CK-12

flexbook
next generation textbooks

Earth Science

Earth Science

Utah OER DOE

AUTHOR
Utah OER DOE

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

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

Printed: June 28, 2016

Contents

1 Standard I: Universe **1**
1.1 How do we know what we know about the universe? . . . 3
1.2 What fuels a star? . . . 11
1.3 What is at the center of the universe? . . . 17
1.4 What are conditions like on the inner planets? . . . 23
1.5 What are condition like on the outer planets? . . . 29
1.6 What other objects are in the solar system? . . . 36
1.7 References . . . 40

2 Standard II: Inside Earth **41**
2.1 How does the internal structure of the Earth affect the temperature of the Earth? . . . 42
2.2 What causes earthquakes and volcanoes? . . . 48
2.3 Does the movement of Earth's plates affect all living things? . . . 57
2.4 References . . . 62

3 Standard III: Atmosphere **63**
3.1 Is the Greenhouse Effect a good thing or a bad thing? . . . 64
3.2 Why is it winter in the Southern Hemisphere when it is summer in the Northern Hemisphere? . . . 68
3.3 What makes the wind blow? . . . 70
3.4 Why were winds so important to the early explorers? . . . 73
3.5 What is ozone and why are we concerned about a hole in the ozone? . . . 75
3.6 What causes the change in the weather? . . . 77
3.7 How do they forecast the weather? . . . 81
3.8 What causes severe weather? . . . 84
3.9 What are short-term climate changes? . . . 87
3.10 How has Earth's climate changed? . . . 90
3.11 What causes climate change? . . . 93
3.12 How are fossil fuels formed? . . . 97

4 Standard IV: Hydrosphere **102**
4.1 Why can't we drink most of the water on Earth? . . . 103
4.2 How do we use water? . . . 107
4.3 What makes H2O unique? . . . 111
4.4 What is a freshwater ecosystem? . . . 114
4.5 Was there always water on Earth? . . . 117
4.6 What causes water to move in the ocean? . . . 121

5 Standard V: People and Planet **126**
5.1 How do technological advances increase human knowledge? . . . 127
5.2 How is a seismologist like a medical doctor? . . . 128
5.3 Will water cause the next war? . . . 130
5.4 Are soil and water renewable resources? . . . 133

5.5 Can we use up all of our sunlight? . . . 135
5.6 What data do scientists provide data that informs the discussion of Earth resource use? . . . 138
5.7 Can we Prevent Natural Hazards? . . . 141
5.8 Which human activities contribute to the frequency and intensity of natural hazards? . . . 148
5.9 How do humans impact the carbon cycle? . . . 152
5.10 How do scientists use technology to continually improve estimates of when and where natural hazards . . . 154
5.11 References . . . 157

6 Glossary - Earth Science 158

CHAPTER 1 Standard I: Universe

Chapter Outline

1.1 HOW DO WE KNOW WHAT WE KNOW ABOUT THE UNIVERSE?
1.2 WHAT FUELS A STAR?
1.3 WHAT IS AT THE CENTER OF THE UNIVERSE?
1.4 WHAT ARE CONDITIONS LIKE ON THE INNER PLANETS?
1.5 WHAT ARE CONDITION LIKE ON THE OUTER PLANETS?
1.6 WHAT OTHER OBJECTS ARE IN THE SOLAR SYSTEM?
1.7 REFERENCES

Why science?

Many students equate science to learning vocabulary terms, labeling pictures, and memorizing facts. Science by nature is much more inclusive and loosely defined. Have you ever asked yourself questions about your surroundings and wondered how or why they are happening? This is science. Science works best when driven by curiosity and innovation. In order for you to experience science in its fullest sense you must take it beyond the textbook and into your everyday experience, but in order to be meaningful there are certain guidelines that can help us. Science is not constrained to Earth Science, but there are crosscutting concepts threaded throughout all scientific disciplines. These include:

- Patterns
  - **Example found in Earth Science:** We observe specific patterns in weather over time, which helps us define regional climates.
- Cause and effect: Mechanism and explanation
  - **Example found in Earth Science:** If sections of the Earth's crust moves, then earthquakes occur, mountains form, and volcano erupt.
- Scale, proportion, and quantity
  - **Example found in Earth Science:** The size and distance the solar system is massive, so we produce scale models.
- Systems and system models
  - **Example found in Earth Science:** We create models of Earth's mantle, to show how convection currents move the magma, acting as a conveyer belt for the Earth's crust. Understanding this model can show how moving Earth's crust creates many of the land features we observe.
- Energy and matter: Flows, cycles, and conservation
  - **Example found in Earth Science:** Light from the sun is absorbed by the surface of the Earth and converted to heat. The heat energy is then cycled through the Earth's atmosphere powering the weather.
- Structure and function
  - **Example found in Earth Science:** The structure of a water molecule creates unique characteristic. These characteristics allow it to support life on Earth.
- Stability and change

- **Example found in Earth Science:** When we remove vegetation away a hillside to build a home, we affect the stability of the ground which may cause a mud or land slide when it rains.

When studying any specific scientific discipline you should attempt to keep these crosscutting concepts in mind in order to gain a better perspective of the world as whole and the nature of science. Included in the concepts are the skills and practices that a scientist utilizes. When asking questions about the natural world there are certain skills and practices that can help you be generate better conclusions, explanations and inferences. These practices include:

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

While these practices and crosscutting concepts are crucial to your overall success in science, in order to be most meaningful they do need some context. This is where the study of disciplinary core ideas are most impactful. If you study **Earth Science** or any other scientific discipline without the crosscutting concepts and scientific practices then you limit yourself to fact memorization and miss how these concepts relate to our everyday life and our society as a whole. Studying individual scientific disciplines are the vehicle for understanding crosscutting concepts and acquiring scientific skills. When individual disciplines are studied within the context of practices and crosscutting concepts they become more meaningful and more impactful.

For example: **When looking for solutions to atmospheric pollutions** it is not a problem to be solved by chemists or physicists or geologists independently. It can only be solved when scientists come together with an understanding of how their independent research relates to the larger problem at hand. If we focus solely upon a few facts or cool phenomenon we can overlook how the study of science can really improve and impact our society and personal experiences.

Standard 1: Students will understand the scientific evidence that supports theories that explain how the universe and the solar system developed. They will compare Earth to other objects in the solar system.

Objective 1: Describe both the big bang theory of universe formation and the nebular theory of solar system formation and evidence supporting them.

1. Identify the scientific evidence for the age of the solar system (4.6 billion years), including Earth (e.g., radioactive decay).
2. Describe the big bang theory and the evidence that supports this theory (e.g., cosmic background radiation, abundance of elements, distance/redshift relation for galaxies).
3. Describe the nebular theory of solar system formation and the evidence supporting it (e.g., solar system structure due to gravity, motion and temperature; composition and age of meteorites; observations of newly forming stars).
4. Explain that heavy elements found on Earth are formed in stars.
5. Investigate and report how science has changed the accepted ideas regarding the nature of the universe throughout history.
6. Provide an example of how technology has helped scientists investigate the universe.

Objective 2: Analyze Earth as part of the solar system, which is part of the Milky Way galaxy.

1. Relate the composition of objects in the solar system to their distance from the Sun.
2. Compare the size of the solar system to the Milky Way galaxy.
3. Compare the size and scale of objects within the solar system.
4. Evaluate the conditions that currently support life on Earth (biosphere) and compare them to the conditions that exist on other planets and moons in the solar system (e.g., atmosphere, hydrosphere, geosphere, amounts of incoming solar energy, habitable zone).

1.1 How do we know what we know about the universe?

Objectives

- Investigate and report how science has changed the accepted ideas regarding the nature of the universe throughout history.
- Describe the big bang theory and the evidence that supports this theory (e.g., cosmic background radiation, abundance of elements, distance/redshift relation for galaxies).

The study of the universe is called cosmology. Cosmologists study the structure and changes in the present universe. The universe contains all of the star systems, galaxies, gas and dust, plus all the matter and energy that exist. The universe also includes all of space and time. That part of the entire universe that we can see (because light from objects has had time to reach us) is called the **observable** universe.

Evolution of Human Understanding of the Universe

What did the ancient Greeks recognize as the universe? In their model, the universe contained Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. This idea held for many centuries until new ideas and better observing instruments allowed people to recognize that Earth is not the center of the universe. Galileo's telescope revealed four moons orbiting Jupiter (not Earth), the phases of Venus, the mountains of the Moon, and many more stars than are visible to the naked eye. More importantly, Galileo's experiments established the principle of inertia which countered the physical arguments the Greeks used against a rotating and moving Earth.

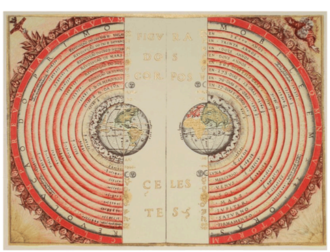
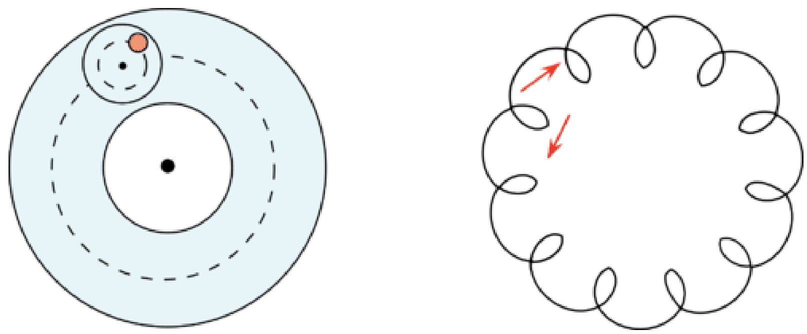


FIGURE 1.1
Timeline of cosmological theories

4th century BCE — Aristotle, building on the ideas of earlier astronomers, proposes that the Sun, Moon, planets, and stars revolve around a stationary Earth. This is known as the geocentric theory, meaning that the universe revolves around the earth.

2nd century AD — Ptolemy publishes a book that describes a mathematical procedure to calculate future positions of the Sun, Moon, and visible planets in the sky. It reaffirms that all these objects move around a stationary Earth. To account for the retrograde motion of Mars, his system uses small circles (epicycles) revolving around larger circles (deferents).



1543 — Nicolaus Copernicus publishes his heliocentric (Sun-centered) theory that proposes that Earth is a planet in motion around the Sun. His model describes retrograde motion caused by relative planetary positions as Earth overtakes Mars compared to background stars.

1610 — Johannes Kepler analyzes the accurate astronomical observations of Tycho Brahe, and discovers that the planets move around the Sun in elliptical orbits.

1687 — Sir Isaac Newton publishes the laws of motion and gravity that are used to accurately predict the motion of the Moon and planets.

1915 — Albert Einstein publishes the General Theory of Relativity, proposing that mass and energy cause space and time to curve or warp. This can be used to describe large-scale motion throughout the universe.

1912 — Henrietta Leavitt discovered an important relationship concerning Cepheid variable stars, a type of star that pulsates in a regular pattern. She found that the larger a Cepheid is, the slower it pulsates. Since larger stars are brighter, this pulsation can be used to find the exact brightness of a Cepheid star.

1922-23 — Edwin Hubble (1889 - 1953) (see Figure 1.2) used Cepheid variable stars to measure the distance to the Andromeda Nebula. He discovered that it was so far away that it had to be a separate galaxy, outside our own Milky Way galaxy. Hubble realized that many of the objects that astronomers called nebulae were enormous collections of stars — island universes that we now call galaxies.

1929 — Edwin Hubble discovers a velocity-distance relationship for galaxies that implies that the universe is expanding.

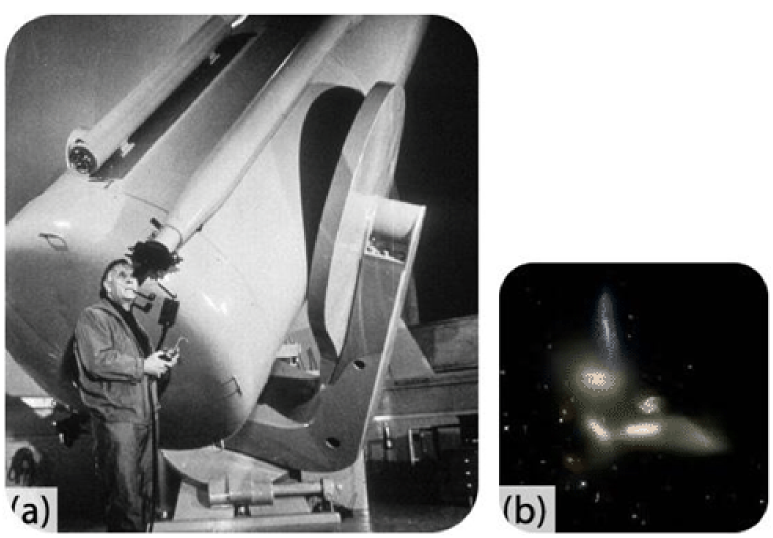


FIGURE 1.2

(a) Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light were galaxies. (b) A photo of the Whirlpool Galaxy in the constellation Canes Venatici, taken by the Hubble Space Telescope, which is named after Edwin Hubble. His work proved that galaxies exist.

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

Is the Universe Getting Bigger or Smaller?

After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distances to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed. To explain his discovery, you will need to understand the concept of **redshift**.

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

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in the Figure 1.3. This shift of absorption bands toward the red end of the spectrum is known as **redshift**.

