, orbits roughly 30 AU from the Sun, we can realize that the distance from the Earth to stars other than our own Sun is much greater than the distance from the Earth to other planets within our own solar system.

Parallax

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

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

As **Figure** 26.6 shows, astronomers use this same principle to measure the distance to stars. However, instead of a finger, they focus on a star. And instead of switching back and forth between eyes, they use the biggest possible difference in observing position. To do that, they first look at the star from one position, and they note where the star appears to be relative to more distant stars. Then, they wait 6 months; during this time, Earth moves from one side of its orbit around the Sun to the other side. When they look at the star again, parallax will cause the star to appear in a different position relative to more distant stars. From the size of this shift, they can calculate the distance to the star.

Parallax

Other Methods

For stars that are more than a few hundred light years away, parallax is too small to measure, even with the most precise instruments available. For these more distant stars, astronomers use more indirect methods of determining distance. Most of these other methods involve determining how bright the star they are looking at really is. For example, if the star has properties similar to the Sun, then it should be about as bright as the Sun. Then, they can compare the observed brightness to the expected brightness. This is like asking, "How far away would the Sun have to be to appear this dim?"

Lesson Summary

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

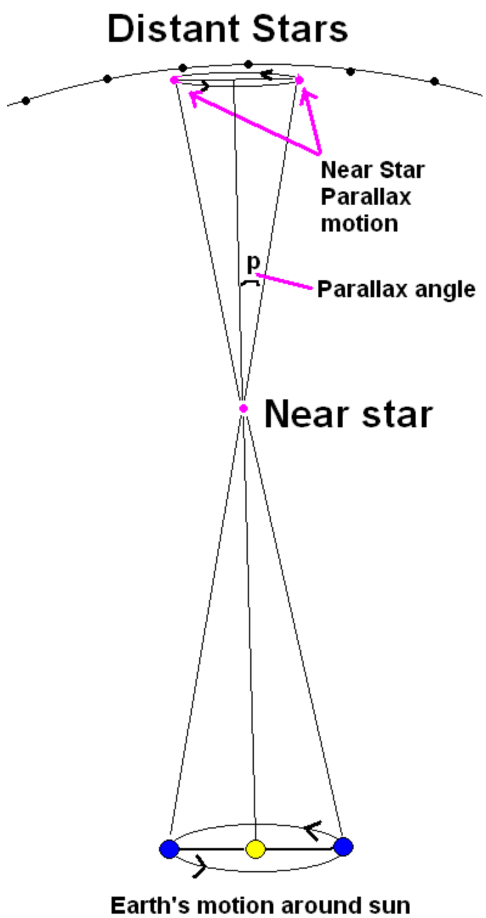

Figure 26.6: Parallax is used to measure the distance to stars that are relatively nearby. (2)

- The color of a star is determined by its surface temperature.
- Stars are classified by color and temperature. The most common system uses the letters O (blue), B (bluish white), A (white), F (yellowish white), G (yellow), K (orange), and M (red), from hottest to coolest.
- Stars form from clouds of gas and dust called nebulas. Stars collapse until nuclear fusion starts in the core.
- Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
- Typical, Sun-like stars expand into red giants, then fade out as white dwarfs.
- Very large stars expand into red supergiants, explode in supernovas, then end up as neutron stars or black holes.
- Astronomical distances can be measured in light-years. A light year is the distance that light travels in one year. 1 light-year = 9.5 trillion kilometers (5.9 trillion miles).
- Parallax is an apparent shift in an object's position when the position of the observer changes. Astronomers use parallax to measure the distance to relatively nearby stars.

Review Questions

1. What distinguishes a nebula and a star?
2. What kind of reactions provide a star with energy?
3. Which has a higher surface temperature: a blue star or a red star?
4. List the seven main classes of stars, from hottest to coolest.
5. What is the primary reaction that occurs in the core of a star, when the star is on the main sequence?
6. What kind of star will the Sun be after it leaves the main sequence?
7. Suppose a large star explodes in a supernova, leaving a core that is 10 times the mass of the Sun. What would happen to the core of the star?
8. What is the definition of a light-year?
9. Why don't astronomers use parallax to measure the distance to stars that are very far away?