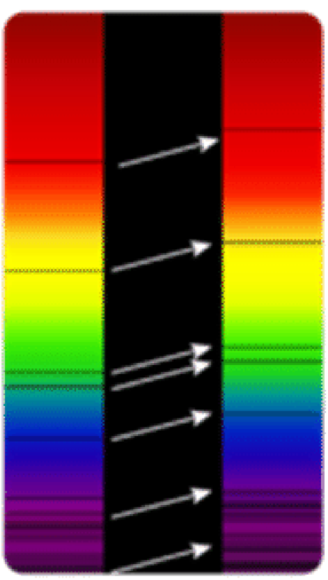
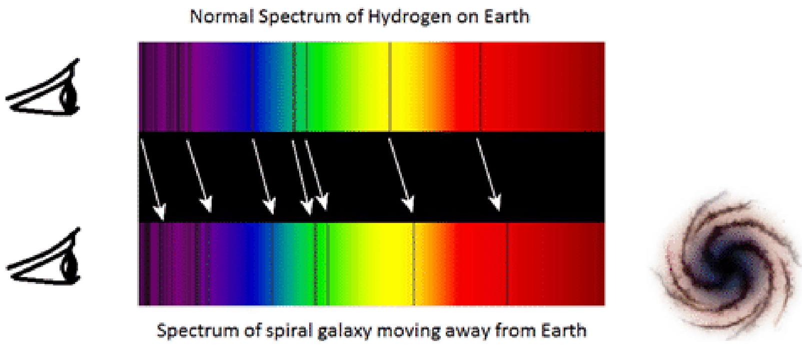


FIGURE 1.3

This figure shows the absorption lines in the visible spectrum of a distant galaxy (right), as compared to absorption lines in the visible spectrum of the Sun (left). Arrows indicate redshift. Wavelength increases up towards the red, showing the galaxy moving away from the Earth.

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



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

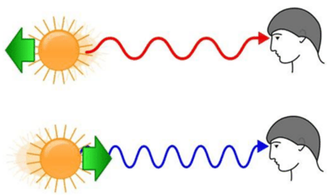


FIGURE 1.4

If a source of light is moving away from an observer then the electromagnetic spectrum will be redshifted, If the source is moving toward the observer it is blueshifted.

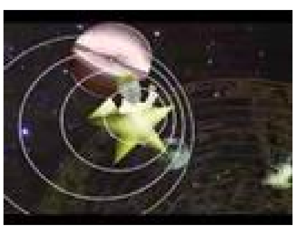
Redshift can occur with other types of waves too. This phenomenon is called the **Doppler Effect** (an increase or decrease in the frequency of sound, light, or other waves as the source and observer move toward (or away from) each other). An analogy to redshift is the noise a siren makes as it passes you. The sound waves shift towards a lower pitch when the ambulance speeds away from you. Though redshift involves light instead of sound, a similar principle operates in both situations.

An animation of **Doppler Effect**:

- http://bit.ly/LxSbyM

Youtube video explaining Doppler Effect:

- http://bit.ly/LiLRKL



MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/177854

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

- http://imagine.gsfc.nasa.gov/features/yba/M31-velocity/hubble-more.html

As we look at galaxies we see a vast majority of them are moving away from our point of view (our galaxy) thus showing the expanding universe as an evidence of the Big Bang Theory. However, people might then believe we are the center of the universe, but that would be incorrect. If you were on another galaxy you would see our galaxy moving away. Referencing an earlier activity of the balloon you can see this point more clearly.

The Figure 1.5 shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. No matter which dot you stand on, all the other dots move away. Also the dots farther away from you on the balloon would move away faster than dots nearby.

Expansion of the Universe Diagram

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

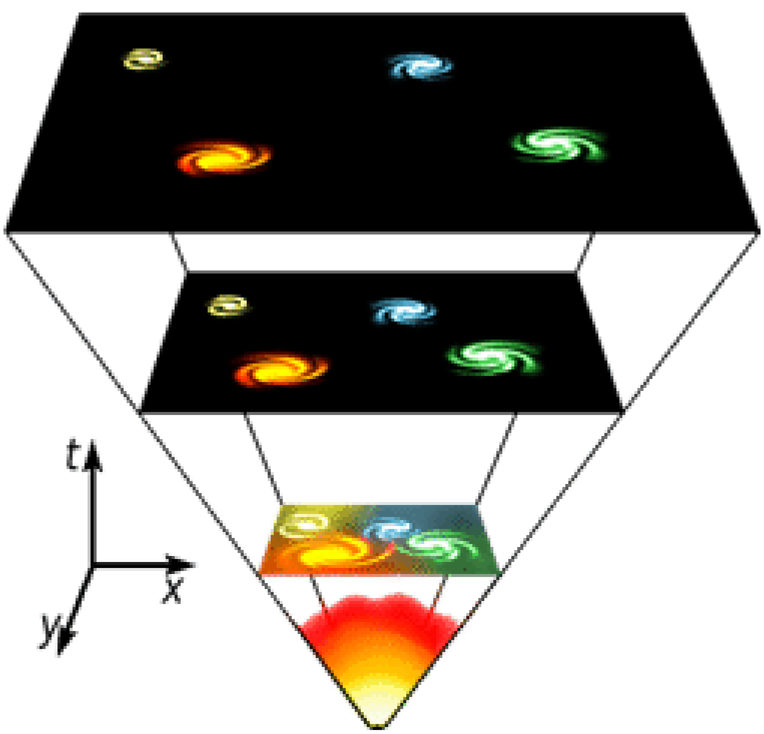


FIGURE 1.5
In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

One other difference between the universe and a balloon involves the actual size of the galaxies. On the balloon, the dots will become larger in size as you inflate it. In the universe, the galaxies stay the same size due to gravitational forces within the galaxy, just as the space between the galaxies expands.

Formation of the Universe

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

How Did the Universe Form?

The **Big Bang theory** - (the theory that the universe originated from the cataclysmic inflation of a small volume of matter at extremely high density and temperature) is the most widely accepted cosmological explanation of how the universe formed. If we start at the present and go back into the past, the universe is contracting - getting smaller and smaller. What is the end result of a contracting universe?

According to the Big Bang theory, the universe began about 13.8 billion years ago. Everything that is now in the universe existed as a single, hot, chaotic mass smaller than an atom. For as yet unknown reasons, this mass began to expand rapidly, rapidly cooling as it grew. All the matter and energy in the universe, and even space and time, resulted from this expansion.

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

After the Big Bang

In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a millionth of a second, protons (hydrogen nuclei) and neutrons could form. After a few minutes some of these subatomic particles came together to create helium nuclei. However it was not cool enough for electrons (which formed soon after protons and neutrons) to join with protons (hydrogen nuclei) or helium to make the first neutral atoms until about 380,000 years later. As the electrons were captured into the first true atoms, a burst of light and heat was released which we still see today as the **cosmic background radiation**. Because of the rapid inflation of the universe in its first moments, matter was smoothly distributed across space. However some of the hydrogen and helium were drawn together by gravity into clumps. These clumps were the seeds that eventually became countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

These stars provide us with another piece of evidence that the universe is aging. The hydrogen in stars is being changed by fusion into helium and bigger elements. As time goes on the hydrogen continues to be used up and turned into helium. When the first elements formed after the Big Bang about 92% were hydrogen, with the rest being 8% helium and traces of lithium. Today we have about 74% hydrogen and 24% helium with the 90 other naturally occurring elements forming the remaining 2%. By measuring how much hydrogen the universe started with, and the rate that stars use it, we can determine when stars began fusing. We can also use this rate to estimate how much longer fusion will continue. Right now you live in the springtime of the universe's life - most of the universe is still hydrogen. Hundreds of billions of stars in hundreds of billions of galaxies are using up hydrogen and turning it into heavier elements as the universe continues to age.

- After the publication of the Big Bang hypothesis, many astronomers still thought the universe was static (or not changing). However, the Big Bang Theory made a prediction that was different from what was expected in a static universe. It predicted that there should be some heat energy left over from the Big Bang. With the continued expansion of the universe, the temperature should be very low today, only a few degrees K (Kelvin) above absolute zero. In 1964, two researchers at Bell Laboratories (Arno Penzias and Robert Wilson) were calibrating a radio telescope. They pointed the scope to empty space, but discovered an annoying hiss coming from space wherever they looked, and that hiss was found to be leftover heat from the Big Bang. This heat was at 4°K, just as Robert Dickie and his team had predicted. Using it, they discovered microwave radiation in all parts of the sky. (Figure 1.6).

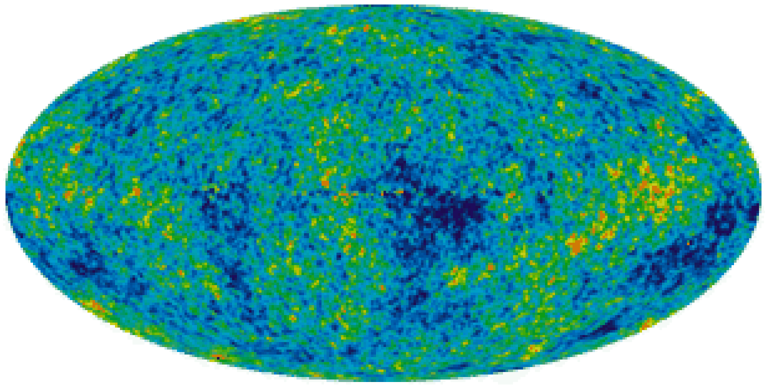
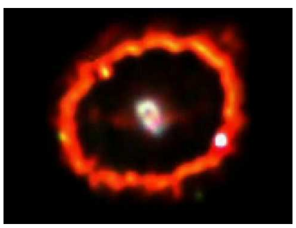


FIGURE 1.6
This image shows the cosmic background radiation in the universe as observed from the Wilkinson Microwave Anisotropy Probe (WMAP).

How we know about the early universe:

- http://www.youtube.com/watch?v=uihNu9Icaeo&feature=channel



MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178196

History of the Universe, part 2:

- http://www.youtube.com/watch?v=bK6_p5a-Hbo&feature=channel

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178198

Other Evidences for the Big Bang Theory

There are several independent pieces of evidence that support the Big Bang Theory, as well as modern cosmology's estimate of the age of the universe. Through Hubble's Law, if you know how fast the universe is expanding (called Hubble's Constant), you can calculate roughly how long ago the universe began for it to reach its current size. This gives us a universe that is at least 12 billion years old.

Another piece of evidence comes from the abundance of the elements we see in the universe. It takes time for hydrogen to fuse into helium and heavier elements. Since the Big Bang, this can only take place inside of stars in a process called **nucleosynthesis** (the combination, or synthesis, of lighter elements to make heavier atomic nucleii). For the universe to have 74% hydrogen and 24% helium would take over 12 billion years.

A third piece of evidence that supports the Big Bang Theory is the age of stars. The universe cannot be younger than the oldest stars. Stars form in different sizes, usually from the collapse of a nebula or cloud of dust and gas in space. The larger stars fuse hydrogen into helium at a tremendous rate, and die as supernova explosions after only a few million years. Smaller stars take longer to use up their hydrogen. Some stars, such as our Sun, have formed partly from the exploded remains of older stars.

The oldest stars are among the smallest, and are called red dwarf stars. Estimates of the age of the oldest red dwarfs give an age for the universe of at least 13 billion years.

The fourth evidence of the Big Bang and the age of the universe comes from recent space probe observations of the cosmic background radiation. The Wilkinson Microwave Anisotropic Probe (WMAP) and the Planck space probe have measured small fluctuations (differences) in the cosmic background radiation (CBR). These differences were imprinted on the background radiation from tiny fluctuations in the quantum energy of the original expanding universe. Theory predicts these differences, and these probes have discovered them. By measuring the size of these clumps, you can calculate the age of the universe with great accuracy. This gives an age for universe of 13.8 billion years.

All four of these lines of evidence agree with each other, and together form the pillars of modern cosmology. Our estimate of the age of the universe has improved greatly just in the last two decades. From all this evidence, we have solved one of the great mysteries of the universe.

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 most galaxies is evidence that the universe is expanding.
- According to the Big Bang theory, the universe started in a very small volume and then began expanding rapidly about 13.8 billion years ago.
- Cosmic background radiation is left over energy from the Big Bang.
- There are several independent lines of evidence that agree on the age of the universe and the existence of the Big Bang. These include Hubble's Law (the rate of the universe's expansion), the abundance of elements in the universe, the age of the oldest stars, and the fluctuations of the cosmic background radiation.

Think like a Cosmologist

1. How has our view of the universe changed since the time of the Greeks?
2. What is redshift, and what does it tell us about the universe?
3. Explain the Doppler effect and how that explains the direction of an object's motion.
4. Identify and explain three or more lines of evidence for the Big Bang Theory.
5. How old is the universe, according to scientists?
6. What did Galileo's telescope reveal? How have scientific instruments, such as telescopes and space probes, improved our understanding of the universe?

1.2 What fuels a star?

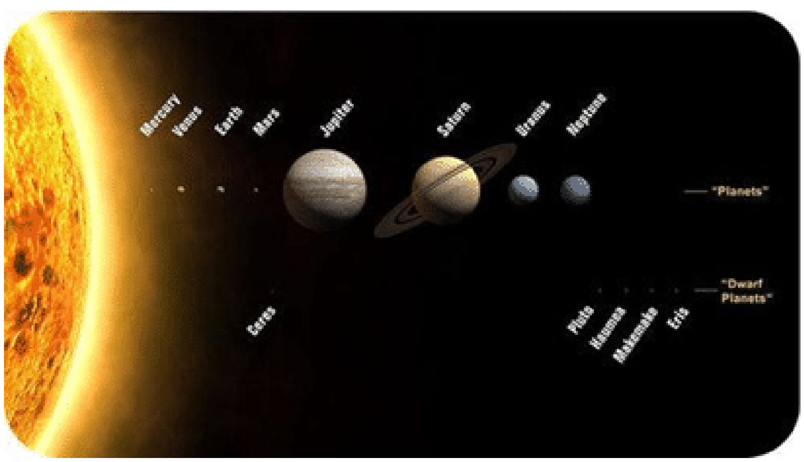
Objectives

- Relate the composition of objects in the solar system to their distance from the Sun.
- Compare the size of the solar system to the Milky Way galaxy.
- Compare the size and scale of objects within the solar system.
- Evaluate the conditions that currently support life on Earth (biosphere) and compare them to the conditions that exist on other planets and moons in the solar system (e.g., atmosphere, hydrosphere, geosphere, amounts of incoming solar energy, habitable zone).

Our Solar System

Our Solar System is all of the objects that orbit around our Sun as well as the Sun itself. The Greek name for the Sun was Sol, so it is called the Solar System.

Astronomers now recognize eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), many dwarf planets (including Ceres, Vesta, Pluto, Makemake, Haumea, Sedna, and Eris), more than 150 moons, and many, many asteroids and other small objects including comets, Kuiper Belt Objects, and meteoroids. These objects move in regular and predictable paths around the Sun.



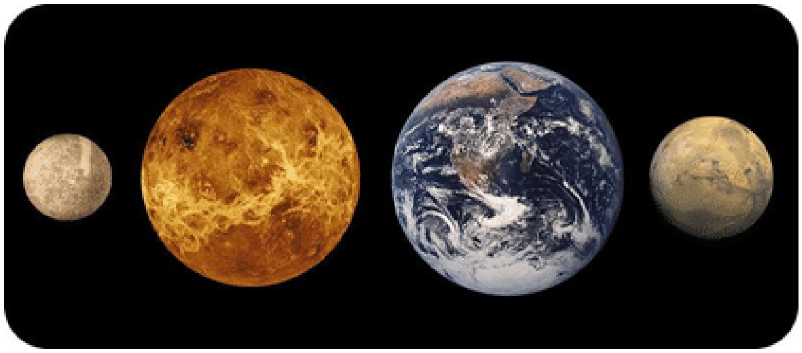
Planet Sizes

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! Listed below is data on the sizes of the Sun and planets relative to Earth (table below).

[INSERT TABLE 2]

The Inner Planets

The inner planets are the four planets closest to the Sun: Mercury, Venus, Earth, and Mars. The figure below shows the relative sizes of these four inner planets.



Unlike the outer planets, which have many satellites, Mercury and Venus do not have moons, Earth has one, and Mars has two. Of course, the inner planets have shorter orbits around the Sun, and they all spin more slowly. Geologically, the inner planets are all made of cooled igneous rock with iron cores, and all have been geologically active, at least early in their history. None of the inner planets has rings. The inner planets are generally smaller than their outer planet relatives.

The Outer Planets

The four planets farthest from the Sun are the outer planets. The Figure 1.7 shows the relative sizes of the outer planets and the Sun. These planets are much larger than the inner planets and are made primarily of gases and liquids, so they are also called gas giants.

FIGURE 1.7
Milky Way Galaxy

The Milky Way Galaxy is our galaxy. Home, sweet home. The Milky Way is made of many types, colors, and ages stars along with a lot of gas and dust. It looks different from other galaxies because we are looking at the main disk from within the galaxy. Astronomers estimate that the Milky Way contains 100 billion to 200 billion stars and is 100 - 120 million light-years across.

Stars, an introduction

When you look at the sky on a clear night, you can see hundreds of stars (or thousands, if you're away from city lights). A **star** is a self-luminous celestial body consisting of a mass of plasma (ionized hydrogen) held together by its own gravity. They have temperatures over a million degrees in their cores. Our Sun has a temperature of about 6000° Kelvin on its surface. A star's color is related to its temperature. Our star has a yellowish color compared to other stars. Many **stars** are like our Sun, but most are smaller than our Sun. They are cooler and more reddish some stars are larger and more white to blue in color. Except for our own Sun, all stars are so far away that they only look like single points, even through a telescope.

Energy of Stars

Only a tiny bit of the Sun's energy reaches Earth, but that light supplies most of the energy at Earth's surface. The Sun is just an ordinary star, but it appears much bigger and brighter than any of the other stars. Of course, this is just because it is very close. Some other stars produce much more energy than the Sun. How do stars generate so much energy?

Nuclear Fusion

Stars shine because of nuclear fusion. Fusion reactions in the Sun's core keep our nearest star burning. Stars are made mostly of hydrogen and helium. Both are very lightweight gases. A star contains so much hydrogen and helium that the weight of these gases is enormous. The pressure at the center of a star heats the plasma to extreme temperatures of millions of degree. This combination of high temperature and pressure causes nuclear fusion reactions.

We call it nuclear fusion because under these conditions, the collision of atomic nuclei causes them to fuse (join) together. In stars like our Sun, four hydrogen atoms join together to create a helium atom. Nuclear fusion reactions need a lot of energy to get started. Once they begin, they produce even more energy.

Energy from Nuclear Fusion

In fusion, two or more small nuclei combine to form a single, larger nucleus. Energy is created as a small amount of the mass of hydrogen is converted to energy in each reaction. Since there are so many hydrogen atoms fusing in the Sun, it produces a huge amount of energy. When nuclei lighter than iron undergo fusion, energy is released. The Sun is actually a huge hydrogen bomb going off continuously! Energy is absorbed when iron or nuclei more massive than iron undergo fusion. Because of this, heavier atoms tend to split instead of fuse. This is called fission.

In this nuclear fusion reaction, nuclei of four hydrogen nuclei fuse together, forming a helium nucleus and energy.

The Power of Stars

The sun's energy comes from fusion in its core, where temperatures reach millions of degrees Kelvin (Figure 1.8). This energy travels slowly to the surface through the processes of convection and radiation. Once it reaches the surface, it travels through space at the speed of light, reaching Earth in about eight minutes.

The Death of Stars

What happens when a star dies? We could say that stars are born, change over time, and eventually die. Most stars change in size, color, and class at least once during their lifetime.

Stars have a wide range of size, temperature and brightness. The properties of a star are determined by the star's mass. While most stars appear white, some stars have a slight blue or red color. The color relates to a star's temperature. Reddish stars are cooler than white stars and bluish stars are hotter.

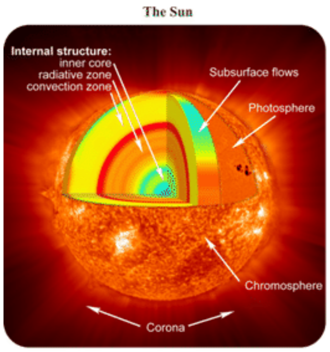
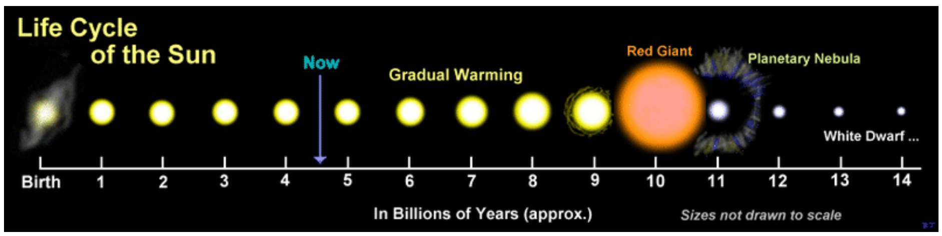


FIGURE 1.8
The extremely hot core of the sun radiates energy from nuclear fusion.



Formation of Stars

Stars are born in clouds of gas and dust called nebulas. Our Sun and solar system formed out of a nebula. A nebula is shown in the Figure 1.9. This is the Orion Nebula, which is a huge cloud of dust and gas in the constellation Orion. New stars are forming inside this nebula. As astronomers look at it through the Hubble Space Telescope, they see dusty disks in the cloud that appear to be new star systems forming. This evidence supports our theories of how stars and our Solar System formed.

For a star to form, gravity pulls gas and dust together. As mores gas continues to accumulate, the material becomes denser, the pressure and the temperature increase. When the temperature at the center becomes hot enough, nuclear fusion begins. The ball of gas has become a star!

FIGURE 1.9
Stars form in a nebula like this one in Orion's sword.

Main Sequence Stars

In 1910, two astronomers named Ejnar Hertzsprung and Henry Norris Russell independently discovered a relationship between the total brightness of a star and the star's temperature or color. They mapped these properties, and created a chart that is now known as the **H-R Diagram**. They found that stars fell into certain well-defined areas of the diagram. Most stars were located in an S-shaped region running from hot, blue stars in the upper left to cool, red stars in the lower right. This region of the chart is called the **Main Sequence**.

A star is a **main sequence star** for most of its life. These stars are fusing hydrogen into helium and releasing energy. The mass of a main sequence star determines its properties such as how hot it is, how bright is, how big it is, and how long it will exist. Stars with more mass are hotter, brighter, and have shorter lives than lower mass stars.

Our Sun has been a main sequence star for about 5 billion years. As a medium-sized star, it will continue to shine for about 5 billion more years. Large stars burn through their supply of hydrogen very quickly. These stars "live fast and die young!" A very large star may only be on the main sequence for 10 million years. A very small star such as a red dwarf may be on the main sequence for tens to hundreds of billions of years.

Red Giants and Element Production

A star like our Sun will become a **red** giant (a very large star of high luminosity or intrinsic brightness and low surface temperature) in its next stage. When a star uses up its hydrogen, the star's core starts to collapse inward and the core temperature increases. When the temperature is high enough, helium fuses into heavier nuclei like carbon and oxygen. As the core collapses, the star's outer layers spread out and cool. The result is a larger star that is cooler on the surface, and red in color.

Eventually a **red giant** fuses all of the helium in its core. At this point the star has a core filled with carbon and oxygen. Surrounding the core are two separate layers where fusion still occurs - an inner layer of helium and an outer layer of hydrogen. Nuclei within the helium-burning shell can be changed into heavier nuclei by capturing neutrons. Extra neutrons can make a nucleus unstable and one of the neutrons will suddenly change into a proton. In larger stars, this process can produce some elements as heavy as bismuth with 83 protons. This process is called **nucleosynthesis**.

White Dwarfs

What happens next depends on the star's mass. A star like the Sun stops fusion and the core becomes a white dwarf star. A white dwarf is a hot, white, glowing object about the size of Earth. The outer layers of the star are blown into space carrying with them many of the heavier elements produced in the star. The expanding bubble of gas is called a **Planetary Nebula**. After a very long time, a white dwarf will cool down and its light will fade. This is the potential end of our star, the Sun, based on its mass.

Supergiants and Supernovas

A more massive star ends its life in a more dramatic way. Very massive stars become red supergiants, like Betelgeuse in the constellation Orion.

In a red supergiant, fusion does not stop with carbon and oxygen. These elements fuse into heavier ones until iron nuclei form. Fusion of iron does not produce energy to sustain the star. With no more energy from fusion, the core will rapidly collapse. Collapse of the core creates a shock wave that moves outward and the star explodes violently. This is called a **supernova** explosion. The incredible energy released fuses heavy nuclei together. Astronomers think gold, uranium and other heavy elements may form in a supernova explosion. A supernova can shine as brightly as an entire galaxy, but only for a short time. The heavy elements are blown into space as shown in Figure 1.10.

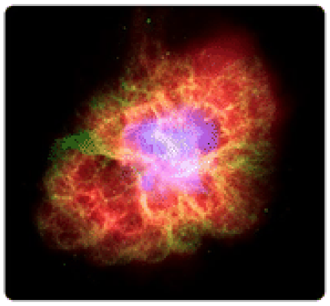


FIGURE 1.10
A supernova remnant, as seen by the Hubble Space Telescope.

Neutron Stars and Black Holes

After a supernova explosion, the star's core is left over. This material is extremely dense. If the core is less than about four times the mass of the Sun, the star will become a neutron star. This is a celestial object of very small radius (typically 18 miles/30 km) and very high density, composed predominantly of closely packed neutrons. A neutron star has more mass than the Sun, yet it is only a few kilometers in diameter. Research indicates that a collision between two neutron stars could also be the source of many heavy elements such as gold. A teaspoon of matter from a neutron star would weigh 10 million tons on Earth. Most neutron stars are rotating very rapidly, faster than 30 times per second. They can produce massive magnetic fields that send waves of light into space. Such stars are called **pulsars**.

If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses to become a **black hole**. Black holes are so massive that not even light can escape their gravity. For that reason, we can't see black holes. How can we know something exists if radiation can't escape it? We know a black hole is there by the gravitational effect that it has on objects around it. Also, if a black hole is pulling in matter, collisions between particles can heat the matter to high enough temperatures for the matter to give off high energy radiation like x-rays. A black hole isn't a hole at all. It is the tremendously dense core of what was once a supermassive star.

Summary

- A star generates energy by nuclear fusion reactions in its core.
- The properties of a star are determined by its mass.
- Stars form from clouds of gas and dust called nebulae. Nebulae collapse until nuclear fusion starts.
- Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
- Sun-like stars expand into red giants, and then fade out as white dwarf stars.
- Very massive stars expand into red supergiants, explode as supernovas, and then end up as neutron stars or black holes.
- Elements heavier than lithium are made inside stars through nucleosynthesis. The heaviest elements come from supernova explosions or the collisions of neutron stars.

Think like a Cosmologist

1. Explain the process of nuclear fusion. How are heavy elements formed?
2. What is a black hole? Why is it called that?
3. Compare and contrast the life cycles of large and small mass stars.
4. Describe one process in which each of the following elements formed: Helium, Iron, and Uranium?
5. Describe the Sun's life from its beginning to its eventual end.
6. How do astronomers know how stars form? What evidence do they have?

1.3 What is at the center of the universe?

Objectives

- Describe some early ideas about our solar system.
- Name the planets, and describe their motion around the Sun.
- Explain how the solar system formed.

The Sun and all the objects that are held by the Sun's gravity are known as the Solar System (the collection of eight planets and their moons in orbit around the Sun, together with smaller bodies in the form of asteroids, meteoroids, and comets). These objects all revolve around the Sun. The ancient Greeks recognized five planets. These lights in the night sky changed their position against the background of stars. They appeared to wander. In fact, the word "planet" comes from a Greek word meaning "wanderer". These objects were thought to be important, so they named them after gods from their mythology. The names for the planets Mercury, Venus, Mars, Jupiter, and Saturn came from the names of gods and a goddess.