Further Reading / Supplemental Links

- http://www.ianridpath.com/startales/contents.htm
- http://hsci.cas.ou.edu/exhibits/exhibit.php?exbgrp=3&exbid=20&exbpg=0
- http://www.nasa.gov/worldbook/star_worldbook.html
- http://imagine.gsfc.nasa.gov/docs/science/know_l1/stars.html
- http://www.spacetelescope.org/science/formation_of_stars.html
- http://hurricanes.nasa.gov/universe/science/stars.html
- http://starchild.gsfc.nasa.gov/docs/StarChild/questions/parallax.html
- http://imagine.gsfc.nasa.gov/YBA/HTCas-size/parallax1-more.html

- http://www-spof.gsfc.nasa.gov/stargaze/Sparalax.
- http://www.youtube.com/watch?v=VMnLVkV_ovc

Vocabulary

asterism A group or cluster of stars that appear close together in the sky.

black hole The super dense core left after a supergiant explodes as a supernova.

constellation An apparent pattern of stars in the night sky.

light-year The distance that light travels in one year; 9.5 trillion kilometers.

main sequence star A star that is fusing hydrogen atoms to helium; a star in the main portion of its "life."

nebula An interstellar cloud of gas and dust.

neutron star The remnant of a massive star after it explodes as a supernova.

nuclear fusion reaction When nuclei of two atoms fuse together, giving off tremendous amounts of energy.

parallax A method used by astronomers to calculate the distance to nearby stars, using the apparent shift relative to distant stars.

red giant Stage in a star's development when the inner helium core contracts while the outer layers of hydrogen expand.

supernova A tremendous explosion that occurs when the core of a star is mostly iron.

star A glowing sphere of gases that produces light through nuclear fusion reactions.

Points to Consider

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

26.2 Galaxies

Lesson Objectives

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

Introduction

Compared to your neighborhood, your country, or even planet Earth, the solar system is an extremely big place. But there are even bigger systems in the universe; groups of two, two hundred, or two billion stars! Small groups of stars are called star systems, and somewhat larger groups are called star clusters. There are even larger groups of stars, called galaxies. Our solar system is in the Milky Way Galaxy, which is just one galaxy in the universe. There are several different types of galaxies and there are possibly billions of galaxies in the universe.

Star Systems and Star Clusters

Constellations are patterns of stars that we see in the same part of the night sky, but these stars may not be close together at all out in space. However, some stars are actually grouped closely together in space. These small groups of stars are called **star systems** and larger groups of hundreds or thousands of stars are called **star clusters.**

Star Systems

Our solar system has only one star, the Sun. But many stars—in fact, more than half of the bright stars in our galaxy—are in systems of two or more stars. A system of two stars orbiting each other is called a **binary star**. A system with more than two stars is called a *multiple star system*. In a multiple star system, each of the stars orbits around the others.

Often, the stars in a multiple star system are so close together that you can only tell there are multiple stars using binoculars or a telescope. **Figure** 26.7 shows Sirius A, the brightest star in the sky. Sirius A is a very large star. If you look to the lower left of Sirius A in the figure, you can see a much smaller star. This is Sirius B, a white dwarf companion to Sirius A.

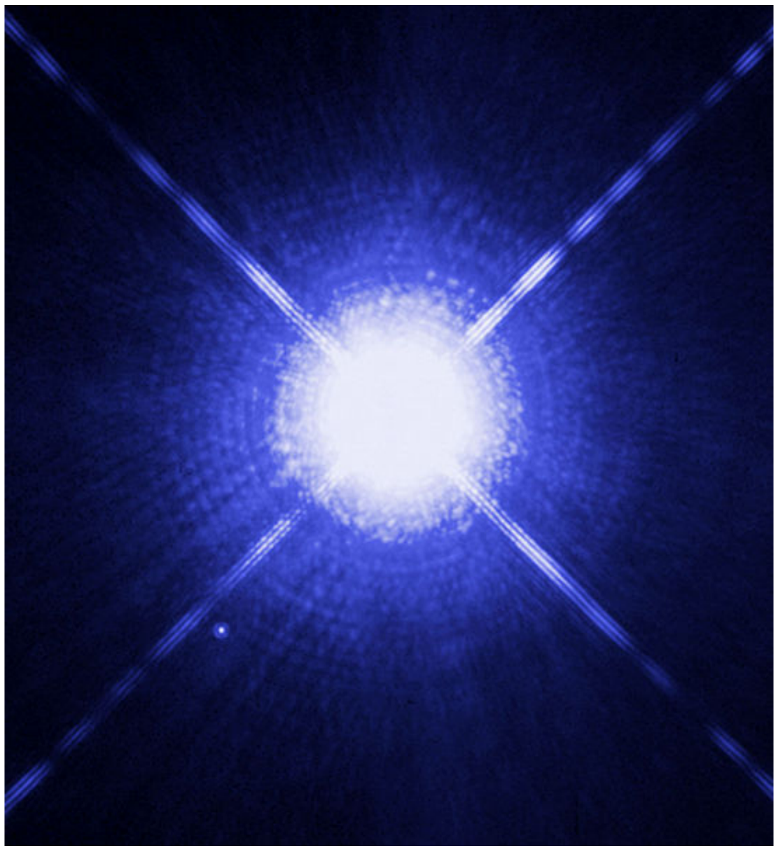

Figure 26.7: The bright star Sirius is actually a binary system with one large star (Sirius A) and one small star (Sirius B). This image from the Hubble Space Telescope shows Sirius B to the lower left of Sirius A. As you might guess, Sirius A is much, much brighter than Sirius B. Sirius B once was brighter than its companion, but it became a red giant and collapsed into its current dim state about 100-125 million years ago. (4)

Star Clusters

Star clusters are divided into two main types, **open clusters** and **globular clusters**. Open clusters are groups of up to a few thousand stars that are loosely held together by gravity. The Pleiades, shown in **Figure** 26.8, is a well-known open cluster. The Pleiades are also called the Seven Sisters, because you can see seven stars in the cluster without a telescope, but with good vision. Using a telescope reveals that the Pleiades has close to a thousand stars.

Figure 26.8: The Pleiades is an open cluster containing several hundred stars surrounded by gas. Note that the stars are mostly blue. (5)

Open clusters tend to be blue in color and often contain glowing gas and dust. That is because the stars in an open cluster are young stars that formed from the same nebula. Eventually, the stars may be pulled apart by gravitational attraction to other objects.

Figure 26.9 shows an example of a globular cluster. Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. Unlike open clusters, globular clusters have a definite, spherical shape. Globular clusters contain mostly old, reddish stars. As you get closer to the center of a globular cluster, the stars are closer together. Globular clusters don't have much dust in them — the dust has already formed into stars.

Types of Galaxies

The biggest groups of stars are called **galaxies.** Galaxies can contain anywhere from a few million stars to many billions of stars. Every star you can see in the sky is part of the Milky Way Galaxy, the galaxy we live in. Other galaxies are extremely far away, much farther away

Figure 26.9: M80 is a large globular cluster containing hundreds of thousands of stars. Note that the cluster is spherical and contains mostly red stars. (8)

than even the most distant stars you can see. The closest major galaxy—the Andromeda Galaxy, shown in **Figure** 26.10—looks like only a dim, fuzzy spot to the naked eye. But that fuzzy spot contains one trillion stars; that is a thousand billion, or 1,000,000,000,000 stars!

Figure 26.10: The Andromeda Galaxy is the closest major galaxy to our own. Andromeda is a large spiral galaxy that contains about a trillion stars. (3)

Spiral Galaxies

Galaxies are divided into three types according to shape: spiral galaxies, elliptical galaxies, and irregular galaxies. **Spiral galaxies** rotate or spin, so they have a rotating disk of stars and dust, a bulge in the middle, and several arms spiraling out from the center. Spiral galaxies have lots of gas and dust and lots of young stars. **Figure** 26.11 shows a spiral galaxy from the side, so you can see the disk and central bulge.

Figure 26.12 shows a spiral galaxy face-on, so you can see the spiral arms. The spiral arms of a galaxy contain lots of dust. New stars form from this dust. Because they contain lots of young stars, spiral arms tend to be blue.

Elliptical Galaxies

Figure 26.13 shows a typical **elliptical galaxy**. As you might have guessed, elliptical galaxies are elliptical, or egg-shaped. The smallest elliptical galaxies are as small as some globular clusters. *Giant elliptical galaxies*, on the other hand, can contain over a trillion stars. Elliptical galaxies are reddish to yellowish in color because they contain mostly old stars.

Figure 26.11: The Sombrero Galaxy is a spiral galaxy that we see from the side. (1)

Figure 26.12: The Pinwheel Galaxy is a spiral galaxy we see face-on. Note the blue spiral arms. (14)