Earth at the Center of the Universe

Most ancient Greeks thought that Earth was at the center of the universe, as shown in the Figure 1.11. One model they proposed had a set of spheres layered on top of one another. Each object in the sky was attached to one of these spheres. The object moved around Earth as that sphere rotated. These spheres contained the Moon, the Sun, and the five planets they recognized: Mercury, Venus, Mars, Jupiter, and Saturn. An outer sphere contained all the stars. Greek astronomers developed mathematical models of the **solar system** that they used to predict future positions of the Sun, Moon and planets. These models and procedures were finalized by Claudius Ptolemy. He published his model of the solar system around 150 AD. It was used by astronomers for fifteen hundred years.

FIGURE 1.11

On left is a line art drawing of the Ptolemaic system with Earth at the center. On the right is a drawing of the Ptolemaic system from 1568 by a Portuguese astronomer.

The Sun at the Center of the Universe

About 1,500 years after Ptolemy, Nicolaus Copernicus proposed a startling idea. He suggested that Earth was not stationary but that Earth and the planets revolved around the Sun.

Copernicus did not publish his new model until he was close to death. He may have thought that it could be considered heresy to say that Earth was in motion. Most people did not accept Copernicus' model. One of the few that did was Galileo. He tried to find evidence to support the Copernican model. He discovered the law of inertia which he used to explain why we cannot easily sense that Earth is in motion. Through his telescope, Galileo saw moons orbiting Jupiter. He proposed that this was like the planets orbiting the Sun.

Today we know that we have eight planets, many dwarf planets (a celestial body resembling a small planet), over 165 moons, and many, many asteroids, comets, meteoroids and other small objects in our solar system. We also know that the Sun is not the center of the universe. But it is the center of the solar system.

What is (and is not) a planet?

You've probably heard about Pluto. When it was discovered in 1930, Pluto was called the ninth planet. Astronomers later found out that Pluto was not like other planets. For one thing, it was discovered in the 1970s that Pluto was much smaller than previously thought. It was smaller than any of the other planets and even smaller than the Moon. Beginning in 1992, astronomers also discovered many objects in orbits similar to the orbit of Pluto. They were also icy and there thousands of them.

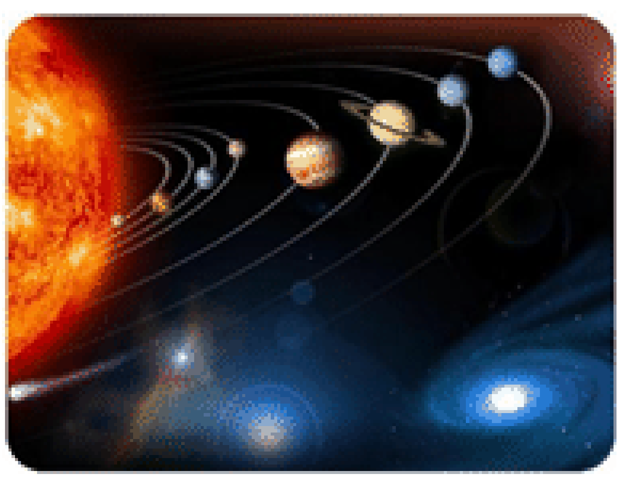
Astronomers were faced with a problem. They needed to call the largest of these other objects planet, or they needed to decide that Pluto was not a planet. In 2006, these scientists defined what a planet is. According to the new definition, a *planet* must:

- Orbit the sun.
- Be massive enough that its own gravity causes it to be round.
- Be small enough that it isn't a star itself.
- Have cleared the area of its orbit of smaller objects.

If the first three are true but not the fourth, then that object is classified as a *dwarf planet*. We now call Pluto a **dwarf planet**. There are other dwarf planets in the solar system. They include Sedna, Vesta Eris, Ceres, Makemake, and Haumea. There are other ways that Pluto is different from the planets in our solar system.

The Size and Shape of Orbits

The figure below shows the Sun and planets with the correct sizes. The distances between them are way too small. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next.



The Figure 1.12 shows those distances correctly. In the upper left are the orbits of the inner planets and the asteroid belt. The asteroid belt is a collection of many small objects between the orbits of Mars and Jupiter. In the upper right are the orbits of the outer planets and the Kuiper belt. The Kuiper belt is a group of objects beyond the orbit of Neptune.

In the Figure 1.12, you can see that the orbits of the planets are nearly circular. Pluto's orbit is more elliptical. Also, its orbit is tilted about 17 degrees with respect to the orbits of the planets. They all orbit the Sun in nearly the same plane, which is called the Ecliptic.

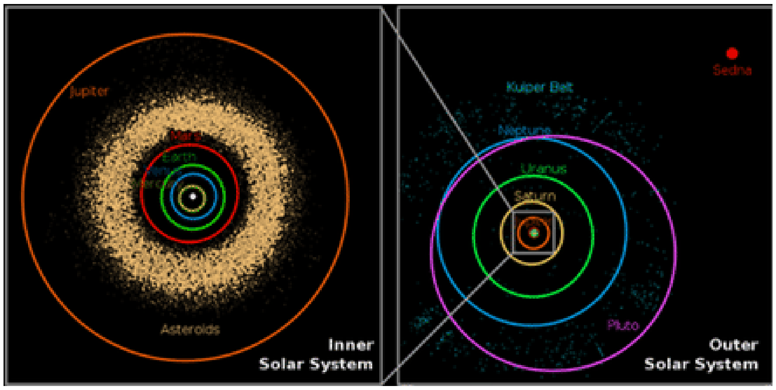


FIGURE 1.12
In this image distances are shown to scale.

Distances in Our 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 (93 million miles). The table below shows the distance from the Sun to each planet in **AU's**. The table shows how long it takes each planet to spin on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually longer than a year on Venus!

The Table below shows our solar system and gives some additional data on the mass and diameter of the Sun and planets relative to Earth.

[INSERT TABLE 1]

The Role of Gravity

Planets are held in their orbits by the force of gravity. What would happen without gravity? Imagine that you are swinging a ball on a string in a circular motion. Now let go of the string. The ball will fly away from you in a straight line. It was the string pulling on the ball that kept the ball moving in a circle. The motion of a planet is very similar to the ball on a strong. The force pulling the planet is the pull of gravity between the planet and the Sun.

According to Sir Isaac Newton, every object is attracted to every other object by gravity. The force of gravity between two objects depends on the mass of the objects. It also depends on how far apart the objects are. When you are sitting next to your dog, there is a gravitational force between the two of you. That force is far too weak for you to notice. You can feel the force of gravity between you and Earth because Earth has a lot of mass. The force of gravity between the Sun and planets is also very large. This is because the Sun and the planets are very large objects. Gravity is great enough to hold the planets in orbit around the Sun even though the distances between them are enormous. Gravity also holds moons in orbit around planets.

Extrasolar Planets

Since the early 1990s, astronomers have discovered other systems like our solar system. These "stellar" systems have one or more planets orbiting one or more stars. We call these planets "extrasolar planets", or "exoplanets", so named because they orbit a star other than the Sun. As of January 2016, over 1900 exoplanets have been confirmed.

See how many there are now:

- http://planetquest.jpl.nasa.gov/

We have been able to take pictures of only a few exoplanets. Most are discovered because of some tell-tale signs. One sign is a very small Doppler shift of a star, with its light shifting first to the red, then to the blue. This must be caused by the pull of a planet. Another sign is the partial dimming of a star's light as the planet passes in front of it. By looking at the timing between the red-blue shifts or the star's dimming, we can tell the length (period) of a planet's orbit. By looking at the strength of the red-blue shift, or the amount of dimming, we can tell the size of the planet.

How Did the Solar System Form?

To figure out how the solar system formed, we need to put together what we have learned. There are two other important features to consider. First, all the planets orbit in nearly the same flat, disk-like region (the ecliptic). 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

Scientists think the solar system formed from a **nebula** (a big cloud of gas and dust). This is the solar **nebula** hypothesis. The **nebula** was made mostly of hydrogen and helium leftover from the Big Bang. There were also heavier elements that had formed inside stars and then were expelled into space (see Figure 1.13). Gravity caused the nebula to contract. These nebulae may be formed from material leftover from the Big Bang or recycled from previous supernovas.

As the nebula contracted, it had some initial rotation. As it got smaller and smaller, it spun faster and faster. This is what happens when ice skaters pull their arms to their sides during a spin move. They spins faster. The spinning motion and gravity caused the nebula to form into a disk shape.

This model explains why all the planets are found in the flat, disk-shaped region. It also explains why all the planets revolve in the same direction. The solar system formed from the nebula about 4.6 billion years ago.

Formation of the Sun and Planets

The Sun was the first object to form in the Solar System. Gravity pulled matter together to the center of the disk. Density and pressure increased tremendously. Nuclear fusion reactions begin. In these reactions, the nuclei of atoms come together to form new, heavier chemical elements. Fusion reactions release huge amounts of nuclear energy. From these reactions a star was born, the Sun.

Meanwhile, the outer parts of the disk were cooling off. Small pieces of dust started clumping together. These clumps collided and combined with other clumps, called **planetesimals**. Larger clumps attracted smaller clumps with their gravity. Eventually, all these pieces grew into the planets and moons that we find in our solar system today. In the early Solar System, as many as 100 small planetoids formed. They gradually combined into the current planets through collisions. One such planetoid, called Theia (about the size of Mars), collided with Earth. Material

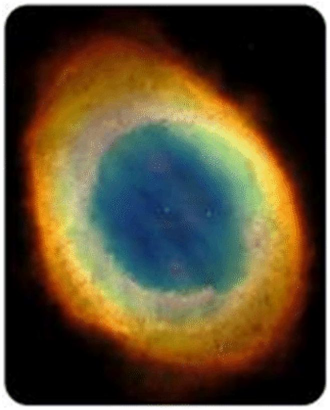


FIGURE 1.13
The nebula is formed as a star blows its outer layers into space.

from the mantles of both objects splashed into orbit and formed our Moon. Moon rocks brought back to Earth by the Apollo astronauts confirm this Big Impact hypothesis.

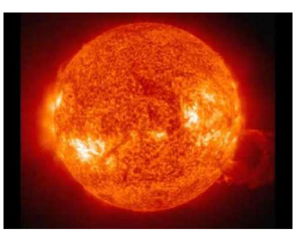
The outer planets — Jupiter, Saturn, Uranus, and Neptune — condensed from lighter materials. Hydrogen, helium, water, ammonia, and methane were among them. It's so cold by Jupiter and beyond that these materials can form solid particles. Astronomers call these solid particles "ices". Closer to the Sun, they are gases. Since the gases can escape, the inner planets — Mercury, Venus, Earth, and Mars — formed from denser elements. These elements are solid even when close to the Sun.

The Age of the Solar System

Based on the age of the oldest meteorites, a group of research scientists at the Institute of Physical Earth Sciences in Paris has carried out very precise measurements of the decay of Uranium 238 to Lead 206. Using radiometric dating we can calculate the age of the Solar System at about 4.56 billion years.

The Age of the World Made Easy:

- http://www.youtube.com/watch?v=w5369-OobM4



MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/177856

The Size of the Solar System

The universe contains an estimated 100 to 200 billion galaxies, of which our Milky Way is one. The Milky Way itself contains an estimated 100 to 200 billion stars, of which our Sun is one. If our galaxy is average, then there are over 10^{22} stars in the observable universe. The Milky Way is a barred-spiral galaxy with a radius of around 50,000 light-years (a light-year being the distance that light travels in one year), and the Sun and its Solar System are around 30,000 light-years from the center of the galaxy. Our galaxy is part of a Local Group of galaxies that includes the Andromeda galaxy. We are part of the Virgo Supercluster of galaxies, which makes up one filament of the entire observable universe. Our Solar System is a very small place in a very large universe.

Studies of exoplanets show that there could be at least one planet on average for each star (some star systems have multiple planets such as our own, others probably have none). With billions of planets in our galaxy, the odds are good that life exists somewhere outside of Earth. The study of life elsewhere is called astrobiology. Are we alone in the universe? Perhaps we will answer this question soon.

Summary

- The Sun and all the objects held by its gravity make up the solar system.
- There are eight planets in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Neptune. Some of the dwarf planets are Pluto, Eris, Ceres, Makemake, and Haumea.
- The ancient Greeks believed Earth was at the center of the universe and everything else orbited Earth.
- Copernicus proposed that Earth is a planet and that Earth and the other planets orbit the Sun.
- Planets are held by the force of gravity in elliptical orbits around the Sun.
- The solar system formed from a giant cloud of gas and dust about 4.6 billion years ago.
- This model explains why the planets all lie in one plane and orbit in the same direction around the Sun.
- Our Solar System is just one star among 100-200 billion in our Milky Way galaxy. There are a over 100 billion galaxies in the observable universe.

Think like a Cosmologist

1. What are the names of the eight planets from the Sun outward?
2. Name five of the dwarf planets.
3. How old is the Sun and the Solar System? How do we know this?
4. Explain some of the differences between the inner planets and the outer planets.
5. Describe the role of gravity in how the solar system functions. Why don't the planets fly off into space? Why aren't the planets pulled into the sun?
6. How does the nebular hypothesis explain how the solar system originated?
7. Why do you think so many people for so many centuries thought that Earth was the center of the universe?
8. People were pretty upset when Pluto was made a dwarf planet. Explain why Pluto is now classified as a dwarf planet.

1.4 What are conditions like on the inner planets?

Objectives

- Describe the main features of each of the inner planets.
- Compare each of the inner planets to Earth and to one another.

Introduction

The four inner planets (closest to the Sun - Mercury, Venus, Earth, and Mars) - are referred to as the inner planets. They are similar to Earth. All are solid, dense, and rocky. None of the inner planets have rings. Compared to the outer planets, the inner planets are small. They have shorter orbits around the Sun and they spin more slowly. Venus spins backwards and spins the slowest of all the planets.