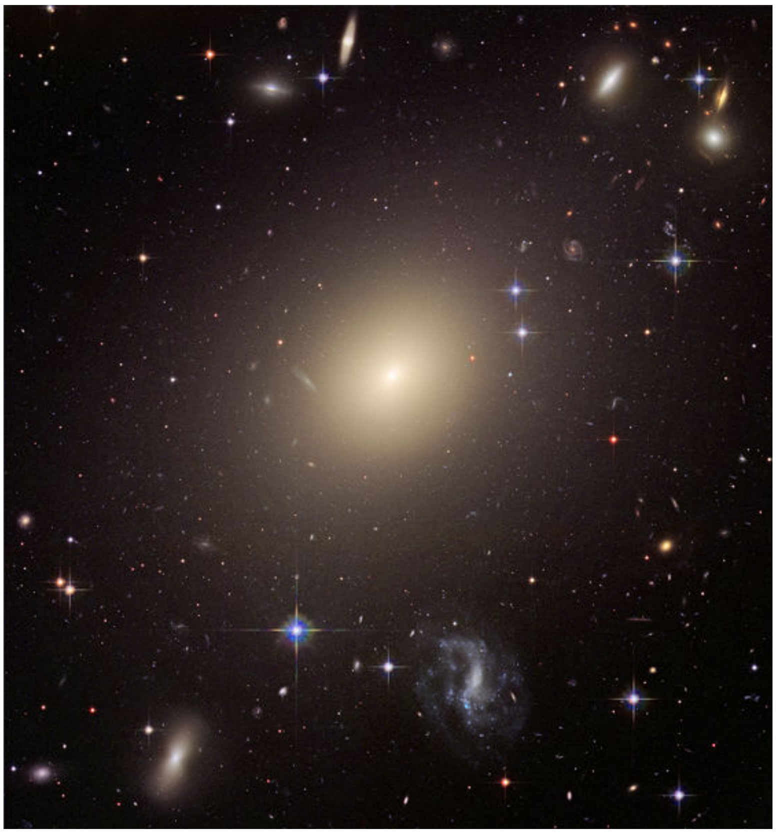

Figure 26.13: The large, reddish-yellow object in the middle of this figure is a typical elliptical galaxy. Can you find other galaxies in the figure? What kind? (7)

Typically, elliptical galaxies contain very little gas and dust because the gas and dust has already formed into stars. However, some elliptical galaxies, like the one shown in **Figure** 26.14, contain lots of dust. Astronomers believe that these dusty elliptical galaxies form when two galaxies of similar size collide.

Figure 26.14: This elliptical galaxy probably formed when two galaxies of similar size collided with each other. (9)

Irregular Galaxies and Dwarf Galaxies

Look at the galaxy in **Figure** 26.15. Do you think this is a spiral galaxy or an elliptical galaxy? It is neither one! Galaxies that are not clearly elliptical galaxies or spiral galaxies are called **irregular galaxies**. Most irregular galaxies were once spiral or elliptical galaxies that were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy.

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

Figure 26.15: This galaxy, called NGC 1427A, is an irregular galaxy. It has neither a spiral nor an elliptical shape. (15)

Look back at **Figure 4**. In the figure, you can see two dwarf elliptical galaxies that are companions to the Andromeda Galaxy. One is a bright sphere to the left of center, and the other is a long ellipse below and to the right of center. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

The Milky Way Galaxy

If you look up in the sky on a very clear night, you may see a milky band of light stretching across the sky, as in **Figure** 26.16. This band is called the **Milky Way**, and it consists of millions of stars along with a lot of gas and dust. This band is the disk of a galaxy, the **Milky Way Galaxy**, which is our galaxy. The Milky Way Galaxy looks different to us than other galaxies because we are actually living inside of it!

Figure 26.16: The band of light called the Milky Way can be seen on a clear, dark night. Looking at this band, you are looking along the main disk of our galaxy. (19)

Shape and Size

Because we live inside the Milky Way Galaxy, it is hard to know exactly what it looks like. But astronomers believe the Milky Way Galaxy is a typical spiral galaxy that contains about 100 billion to 400 billion stars. **Figure** 26.17 shows what our Galaxy would probably look like if seen from the outside.

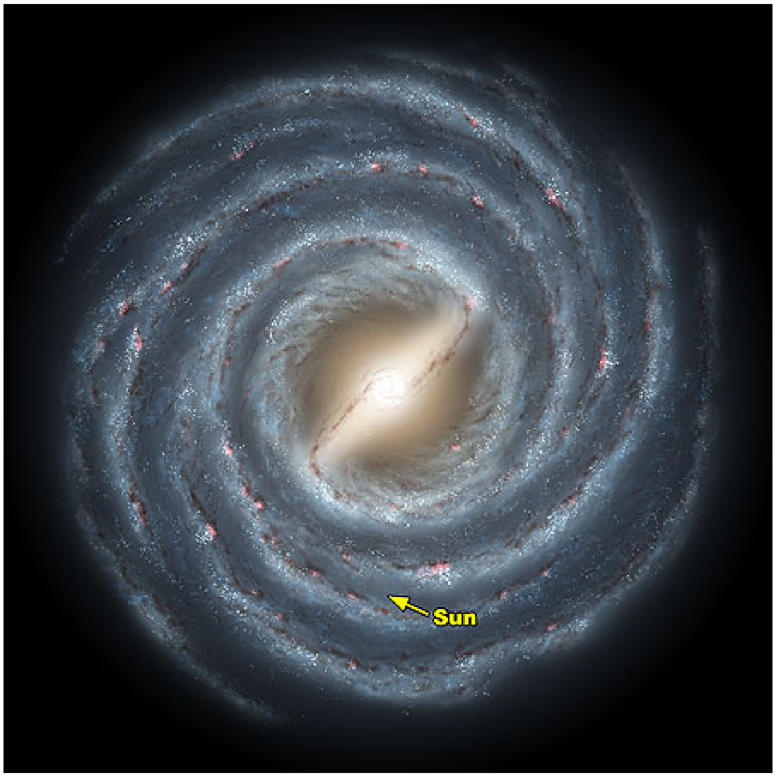

Figure 26.17: This artist's rendering shows what we currently think the Milky Way Galaxy would look like seen from above. The Sun and solar system (and you!) are a little more than halfway out from the center. (10)

Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy's gas, dust, young stars, and open clusters are in the disk.

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

The Milky Way Galaxy is a big place. If our solar system were the size of your fist, the

Galaxy's disk would still be wider than the entire United States!

Where We Are

Our solar system, including the Sun, Earth, and all the other planets, is within one of the spiral arms in the disk of the Milky Way Galaxy. Most of the stars we see in the sky are relatively nearby stars, that are also in this spiral arm. We are about 26,000 light years from the center of the Galaxy. In other words, we live a little more than halfway out from the center of the Galaxy to the edge, as shown in **Figure 11**.

Just as Earth orbits the Sun, the Sun and solar system orbit the center of the Galaxy. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago.

Lesson Summary

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

Review Questions

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

Further Reading / Supplemental Links

- http://www.cfa.harvard.edu/press/2006/pr200611.html
- http://hypertextbook.com/facts/2000/MarissaWager.shtml
- http://seds.lpl.arizona.edu/messier/more/mw.html
- http://www.space.com/scienceastronomy/050816_milky_way.html
- http://seds.org/messier/cluster.html; http://hubblesite.org/newscenter/archive/releases/star-cluster/
- http://stardate.org/resources/btss/galaxies/; http://casswww.ucsd.edu/public/tutorial/Galaxies.html; http://www.smv.org/hastings/student1.htm
- http://en.wikipedia.org

Vocabulary

binary star One of two stars that orbit each other.

elliptical galaxy An oval or egg shaped galaxy with older stars and little gas and dust.

galaxy A very large group of stars held together by gravity; few million to a few billion stars.

globular cluster Groups of tens to hundreds of thousands of stars held together by gravity.

irregular galaxy A category of galaxy that is neither a spiral nor an elliptical galaxy.

Milky Way The name of our galaxy; also the whitish band of stars visible in the night sky.

open cluster Groups of up to a few thousand stars loosely held together by gravity.

spiral arm Regions of gas and dust plus young stars that wind outward from the central area of a spiral galaxy.

spiral galaxy A rotating type of galaxy with a central bulge and spiral arms with young stars, gas and dust.

star system Small groups of stars.

star cluster Larger groups of hundreds of thousands of stars.

Points to Consider

- Objects in the universe tend to be grouped together. What forces or factors do you think cause objects to form and stay in groups?
- Some people used to call galaxies "island universes." Are they really universes? Why or why not?
- Can you think of anything, either an object or a group of objects, that is bigger than a galaxy?

26.3 The Universe

Lesson Objectives

- Explain the evidence for an expanding universe.
- Describe the formation of the universe according to the Big Bang Theory.
- Define dark matter and dark energy.

So far we have talked about bigger and bigger systems, from stars to star systems to star clusters and galaxies. The **universe** contains all these systems, including all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe also includes all of space and time.

Our understanding of the universe has changed a lot over time. The ancient Greeks thought the universe contained only Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. Most people had this basic idea of the universe for centuries, until Galileo first used a telescope to look at the stars. Then people realized that Earth is not the center of the universe, and there are many more stars than thought before. Even as recently as the early 1900s, some scientists still thought the universe was no larger than the Milky Way Galaxy.

In the early 20th century, an astronomer named Edwin Hubble (**Figure** 26.18) discovered that the "Andromeda Nebula" is actually over 2 million light years away—many times farther than the farthest distances we had measured before. He realized that many of the objects astronomers called nebulas were not clouds of gas, but collections of millions or billions of stars—what we now call galaxies. Our view of the universe changed again—we now knew that the universe was much larger than our own galaxy. Today, we know that the universe contains about a hundred billion galaxies—about the same number of galaxies as there are stars in the Milky Way Galaxy.

Figure 26.18: Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light seen through telescopes are actually other galaxies. He also measured these distances to hundreds of galaxies, and discovered that the universe is expanding. (11)

Expansion of the Universe

After discovering that there are galaxies outside our own, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show us how the universe is changing, and even give us clues as to how the universe formed.