All of the inner planets were geologically active at one time. They are all made of cooled igneous rock with inner iron cores. Earth has one big, round moon, while Mars has two very small, irregular moons. Mercury and Venus do not have moons.

Mercury

Mercury is the smallest planet. It has no moon. The planet is also closest to the Sun. As the Figure below 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. With only a trace of an atmosphere, it has no weather to wear down the ancient craters.

Short year, long days

Mercury is named after the Roman messenger god. Mercury was a messenger because he could run extremely fast. The Greeks gave the planet this name because Mercury appears to move very quickly in its orbit around the Sun. Mercury orbits the Sun in just 88 Earth days. Mercury has a very short **year** (one complete revolution around the sun), but it also has very long days. Mercury rotates slowly on its axis, turning exactly three times for every two times it orbits the Sun. This combination of rotation and orbital motion results in a solar day (noon to noon) on Mercury that is two Mercury years long.

Extreme Temperatures

Mercury is very close to the Sun, so it can get very hot. Mercury also has virtually no atmosphere. As the planet rotates very slowly, the temperature varies tremendously. In direct sunlight, the surface can be as hot as 427°C (801°F). On the dark side, the surface can be as cold as -183°C (-297°F)! The coldest temperatures may be on the insides of craters. Most of Mercury is extremely dry. Scientists think that there may be a small amount of water, in the form of ice, at the planet's poles. The poles never receive direct sunlight.

Venus

Named after the Roman goddess of love, Venus is the only planet named after a female. Venus is sometimes called Earth's "sister planet". But just how similar is Venus to Earth? Venus is our nearest neighbor. Venus is most like Earth in size.

A Harsh Environment

Viewed through a telescope, Venus looks smooth and featureless. The planet is covered by a thick layer of clouds. You can see the clouds in pictures of Venus, such as the Figure 1.14. We make maps of the surface using radar, because the thick clouds won't allow us to take photographs of the surface of Venus.

FIGURE 1.14
A topographical map of Venus produced by the Magellan probe using radar. Color differences enhance small scale structure.

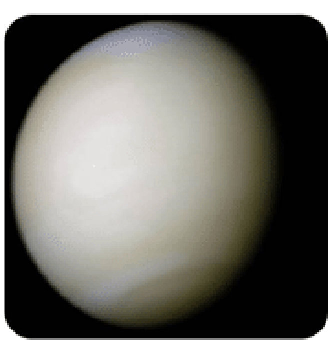


FIGURE 1.15
Venus in real color. The planet is covered by a thick layer of clouds.

The Figure 1.15 shows a topographical map of Venus. The map was produced by the Magellan probe in orbit around Venus. The spacecraft sent radar waves that reflected off Venus' surface to reveal mountains, valleys, vast lava plains, and canyons. Like Mercury, Venus does not have a moon.

Clouds on Earth are made of tiny water droplets. Venus' clouds are a lot less pleasant. They are made of tiny droplets of corrosive sulfuric acid! The atmosphere on Venus is so thick that the pressure on the surface of Venus is very high. In fact, it is 90 times greater than the pressure at Earth's surface! The thick atmosphere causes a strong greenhouse effect. As a result, Venus is the hottest planet. Even though it is farther from the sun, Venus is much hotter even than Mercury. Temperatures at the surface reach 464°C (867°F). That's hot enough to melt lead!

Volcanoes

Venus has more volcanoes than any other planet. Most of the planet's surface is covered by lava flows and volcanoes. There are over a thousand large volcanoes and there are many more small volcanoes. Most of the volcanoes are now inactive. There are also a large number of craters. There is no clear evidence that Venus or any other planet besides Earth has tectonic plates.

Motion and Appearance

Venus is the only planet that rotates clockwise as viewed from above the northern plane of the solar system. All of the other planets rotate counterclockwise. Venus turns slowly, making only one turn every 243 days. This is longer than a **year** on Venus! It takes Venus only 225 days to orbit the Sun.

Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. You can see Venus rising early in the morning, just before the Sun rises. For this reason, Venus is sometimes called "the morning star". When it sets in the evening, just after the Sun sets, it may be called "the evening star". Since planets only reflect the Sun's light, Venus should not be called a star at all! Venus is very bright because its clouds reflect sunlight very well. Venus is the brightest object in the sky besides the Sun and the Moon.

Earth

Earth is the third planet from the Sun, shown in the Figure below. Because it is our planet, we know a lot more about Earth than we do about any other planet. What are some of the main features of Earth?

Oceans and Atmosphere

Earth is a very diverse planet. Water appears as vast oceans of liquid. Water is also seen as ice at the poles or as clouds. Earth also has large masses of land. Earth's average surface temperature is 14°C (59°F). At this temperature, water is a liquid. The oceans and the atmosphere help keep Earth's surface temperatures fairly steady.

Earth is the only planet known to have life. Conditions on Earth are ideal for life! The atmosphere and magnetic field filters out harmful radiation. Water is abundant. Carbon dioxide was available for early life forms. The evolution of plants introduced more oxygen for animals.

Plate Tectonics

The Earth is divided into many plates. These plates move around on the surface. The plates collide or slide past each other. One may even plunge beneath another. Plate motions cause most geological activity. This activity includes earthquakes, volcanoes, and the buildup of mountains. The reason for plate movement is convection in the mantle. Earth is the only planet that we know has plate tectonics.

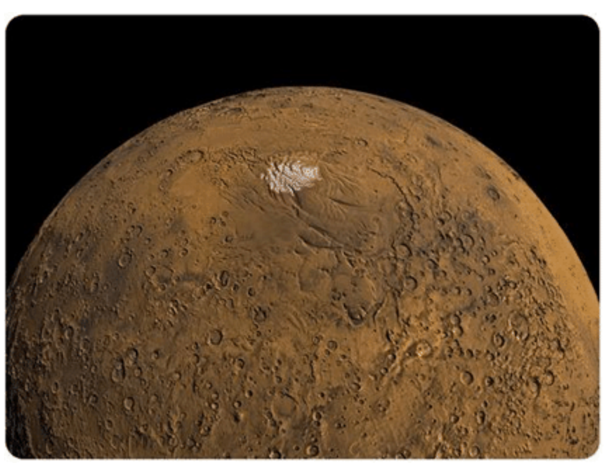
Earth's Motions and Moon

Earth rotates on its axis once every day. This is the length of an Earth day. Earth orbits the Sun once every 365.24 days. This is the length of an Earth year. Earth has one large moon. The moon orbits Earth once every 29.5 days with respect to the sun. This moon is covered with craters, and also has large impact basins that were later filled with lava. Many astronomers think that the Moon came into being from material that flew into space after Earth and a Mars-sized object collided during the formation of the solar system. This moon is not a captured asteroid like other moons in the solar system.

Mars

Mars, shown in the Figure below, is the fourth planet from the Sun. The Red Planet is the first planet beyond Earth's orbit. Mars' atmosphere is thin compared to Earth's. This means that there is much lower pressure at the surface. Mars also has a weak greenhouse effect, so temperatures are only slightly higher than they would be if the planet did not have an atmosphere.

Mars is the only planet that has a surface that can be observed from Earth through a telescope. As a result, it has been studied more than any other planet besides Earth. We have also sent many space probes to Mars. In April 2011, there were three scientific satellites in orbit around Mars. The rover, Opportunity, was still moving around on the surface. No humans have ever set foot on Mars. NASA and the European Space Agency have plans to send people to Mars. The goal is to do it sometime between 2030 and 2040. The expense and danger of these missions are phenomenal.



A Red Planet

Viewed from Earth, Mars is red. This is due to large amounts of iron oxide in the soil. The ancient Greeks and Romans named the planet Mars after the god of war. The planet's red color reminded them of blood. Mars has only a very thin atmosphere, made up mostly of carbon dioxide.

Surface Features

Mars is home to the largest volcano in the solar system. Olympus Mons is shown in the Figure 1.16. Olympus Mons is a shield volcano. The volcano is similar to the volcanoes of the Hawaiian Islands. But Olympus Mons is a giant, about 27 km (16.7 miles/88,580 feet) tall. That's three times taller than Mount Everest! At its base, Olympus Mons is about the size of the entire state of Arizona.

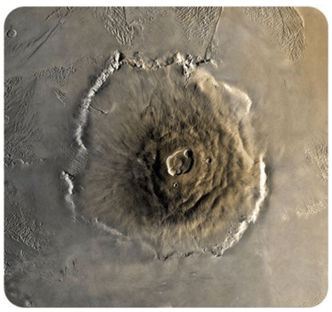


FIGURE 1.16
The largest volcano in the solar system, Olympus Mons.

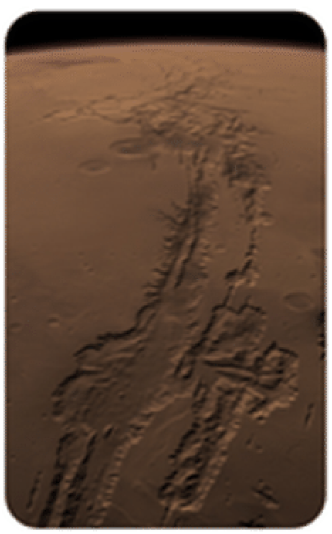


FIGURE 1.17
The largest canyon in the solar system, Valles Marineris.

Mars also has the largest canyon in the solar system, Valles Marineris. This canyon is 4,000 km (2,500 miles) long. That's as long as Europe is wide! One-fifth of the circumference of Mars is covered by the canyon. Valles Marineris is 7 km (4.3 miles) deep. How about Earth's Grand Canyon? Earth's most famous canyon is only 446 km (277 miles) long and about 2 km (1.2 miles) deep.

Mars has mountains, canyons, and other features similar to Earth. But 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. But there are fewer craters than on the Moon. What does this suggest to you regarding Mars' plate tectonic history?

Is There Water on Mars?

Water on the surface of Mars can't be a liquid. This is because the pressure of the atmosphere and the temperature are too low. The planet does have a lot of water; it is in the form of ice. The south pole of Mars has a very visible ice cap. Scientists also have evidence that there is a lot of ice just under the Martian surface.

Scientists think that there was once liquid water on the planet. There are many surface features that look like water-eroded canyons. Rovers and orbiters sent to Mars have found minerals that, on Earth, usually form in water. If there was liquid water on Mars, life might have existed there in the past.

Summary

- The four inner planets are small, dense, solid, rocky planets.
- Mercury is the smallest planet and the closest to the Sun. It has an extremely thin atmosphere so surface temperatures range 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. Venus has a very thick, corrosive atmosphere, and the surface temperature is extremely high.
- Radar maps of Venus show that it has mountains, canyons and 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 is the only inner planet that has a large round moon.
- Mars is the fourth planet from the Sun. It has two small, irregular moons. Mars is red because of 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.

Think like an Astronomer

1. Name the four inner planets from nearest to the Sun to farthest out from the Sun.
2. Which planet is most like Earth? Why?
3. How do scientists get maps of Venus' surface? What do you see if you look at Venus from Earth through a telescope?
4. Which planet do you think has the smallest temperature range? Why?
5. If you were told to go to one of the three inner planets besides Earth to look for life where would you go? Why?
6. Venus is said to have runaway greenhouse effect? Why does it have such a large amount of greenhouse effect? Why do you think is meant by runaway greenhouse effect?

1.5 What are condition like on the outer planets?

Objectives

- Describe main features of the outer planets and their moons.
- Compare the outer planets to each other and to Earth.

Introduction

Jupiter, Saturn, Uranus, and Neptune are the outer planets of our solar system. These are the four planets farthest from the Sun. The outer planets are much larger than the inner planets. Since they are mostly made of gases, they are also called gas giants.

The gas giants are mostly made of hydrogen and helium. These are the same elements that make up most of the Sun. Astronomers think that most of the nebula was hydrogen and helium. The inner planets lost these very light gases. In the inner solar system the gases were too hot for the gravity of the inner planets to keep them. In the outer solar system it was cold enough for the gravity of the planets to keep the colder slower moving hydrogen and helium gas.

All of the outer planets have numerous moons. They also have planetary rings made of ice. Only the rings of Saturn can be easily seen from Earth.

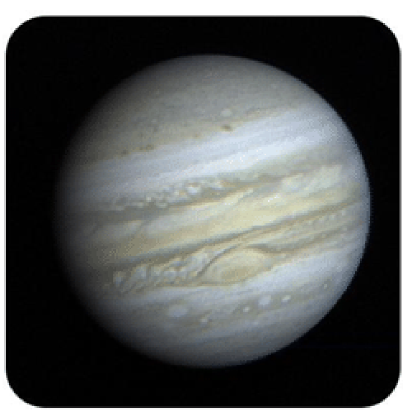
Jupiter

Jupiter is the largest planet in our solar system.

Jupiter, shown in the figure below, is the largest planet in our solar system. Jupiter is named for the king of the gods in Roman mythology.

Jupiter is truly a giant! The planet has 318 times the mass of Earth, and about 1400 times Earth's volume. So Jupiter is much less dense than Earth. 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 Sun. Jupiter is quite far from the Earth. The planet is more than five times as far from the Sun as Earth. It takes Jupiter about 12 Earth years to orbit once around the Sun.

A Ball of Gas and Liquid



Since Jupiter is a gas giant, could a spacecraft land on its surface? The answer is no. 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, the intense pressure condenses the gases into a liquid. Jupiter may have a small rocky core at its center.

A Stormy Atmosphere

Jupiter's atmosphere is made mostly of hydrogen and helium gas. There are also small amounts of other gases that contain hydrogen, like methane, ammonia and water vapor. Astronomers think that clouds in the atmosphere are particles of water, ice and compounds made of ammonia. Alternating cloud bands rotate around the planet in opposite directions. Colors in these cloud bands may come from complex organic molecules. The Great Red Spot, shown in the Figure above, is Jupiter's most noticeable feature. The spot is an enormous, oval-shaped storm. It can expand to be more than two times as wide as the entire Earth! Clouds in the storm rotate counterclockwise. They make one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years. It may have been observed as early as 1664. It is possible that this storm is a permanent feature on Jupiter. No one knows for sure.

Jupiter's Moons and Rings

Jupiter has lots of moons. As of 2012, we have discovered over 67 natural satellites of Jupiter. Four are big enough and bright enough to be seen from Earth using a pair of binoculars. These four moons were first discovered by Galileo in 1610. They are called the Galilean moons. The Figure 1.18 shows the four Galilean moons and their sizes relative to Jupiter's Great Red Spot. These moons are named Io, Europa, Ganymede, and Callisto. The Galilean moons are larger than even the biggest dwarf planets, Pluto and Eris. Ganymede is the biggest moon in the solar system. It is even larger than the planet Mercury!

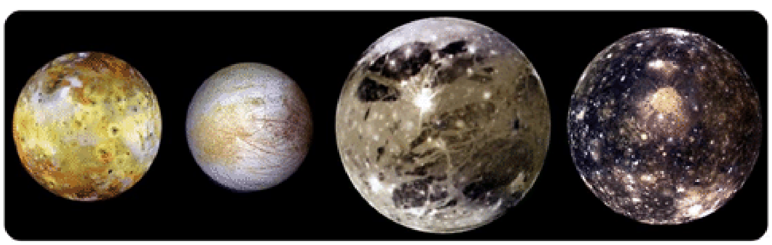


FIGURE 1.18
The Galilean moons are as large as small planets.

Scientists think that Europa is a good place to look for extraterrestrial life. Europa is the smallest of the Galilean moons. The moon's surface is a smooth layer of ice. Scientists think that the ice may sit on top of an ocean of liquid water. How could Europa have liquid water when it is so far from the Sun? Europa is heated by differences in Jupiter's gravity as Europa's distance changes during an orbit. These tidal forces are so great that they stretch and squash its moon. This could produce enough heat for there to be liquid water. Various missions have been discussed to explore Europa, including the idea to have a probe melt deep down through the ice 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 the Figure 1.19, is famous for its beautiful rings. Saturn is the second largest planet in the solar system. Saturn's mass is about 95 times Earth's mass. The gas giant is 755 times Earth's volume. Despite its large size, Saturn is the least dense planet in our solar system. Saturn is actually less dense than water. This means that if there were a bathtub big enough, Saturn would float! In Roman mythology, Saturn was the father of Jupiter. Saturn orbits the Sun once about every 30 Earth years.

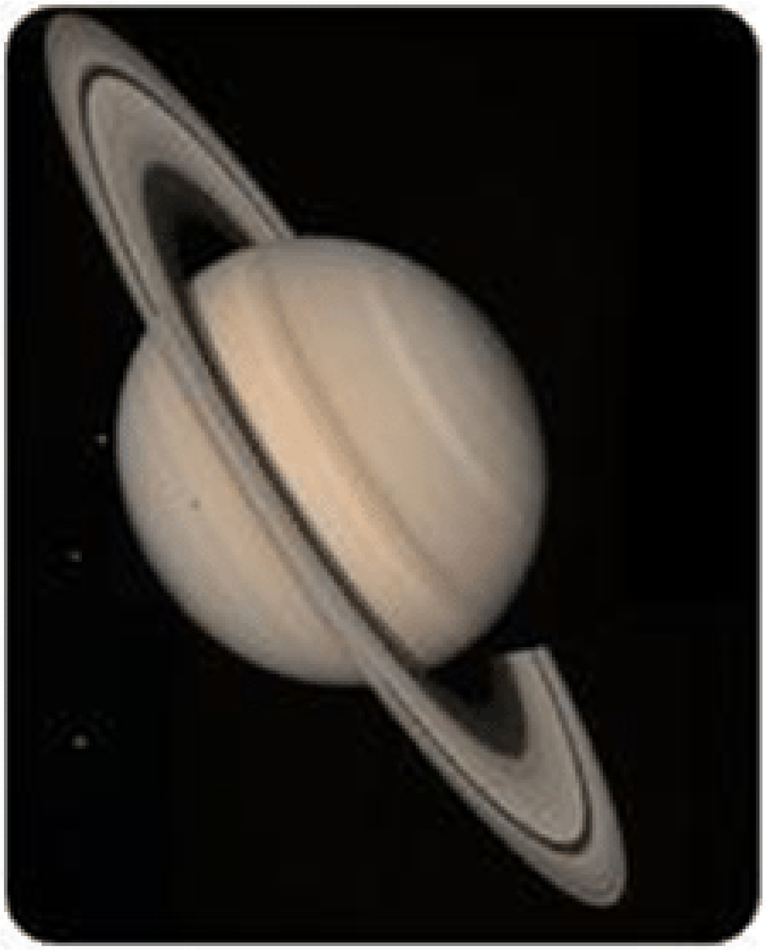


FIGURE 1.19
Saturn is the least dense planet in our solar system.

Saturn's composition is similar to Jupiter's. The planet is made mostly of hydrogen and helium. These elements are gases in the outer layers and liquids in the deeper layers. Saturn may also have a small solid core. Saturn's upper atmosphere has clouds in bands of different colors. These clouds rotate rapidly around the planet. But Saturn has fewer storms than Jupiter.

Saturn's Rings

Saturn's rings were first observed by Galileo in 1610. He didn't know they were rings and thought that they were two large moons. One moon was on either side of the planet. In 1659, the Dutch astronomer Christiaan Huygens realized that they were rings circling Saturn's equator. The rings appear tilted. This is because Saturn's rotation axis is tilted about 27 degrees from a line perpendicular to its orbit.

The Voyager 1 spacecraft visited Saturn in 1980. Voyager 2 followed in 1981. These probes sent back detailed pictures of Saturn, its rings, and some of its moons. The Cassini spacecraft has been in orbit around Saturn since 2004. From the Voyager and Cassini data, we learned that Saturn's rings are made of mostly ice particles of different sizes with a little bit of dust. There are several gaps in the rings. The gaps result from gravitational interactions between the ring particles and Saturn's moons that orbit outside the ring or by a small moon orbiting within the gap.

Saturn's Moons

As of 2012, over 62 moons have been identified around Saturn. Only seven of Saturn's moons are round. All but one is smaller than Earth's moon. Some of the very small moons are found within the rings. All the particles in the rings are like little moons, because they orbit around Saturn.

Saturn's largest moon, Titan, is about one and a half times the diameter of Earth's moon. Titan is even larger than the planet Mercury. Scientists are very interested in Titan. The moon has an atmosphere that is thought to be like Earth's first atmosphere. This atmosphere was around before life developed on Earth. Like Jupiter's moon, Europa, Titan may have a layer of liquid water under a layer of ice. Scientists now think that there are lakes on Titan's surface. Don't take a dip, though. These lakes contain liquid methane and ethane instead of water! Methane and ethane are compounds found in natural gas.

Uranus

FIGURE 1.20

Uranus is the 7th planet out from the Sun. Uranus' rings are almost perpendicular to the planet.

Uranus, shown in the Figure 1.20, is named for the Greek god of the sky, the father of Saturn. Astronomers pronounce the name "YOOR-uh-nuhs". Uranus was not known to ancient observers. The planet was first discovered with a telescope by the astronomer William Herschel in 1781.

Uranus is faint because it is very far away. Its distance from the Sun is 2.8 billion kilometers (1.8 billion miles). A photon 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

Uranus is a lot like Jupiter and Saturn. The planet is composed mainly of hydrogen and helium, but Uranus has a higher percentage of "ices" than Jupiter and Saturn. These "ices" include water, ammonia, and methane. Uranus is also different because of its blue-green color. Methane gas absorbs red light so the reflected light gives Uranus a blue-green color. The atmosphere of Uranus has bands of clouds. These clouds are hard to see in normal light. The result is that the planet looks like a plain blue ball.

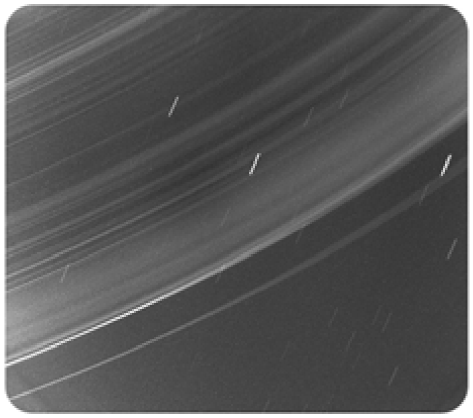
Uranus is the least massive outer planet. Its mass is only about 14 times the mass of Earth. Like all of the outer planets, Uranus is much less dense than Earth. Gravity is actually weaker than on Earth's surface. If you were at the top of the clouds on Uranus, you would weigh about 10 percent less than what you weigh on Earth.

The Sideways Planet

All of the planets rotate on their axes in the same direction that they move around the Sun except for Venus and Uranus. While Venus rotates in the opposite direction, Uranus is tilted on its side. Its axis is almost parallel to its orbit. How did Uranus get this way? One possibility is that the planet was struck by a large planet-sized object as it was forming during the early days of the solar system.

Rings and Moons of Uranus

Uranus has a faint system of rings, as shown in the Figure below. The rings circle the planet's equator. However, Uranus is tilted on its side. So the rings are almost perpendicular to the planet's orbit.



We have discovered 27 moons around Uranus. All but a few are named for characters from the plays of William Shakespeare.

Neptune

Neptune is shown in the Figure 1.21. It is the eighth planet from the Sun. Neptune is so far away you need a telescope to see it from Earth. Neptune is the most distant planet in our solar system. It is nearly 4.5 billion kilometers (2.8 billion miles) from the Sun. One orbit around the Sun takes Neptune 165 Earth years.

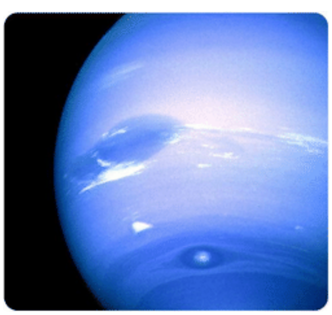


FIGURE 1.21
Neptune has a great dark spot at the center left and a small dark spot at the bottom center.

Scientists guessed Neptune's existence before it was discovered. Uranus did not always appear exactly where it should. They said this was because a planet beyond Uranus was pulling on it. This gravitational pull was affecting its orbit. Neptune was discovered in 1846. It was just where scientists predicted it would be! The planet was named Neptune for the Roman god of the sea.

Uranus and Neptune are often considered "sister planets". They are very similar to each other. Neptune has slightly more mass than Uranus, but it is slightly smaller in size.

Extremes of Cold and Wind

Like Uranus, Neptune is blue. The blue color is mostly caused by the absorption of red light by methane in Neptune's atmosphere. Neptune is not a smooth looking ball like Uranus. The planet has a few darker and lighter spots. 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. When the Hubble Space Telescope photographed Neptune in 1994, the Great Dark Spot had disappeared. Another dark spot had appeared north of the equator.

Neptune's appearance changes due to its turbulent atmosphere. Winds are stronger than on any other planet in the solar system. Wind speeds can reach 1,100 km/h (700 mph). This is close to the speed of sound! The rapid winds surprised astronomers. This is because Neptune receives little energy from the Sun to power weather systems. It is not surprising that Neptune is one of the coldest places in the solar system. Temperatures at the top of the clouds are about -218°C (-360°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 Saturn's. Neptune's rings may be unstable. They may change or disappear in a relatively short time.

Neptune has 13 known moons. Only Triton, shown in the Figure 1.22, has enough mass to be round. Triton orbits in the direction opposite to Neptune's orbit. Because of this, scientists think Triton did not form around Neptune. The satellite may have been captured by Neptune's gravity as it passed very close to Neptune.

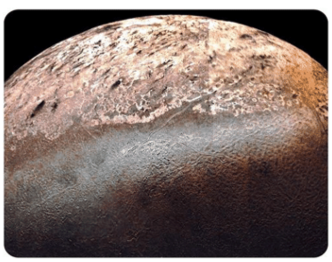


FIGURE 1.22
Neptune's moon Triton.

Summary

- The four outer planets — Jupiter, Saturn, Uranus, and Neptune — are all gas giants made mostly of hydrogen and helium. Their thick outer layers are gases and have liquid interiors.
- All of the outer planets have lots of moons, as well as planetary rings made of dust and other particles.
- Jupiter is 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 very similar to Jupiter. 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 using a telescope. 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 distant past.
- Neptune is very cold and has very strong winds. It had a large dark spot that disappeared. Another dark spot appeared on another part of the planet. These dark spots are storms in Neptune's atmosphere.

Think like an Astronomer

1. Why were the Galilean moons given that name? What are they?
2. How are the outer planets different from the inner planets?
3. If you were given the task of finding life in the outer solar system where would you look?
4. The atmosphere of Saturn's moon Titan may resemble the early Earth's atmosphere. Why is this interesting to scientists?
5. The inner planets are small and rocky, while the outer planets are large and made of gases. Why might the planets have formed into these two groups?
6. 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?

1.6 What other objects are in the solar system?

Objectives

- Locate and describe the asteroid belt.
- Explain where comets come from and what causes their tails.
- Discuss the differences between meteors, meteoroids, and meteorites.

Introduction

Debris. Space junk. After the Sun and planets formed, there was some material left over. These small chunks didn't get close enough to a large body to be pulled in by its gravity. They now inhabit the solar system as asteroids and comets.

Asteroids

Asteroids are very small, irregularly shaped, rocky bodies. Asteroids orbit the Sun, but they are more like giant rocks than planets. Since they are small, they do not have enough gravity to become round. They are too small to have an atmosphere. Except for a few of the largest asteroids, they are too small to have internal heat, so they are not geologically active. These asteroids can only change due to a collision. A collision may cause the asteroid to break up. It may create craters and melt some of the rocky material on the asteroid's surface. An asteroid may strike a planet if it comes near enough to be pulled in by its gravity. The Figure 1.23 shows a typical asteroid.