Redshift

If you look at a star through a prism, you will see a **spectrum,** or a range of colors through the rainbow. Interestingly, the spectrum will have specific dark bands where elements in the star absorbed light of certain energies. By examining the arrangement of these dark absorption lines, astronomer can actually determine which elements are in a distant star. In fact, the element helium was first discovered in our Sun — not on Earth — by analyzing the absorption lines in the spectrum of the Sun.

When astronomers started to study the spectrum of light from distant galaxies, they noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in **Figure** 26.19. This shift of absorption bands toward the red end of the spectrum is known as **redshift**.

Redshift occurs when the source of light is moving away from the observer. So when astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth. The strange part is that almost every galaxy in the universe has a redshift, which means that almost every galaxy is moving away from us.

An analogy to redshift is the noise a siren makes as it passes by you. You may have noticed that an ambulance lowers the pitch of its siren after it passes you. The sound waves shift towards a lower pitch when the ambulance speeds away from you. Though redshift involves light instead of sound, a similar principle operates in both situations.

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. He noticed a relationship, which is now called *Hubble's Law:* The farther away a galaxy is, the faster it is moving away from us. In other words, the universe is expanding!

Figure 26.20 shows a simplified diagram of the expansion of the universe. Another way to picture this is to imagine a balloon covered with tiny dots. Each dot represents a galaxy. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If it were a giant balloon and you were standing on one of the dots, you would see the other dots moving away from you. Not only that, but dots farther away from you on the balloon would move away faster than dots nearby.

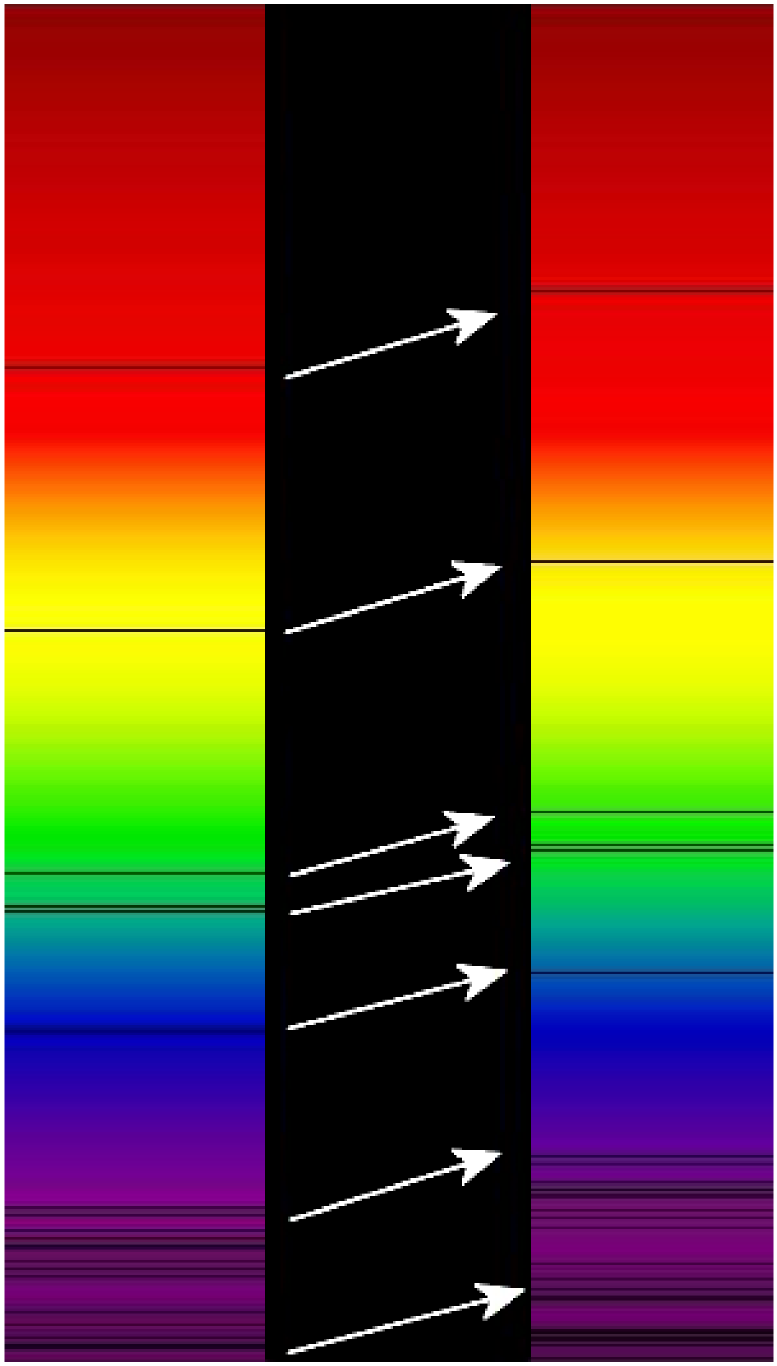

Figure 26.19: Redshift is a shift in absorption bands toward the red end of the spectrum. Redshift occurs when the light source is moving away from you or when the space between you and the source is stretched. (12)

Expansion of the universe diagram

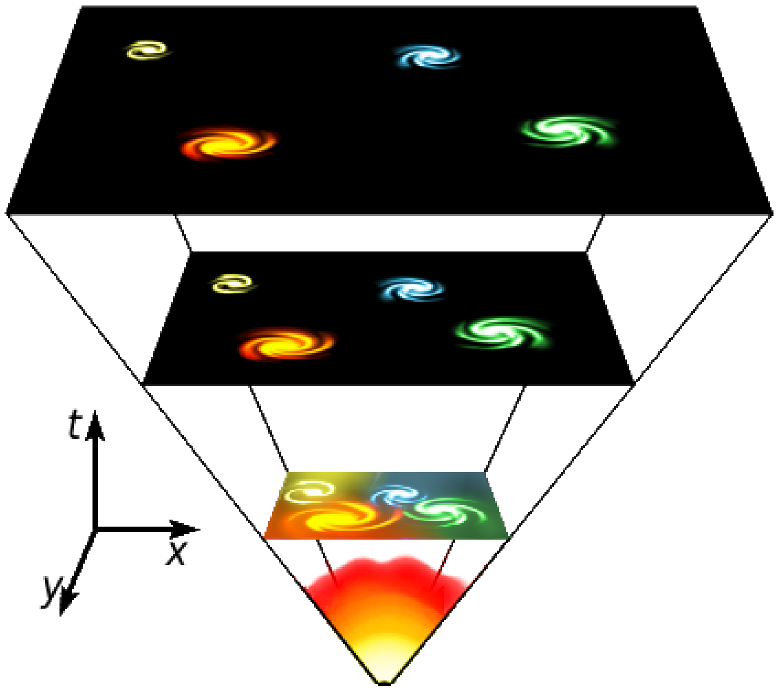

Figure 26.20: This is a simplified diagram of the expansion of the universe over time. Note that the distance between galaxies gets bigger as you go forward in time, but the size of each galaxy stays about the same. (17)

An inflating balloon is not exactly like the expanding universe. For one thing, the surface of a balloon has only two dimensions, while space has three dimensions. But it is true that space itself is stretching out between galaxies like the rubber stretches when a balloon is inflated. This stretching of space, which causes the distance between galaxies to increase, is what astronomers mean by the expansion of the universe.

One other difference between the universe and our balloon model involves the actual size of the galaxies. On the inflating balloon, the dots you made will become larger in size as you inflate it. In our universe, however, the galaxies stay the same size; it is just the space between the galaxies that increases as the universe expands.

Formation of the Universe

The discovery that the universe is expanding also told astronomers something about how the universe might have formed. Before this discovery, there were many ideas about the universe, most of them thinking of the universe as constant. Once scientists learned that the universe is expanding, the next logical thought is that at one time it had to have been smaller.

The Big Bang Theory

The Big Bang theory is the most widely accepted scientific explanation of how the universe formed. To understand this theory, start by picturing the universe expanding steadily. Then, reverse the direction of time, like pressing the "rewind" button on a video player. Now the universe is contracting, getting smaller and smaller. If you go far enough back in time, you will reach a point when the universe was squeezed into a very small volume.

According to the Big Bang theory, the universe began about 13.7 billion years ago, when everything in the universe was squeezed into a very small volume, as described above. There was an enormous explosion—a big bang—which caused the universe to start expanding rapidly. All the matter and energy in the universe—and even space itself—came out of this explosion.

After the Big Bang

In the first few moments after the Big Bang, the universe was extremely hot and dense. As the universe expanded, it became less dense and it cooled. After only a few seconds, the universe had cooled enough that protons, neutrons, and electrons could form. After a few minutes, hydrogen could form and the energy in the universe was great enough to allow for nuclear fusion, creating helium atoms in the same way we learned that a star can make helium out of hydrogen atoms, even though there were no stars at this point in the universe's history. The first neutral atoms with neutrons, protons, and electrons, did not form until about 380,000 years after the big bang.

The matter in the early universe was not smoothly distributed across space. Some parts of the universe were more dense than others. These clumps of matter were held close together by gravity. Eventually, these clumps became the gas clouds, stars, galaxies, and other structures that we see in the universe today.

Dark Matter and Dark Energy

The Big Bang theory is still the best scientific model we have for explaining the formation of the universe. However, recent discoveries in astronomy have shaken up our understanding of the universe. Astronomers and other scientists are now wrestling with some big unanswered questions about what the universe is made of and why it is expanding like it is.