FIGURE 1.23
Asteroid Ida with its tiny moon Dactyl.

The Asteroid Belt

Hundreds of thousands of asteroids have been found in our solar system. They are now being discovered at a rate of tens of thousands of new asteroids per year! The majority are located in between the orbits of Mars and Jupiter. This region is called the asteroid belt, as shown in the Figure 1.24. There are many thousands of asteroids in the asteroid belt. Still, their total mass adds up to only about 4 percent of Earth's moon.

Asteroids formed at the same time as the rest of the solar system. Although there are many in the asteroid belt, Jupiter's gravity kept the material in this region from forming into a planet, throwing much of it either out of the solar system or into the Sun.

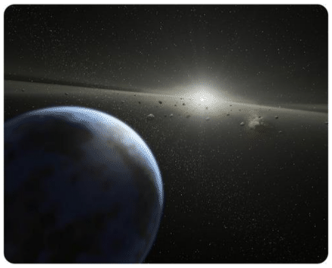


FIGURE 1.24
The asteroid belt is between Mars and Jupiter.

Near-Earth Asteroids

Near-Earth asteroids have orbits that come near to or cross Earth's orbit. This means that they could possibly collide with Earth. There are over 10,000 known near-Earth asteroids. Small asteroids do sometimes collide with Earth. An asteroid about 5-10 m in diameter hits about once per year. About a thousand of the known near-Earth asteroids are much bigger. They are over 1 kilometer in diameter. When large asteroids hit Earth in the past, many organisms died. At times, many species became extinct. Astronomers keep looking for near-Earth asteroids. They hope to predict a possible collision early so they can to try to stop it.

Meteors

If you look at the sky on a dark night, you may see a meteor, like in the Figure 1.25. A meteor forms a streak of light across the sky. People call them shooting stars because that's what they look like. But meteors are not stars at all. The light you see comes from a small piece of matter burning up as it flies through Earth's atmosphere.

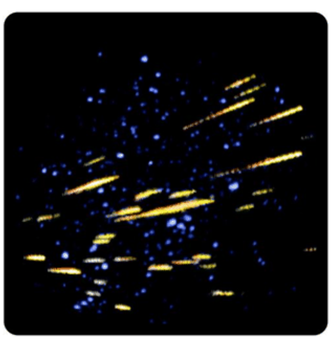


FIGURE 1.25
Meteors burning up as they fall through Earth's atmosphere.

Meteoroids

Before these small pieces of matter enter Earth's atmosphere, they are called meteoroids. Meteoroids are as large as boulders or as small as tiny sand grains. Larger objects are called asteroids; smaller objects are interplanetary dust.

Meteoroids sometimes cluster together in long trails. They are the debris left behind by comets. When Earth passes through a comet trail, there is a meteor shower. During a meteor shower, there are many more meteors than normal for a night or two.

Meteorites

A meteoroid that passes very close to Earth is dragged towards Earth by gravity and enters the atmosphere. As it enters the atmosphere, it compresses the air in front of it, producing enormous heat and the meteoroid starts to vaporize. As it flies through the atmosphere, it leaves a trail of glowing gases. The object is now a meteor. Most meteors vaporize in the atmosphere. They never reach Earth's surface. Large meteoroids may not burn up entirely in the atmosphere. Some pieces of the rock may survive and land on Earth's surface. Once on the ground, it is called a meteorite.

Meteorites provide clues about our solar system. Almost all were formed in the early solar system (the Figure 1.26). Some were part of larger asteroids that have been broken apart. A tiny fraction are rocks from nearby bodies like Mars or the Moon. For this to happen, an asteroid smashed into Mars or the Moon and sent up debris into space. After spending a long time orbiting the Sun, a bit of the debris landed on Earth as a meteorite.

FIGURE 1.26
The Mars Rover, Opportunity, found a metal meteorite on the Red Planet.

Comets

Comets are small, icy objects that orbit the Sun. Comets have highly elliptical orbits. Their orbits carry them from close to the Sun to the solar system's outer edges. When a comet gets close to the Sun, its outer layers of ice melt and evaporate. The vaporized gas and dust forms an atmosphere around the comet. This atmosphere is called a coma. Radiation and particles streaming from the Sun push some of this gas and dust into a long tail. A comet's tail always points away from the Sun, no matter which way the comet is moving. Why do you think that is? The Figure below shows Comet Hale-Bopp, which shone brightly for several months in 1997.

Gases in the coma and tail of a comet reflect light from the Sun. Because comets are very small, they are very hard to see except when they are surrounded by a coma. That is why they are more easily discovered and seen when they are in the inner solar system. They are nearly impossible to see as they move back to the outer solar system. The time it takes a comet to complete one orbit is called the comet's period. The first comet whose period was calculated was Halley's Comet. Its period is about 76 years. Halley's Comet last traveled through the inner solar system in 1986. The comet will appear to Earth observers again in 2061 and pass closest to the Sun in 2062. Who will look up at it?

Where Comets Come From

Some comets have periods of 200 years or less. They are called short period comets. Short period comets are from a region beyond the orbit of Neptune called the Kuiper Belt. Kuiper is pronounced "KI-per", rhyming with "viper". The Kuiper Belt is home to comets, asteroids, and at least two dwarf planets.

Some comets have periods of thousands or even millions of years. Most long-period comets come from a very distant region of the solar system. This region is called the Oort cloud. The Oort cloud is about 50,000-100,000 times the distance from the Sun to Earth.

Comets carry materials in from the outer solar system. Comets may have brought water into the early Earth. Other substances could also have come from comets.

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.

Think like an Astronomer

1. Define each of the following: asteroid, meteoroid, meteorite, meteor, planet, dwarf planet.
2. Which type of asteroid is most likely to hit Earth?
3. What is the asteroid belt? Why are there so many asteroids orbiting in this location?
4. What damage can an asteroid do when it hits Earth?

1.7 References

1. . https://dr282zn36sxxg.cloudfront.net/datastreams/f-d%3A6811abbc13c9989627b4047c94d22e9ffaa706e232c4b98c5acab38a%2BIMAGE_THUMB_POSTCARD%2BIMAGE_THUMB_POSTCARD.1 .
2. . https://en.wikipedia.org/wiki/File:Sun_Life.png .

CHAPTER 2 Standard II: Inside Earth

Chapter Outline

2.1 HOW DOES THE INTERNAL STRUCTURE OF THE EARTH AFFECT THE TEMPERATURE OF THE EARTH?

2.2 WHAT CAUSES EARTHQUAKES AND VOLCANOES?

2.3 DOES THE MOVEMENT OF EARTH'S PLATES AFFECT ALL LIVING THINGS?

2.4 REFERENCES

Standard 2: Students will understand Earth's internal structure and the dynamic nature of the tectonic plates that form its surface.

Objective 1: Evaluate the source of Earth's internal heat and the evidence of Earth's internal structure.

1. Identify that radioactive decay and heat of formation are the sources of Earth's internal heat.
2. Trace the lines of scientific evidence (e.g., seismic studies, composition of meteorites, and samples of the crust and mantle) that led to the inference that Earth's core, mantle, and crust are separated based on composition.
3. Trace the lines of scientific evidence that led to the inference that Earth's lithosphere, asthenosphere, mesosphere, outer core, and inner core are separated based on physical properties.
4. Model how convection currents help distribute heat within the mantle.

Objective 2: Describe the development of the current theory of plate tectonics and the evidence that supports this theory.

1. Explain Alfred Wegener's continental drift hypothesis, his evidence (e.g., fossil record, ancient climates, geometric fit of continents), and why it was not accepted in his time.
2. Cite examples of how the geologic record preserves evidence of past change.
3. Establish the importance of the discovery of mid-ocean ridges, oceanic trenches, and magnetic striping of the sea floor to the development of the modern theory of plate tectonics.
4. Explain how mantle plumes (hot spots) provide evidence for the rate and direction of tectonic plate motion.
5. Organize and evaluate the evidence for the current theory of plate tectonics: seafloor spreading, age of seafloor, distribution of earthquakes and volcanoes.

Objective 3: Demonstrate how the motion of tectonic plates affects Earth and living things.

1. Describe a lithospheric plate and identify the major plates of the Earth.
2. Describe how earthquakes and volcanoes transfer energy from Earth's interior to the surface (e.g., seismic waves transfer mechanical energy, flowing magma transfers heat and mechanical energy).
3. Model the factors that cause tectonic plates to move (e.g., gravity, density, convection).
4. Model tectonic plate movement and compare the results of plate movement along convergent, divergent, and transform boundaries (e.g., mountain building, volcanoes, earthquakes, mid-ocean ridges, oceanic trenches).
5. Design, build, and test a model that investigates local geologic processes (e.g., mudslides, earthquakes, flooding, erosion) and the possible effects on human- engineered structures (e.g., dams, homes, bridges, roads).

2.1 How does the internal structure of the Earth affect the temperature of the Earth?

Earth's Internal Heat

In the Nebular theory of the formation of our solar system there were many collisions that happened to create our present day planets. A lot of heat and energy was created in that process. Many small particles collided and stuck together so that energy was given to the newly formed Earth, raising the its temperature. At this period of the Earth's history it was so hot it was literally a big ball of molten rock.

As time progresses the Earth begins to cool and rocks on the surface harden. But scientists also use seismic waves to show evidence that the interior of the Earth is not as solid as the surface. Where is this heat coming from? Most of it is leftover heat from the formation of the Earth. Another source of Earth's interior heat comes from **radioactive decay** - An element breaks down into another element and energy is released from its nucleus as it breaks apart. That released energy is then absorbed by the surrounding rocks thus increasing their temperature.

Exploring Earth's Interior

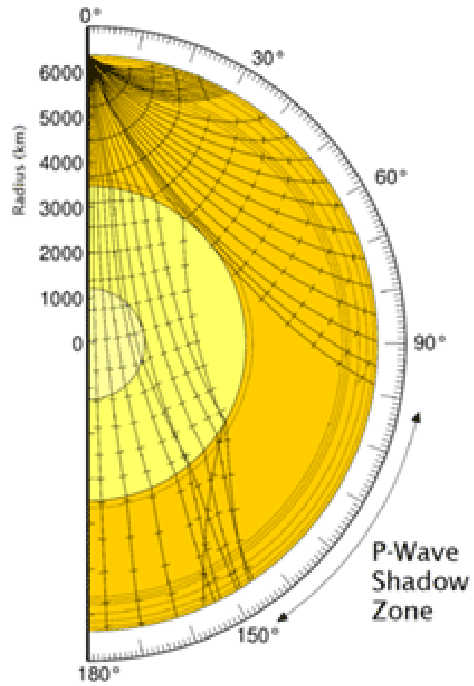
How do scientists know what is inside the Earth? We don't have direct evidence! Rocks yield some clues, but they only reveal information about the outer crust. In rare instances, a mineral, such as a diamond, comes to the surface from deeper down in the crust or the mantle. To learn about Earth's interior, scientists use energy to "see" the different layers of the Earth, just like doctors can use an MRI, CT scan, or x-ray to see inside our bodies.

Seismic Waves

One ingenious way scientists learn about Earth's interior is by looking at how energy travels from the point of an earthquake. These are seismic waves. Seismic waves travel outward in all directions from where the ground breaks at an earthquake. These waves are picked up by seismographs around the world. Two types of seismic waves are most useful for learning about Earth's interior.

- P-waves (primary waves) are fastest, traveling at about 6 to 7 kilometers (about 4 miles) per second, so they arrive first at the seismometer. P-waves move in a compression/expansion type motion, squeezing and unsqueezing earth materials as they travel. This produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. Seismic waves move faster through denser or more rigid material. As P-waves encounter the liquid outer core, which is less rigid than the mantle, they slow down. This makes the P-waves arrive later and further away than would be expected. The result is a P-wave shadow zone. No P-waves are picked up at seismographs 104° to 140° from the earthquakes focus.
- S-waves (secondary waves) are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second, and arrive second at seismographs. S-waves move in an up and down motion perpendicular to the direction of wave travel. This produces a change in shape for the earth materials they move through. Only solids resist a change in shape, so S-waves are only able to travel through solids. S-waves cannot travel through liquid. Some seismographs on Earth don't receive S-wave data leading scientists to infer that there is a liquid layer in the interior of the Earth not allowing S-waves to travel through.

By tracking seismic waves, scientists have learned what makes up the planet's interior (See the figure below).



This animation shows a seismic wave shadow zone:

- http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Shadow+Zone&flash_file=shadowzone&flash_width=220&flash_height=320

Other Clues about Earth's Interior

- Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal.
- Since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic.
- Meteorites are the remains of the material that formed the early Solar System and are thought to be similar to material in Earth's interior (Figure 2.1).

FIGURE 2.1
This meteorite contains silica minerals and iron-nickel. The material is like the boundary between Earth's core and mantle. The meteorite is 4.2 billion years old.

The Earth's Layers

The Earth's compositional and physical properties layers are pictured 2.2.