Dark Matter

Most of the things we see out in space are objects that emit light, such as stars or glowing gases. When we see other galaxies, we are seeing the glowing stars or gases in that galaxy.

However, scientists think that matter that emits light only makes up a small part of the matter in the universe. The rest of the matter is called **dark matter**.

Because dark matter doesn't emit light, we can't observe it directly. However, we know it is there because its gravity affects the motion of objects around it. For example, when astronomers measure how spiral galaxies rotate, they find that the outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot of extra matter in a galaxy that we cannot see.

So what is dark matter? Actually, we don't really know. One possibility is that it could just be ordinary matter—protons, neutrons, and electrons, like what makes up the Earth and all the matter around us. The universe could contain lots of objects that don't have enough mass to glow on their own, such as large planets and *brown dwarfs*, objects larger than Jupiter but smaller than the smallest stars. Or, there could be large numbers of undetected black holes.

Another possibility is that the universe contains a lot of matter that is unlike anything we have ever encountered. For example, scientists have proposed that there might be particles that have mass but don't interact much with other matter. Scientists call these theoretical particles WIMPs, which stands for Weakly Interactive Massive Particles. WIMPs would have a gravitational effect on other matter because of their mass. But because they don't interact much with ordinary matter, they would be very difficult or impossible to detect directly.

Most scientists who study dark matter believe that the universe's dark matter is a combination of ordinary matter and some kind of exotic matter that we haven't discovered yet. Most scientists also think that ordinary matter is much less than half of the total matter in the universe. Researching dark matter is clearly an active area of scientific research, and astronomers' knowledge about dark matter changing rapidly.

Dark Energy

Astronomers who study the expansion of the universe are interested in finding out just how fast the universe is expanding. For years, the big question was whether the universe was expanding fast enough to overcome the attractive pull of gravity. If yes, then the universe would expand forever, although the expansion would slow down over time. If no, then the universe would someday start to contract, and eventually would get squeezed together in a *big crunch*, the opposite of the Big Bang.

Recently, however, these astronomers have made a strange discovery: the rate at which the universe is expanding is actually increasing. In other words, the universe is expanding faster now than ever before, and in the future it will expand even faster! This answers the old question: the universe will keep expanding forever. But it also proposes a perplexing new question: what is causing the expansion of the universe to accelerate?

One possible hypothesis involves a new, as-yet-undiscovered form of energy called **dark energy**. We know even less about dark energy than we know about dark matter. However, some scientists believe that dark energy makes up more than half the total content of the universe. Other scientists have other hypotheses about why the universe is continuing to expand; the causes of the universe's expansion is another unanswered question that scientists are researching.

Lesson Summary

- The universe contains all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe also includes all of space and time.
- Redshift is a shift of element lines toward the red end of the spectrum. Redshift occurs when the source of light is moving away from the observer.
- Light from almost every galaxy is redshifted. The farther away a galaxy is, the more its light is redshifted, and the faster it is moving away from us.
- The redshift of galaxies tells us that the universe is expanding.
- The current expansion of the universe suggests that in the past the universe was squeezed into a very small volume.
- The Big Bang theory proposes that the universe formed in an enormous explosion about 13.7 billion years ago.
- Recent evidence shows that there is a lot of matter in the universe that we cannot detect directly. This matter is called dark matter.
- The rate of the expansion of the universe is increasing. The cause of this increase is unknown; one possible explanation involves a new form of energy called dark energy.

Review Questions

1. What is redshift, and what causes it to occur?
2. What is Hubble's law?
3. What is the most widely accepted scientific theory of the formation of the universe called?
4. How old is the universe, according to the Big Bang theory?
5. Describe two different possibilities for the nature of dark matter.
6. What makes scientists believe that dark matter exists?
7. What observation caused astronomers to propose the existence of dark energy?

Further Reading / Supplemental Links

- http://cdms.berkeley.edu/Education/DMpages/index.shtml
- http://stardate.org/resources/btss/cosmology/
- http://hurricanes.nasa.gov/universe/science/bang.html

- http://imagine.gsfc.nasa.gov/docs/science/know_l1/dark_matter. html
- http://www.youtube.com/watch?v=gCgTJ6ID6ZA
- http://en.wikipedia.org

Vocabulary

Big Bang Theory The hypothesis that all matter and energy were at one time compresses into a very small volume; then there was an explosion that sent everything moving outward, causing the universe to expand.

dark energy An as yet undiscovered form of energy that we cannot see.

dark matter Matter in the universe that doesn't emit light.

redshift Shift of wavelengths of light towards the red end of the spectrum; happens as a light source moves away from us.

universe Everything that exists; all matter and energy; also includes all of space and time.

Points to Consider

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

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