Core, mantle, and crust are divisions based on composition:

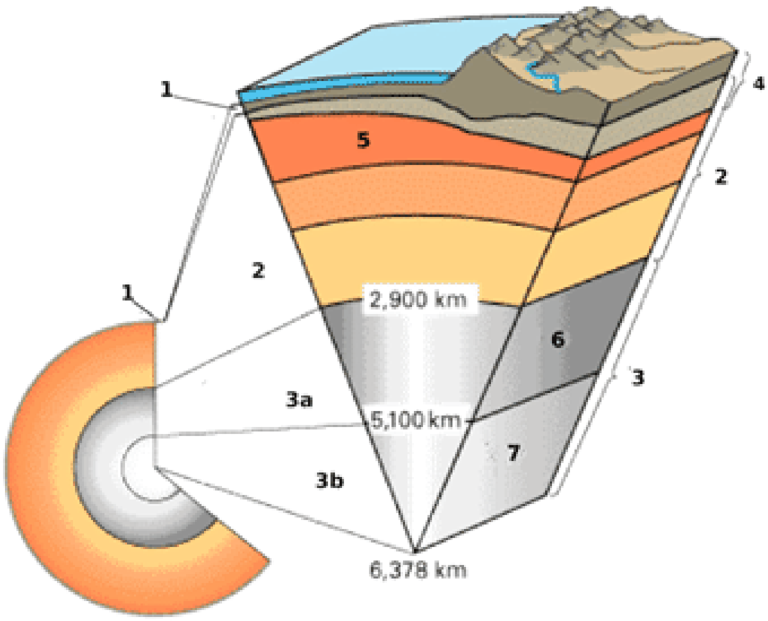


FIGURE 2.2

A cross section of Earth showing the following compositional layers: (1) crust (2) mantle (3a) outer core (3b) inner core and physical properties layers (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

- The crust is less than 1% of Earth by mass. The oceanic crust is mafic (minerals with high levels of ferromagnesian), while continental crust is often more felsic (minerals that are primarily made of feldspars and quartz) rock.
- The mantle is hot, ultramafic rock. It represents about 68% of Earth's mass.
- The core is mostly iron metal. The core makes up about 31% of the Earth.

Lithosphere and asthenosphere are divisions based on (physical) properties:

- The **lithosphere** is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid.
- The **asthenosphere** is partially molten upper mantle material that behaves plastically and can flow.
- The **mesosphere** refers to the mantle in the region under the lithosphere, and the asthenosphere, but above the outer core. The difference between mesosphere and asthenosphere is likely due to density and rigidity differences, that is, physical factors, and not to any difference in chemical composition.

This animation shows the layers by composition and by mechanical (physical) properties:

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html

Crust and Lithosphere

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

[INSERT TABLE 3]

Oceanic crust is composed of mafic magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro (Figure 2.3).

Continental crust is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic rocks of the oceanic crust (Figure 2.4). Because it is

FIGURE 2.3
Gabbro from ocean crust

thick and has relatively low density, continental crust rises higher on the mantle than oceanic crust, which sinks into the mantle to form basins. When filled with water, these basins form the planet's oceans.

FIGURE 2.4
This granite from Missouri is more than 1 billion years old.

The lithosphere is the outermost mechanical (physical) layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. The definition of the lithosphere is based on how earth materials behave, so it includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stresses act on the lithosphere, it breaks. This is what we experience as an earthquake.

Mantle

The two most important things about the mantle are:

1. it is made of solid rock, and
2. it is hot.

Scientists know that the mantle is made of rock based on evidence from seismic waves, heat flow, and meteorites. The properties of the mantle are the same as those of the ultramafic rock peridotite, which is made of the iron- and magnesium-rich silicate minerals (Figure 2.5). Peridotite is rarely found at Earth's surface, leading to the conclusion that this type of rock is from the mantle.

At the planet's center lies a dense metallic core. Scientists infer that the core is metal because:

- The density of Earth's surface layers is much less than the overall density of the planet, as calculated from the planet's rotation. If the surface layers are less dense than average, then the interior must be denser than average. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%.
- Metallic meteorites are thought to be representative of the core. The 85% iron 15% nickel calculation above is also seen in metallic meteorites (See the Figure 2.6).

FIGURE 2.5
Peridotite is formed of crystals of olivine (green) and pyroxene (black).

If Earth's core were not metal, the planet would not have a magnetic field. Metals such as iron are magnetic, but rock, which makes up the mantle and crust, is not.

Scientists know that the outer core is liquid because:

1. S-waves stop at the inner core.
2. The strong magnetic field is caused by convection in the liquid outer core. Convection currents in the outer core are due to heat from the even hotter inner core.

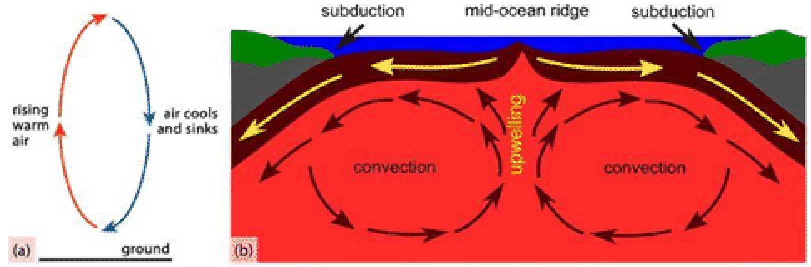
Even though the inner core is very hot it is solid because of the intense pressure keeping the atoms as moving freely as they would in a liquid.

The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core.

FIGURE 2.6
An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

Heat flows in two different ways within the Earth:

1. **Conduction:** When one material is touching another or within a single material energy is transferred heat flows from warmer to cooler places until all are the same temperature. The mantle is hot mostly because of heat conducted from the core.
2. **Convection:** If a material is able to move, even if it moves very slowly, convection currents can form. Convection in the mantle is the same as convection in a pot of water on a stove. Convection currents within Earth's mantle form as material near the core heats up. As the core heats the bottom layer of mantle material, particles move more rapidly, decreasing its density and causing it to rise. The rising material begins the convection current. When the warm material reaches the surface, it spreads horizontally. The material cools because it is no longer near the core. It eventually becomes cool and dense enough to sink back down into the mantle. At the bottom of the mantle, the material travels horizontally and is heated by the core. It reaches the location where warm mantle material rises, and the mantle convection cell is complete (Figure below).



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

Diagram of convection within Earth's mantle.

Summary

- Heat of formation and radioactive decay are the sources of Earth's internal heat.
- Earth is divided into layers based on compositional and physical properties.
- The hot core warms the base of the mantle, which causes mantle convection.

Think like a Geologist

1. How do scientists learn about Earth's interior composition?
2. What is the difference between crust and lithosphere? Include in your answer both where they are located and what their properties are.
3. How do the differences between oceanic and continental crust lead to the presence of ocean basins and continents?
4. How do scientists know that the outer core is liquid?
5. Why is the outer core liquid and the inner core solid?
6. Describe the properties of each of these parts of the Earth's interior: lithosphere, asthenosphere, and mesosphere. What are they made of? How hot are they? What are their physical properties?
7. When you put your hand above a pan filled with boiling water, does your hand warm up because of convection or conduction? If you touch the pan, does your hand warm up because of convection or conduction? Based on your answers, which type of heat transfer moves heat more easily and efficiently?

2.2 What causes earthquakes and volcanoes?

"Doesn't the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? This is an idea I'll have to pursue." - Alfred Wegener said to his future wife, in December, 1910. We can't really get into Alfred Wegener's head, but we can imagine that he started his investigations by trying to answer this question: Why do the continents of Africa and South America appear to fit together so well? Is it a geometric coincidence that they do, or is there some geological reason?

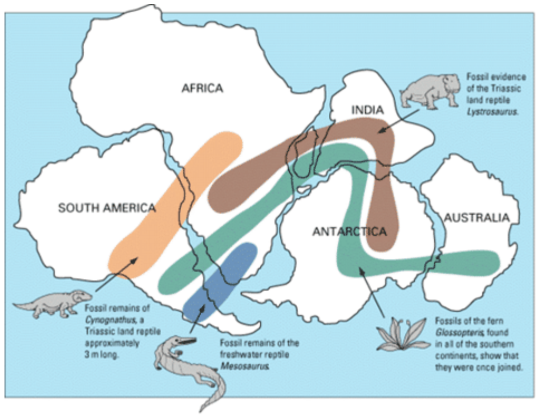
Wegener's Idea

Alfred Wegener, born in 1880, was a meteorologist and explorer. In 1911, Wegener found a scientific paper that listed identical plant and animal fossils on opposite sides of the Atlantic Ocean. Intrigued, he then searched for and found other cases of identical fossils on opposite sides of oceans. The explanation put out by the scientists of the day was that land bridges had once stretched between these continents. Instead, Wegener pondered the way Africa and South America appeared to fit together like puzzle pieces. Other scientists had suggested that Africa and South America had once been joined, but Wegener was the idea's greatest supporter. Wegener obtained a tremendous amount of evidence to support his hypothesis that the continents had once been joined.

Wegener's Evidence

The main evidences that Wegener and his supporters collected for the continental drift hypothesis:

1. The continents appear to fit together.
2. Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated. Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. His critics suggested that the organisms moved over long-gone land bridges, but Wegener thought that the organisms could not have been able to travel across the oceans.



- Fossils of the seed fern Glossopteris were too heavy to be carried so far by wind.
- Mesosaurus was a swimming reptile, but could only swim in fresh water.
- Cynognathus and Lystrosaurus were land reptiles and were unable to swim.

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

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

Problems with his Theory

Even with many forms of evidence that the continents had once fit together and had since moved apart into their present locations, the scientific community at the time could not fully accept his theory. The biggest reason for the rejection of his evidence was that Wegener could not provide an explanation for how something as large as continents could move or by which force they could collide into one another. Wegener incorrectly proposed that the continents were plowing through the ocean floor, but there was no obvious mechanism for how this could be accomplished. Because of this lack of an explanation, Alfred Wegener's hypothesis of continental drift was not widely accepted in his day. However, modern discoveries in plate tectonic theory have greatly led to a further understanding and wider acceptance of his theory.

Seafloor Spreading

Seafloor Bathymetry

During World War II, battleships and submarines carried echo sounders to locate enemy submarines (Figure 2.7). Echo sounders produce sound waves that travel outward in all directions, bounce off the nearest object, and then return to the ship. By knowing the speed of sound in seawater, scientists calculate the distance to the object based on the time it takes for the wave to make a round-trip. During the war, most of the sound waves ricocheted off the ocean bottom.

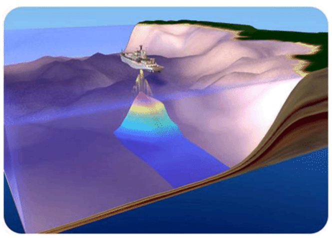


FIGURE 2.7
This echo sounder has many beams and creates a three dimensional map of the seafloor. Early echo sounders had a single beam and created a line of depth measurements.

This animation shows how sound waves are used to create pictures of the sea floor and ocean crust:

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sonar.html

After the war, scientists pieced together the ocean depths to produce bathymetric maps, which reveal the features of the ocean floor as if the water were taken away. Even scientist were amazed that the seafloor was not completely flat (Figure 2.8).

The major features of the ocean basins and their colors on the map in Figure 2.8 include:

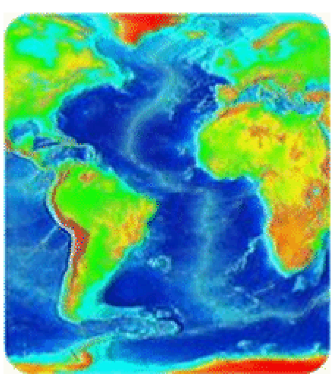


FIGURE 2.8
A modern map of the southeastern Pacific and Atlantic Oceans.

- **Mid-ocean Ridges:** rise up high above the deep seafloor as a long chain of mountains; e.g. the light blue gash in middle of Atlantic Ocean.

- **Deep Sea Trenches:** found at the edges of continents or in the sea near chains of active volcanoes; e.g. the very deepest blue, off of western South America.
- **Abyssal Plains:** flat areas, although many are dotted with volcanic mountains; e.g. consistent blue off of southeastern South America.

When they first observed these bathymetric maps, scientists wondered what had formed these features.

Magnetic Polarity Evidence

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

You have just learned of a new tool that may help you. A magnetometer is a device capable of measuring the magnetic field intensity. This allows scientists to look at the magnetic properties of rocks in many locations, including basalt along the ocean floor.

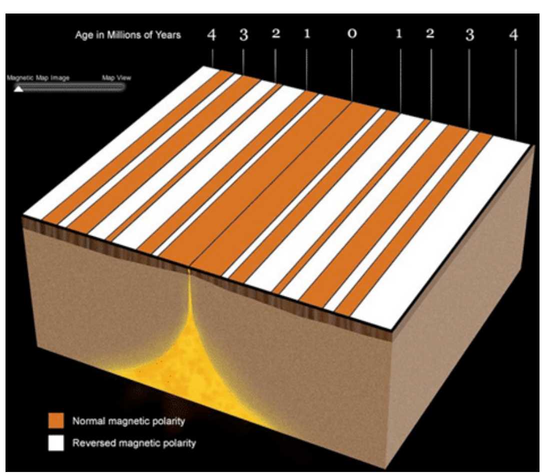
What causes the Magnetic Stripes on the seafloor?

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

Seafloor Magnetism

During World War II, ships towed magnetometers in the ocean in order to find enemy submarines. They observed that the magnetic field strength changed from normal to reversed polarity as they sailed across the ocean. When scientists plotted the points of normal and reversed polarity on a seafloor map they made an astonishing discovery: the normal and reversed magnetic polarity of seafloor basalts creates a pattern:

- Stripes of normal polarity and reversed polarity alternate across the ocean bottom.
- Stripes form mirror images on either side of the mid-ocean ridges.
- Stripes end abruptly at the edges of continents, sometimes at a deep sea trench.



Seafloor Age

By combining magnetic polarity data from rocks on land and on the seafloor with radiometric age dating and fossil ages, scientists came up with a time scale for the magnetic reversals. The scientists noticed that the rocks got older with distance from the mid-ocean ridges. The youngest rocks were located at the ridge crest and the oldest rocks were located the farthest away, next to continents. Scientists also noticed that the characteristics of the rocks and sediments changed with distance from the ridge axis as seen in the Table below.

This animation illustrates how magnetic stripes form as the seafloor spreads.

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_paleomag.html

Data From the sea Floor

[INSERT TABLE 4]

Away from the ridge crest, sediment becomes older and thicker, and the seafloor becomes thicker. Heat flow, which indicates that ocean crust is highest at the mid-ocean ridge.

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

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

This 65 minute video explains "The Role of Paleomagnetism in the Evolution of Plate Tectonic Theory":

- http://online.wr.usgs.gov/calendar/2004/jul04.html

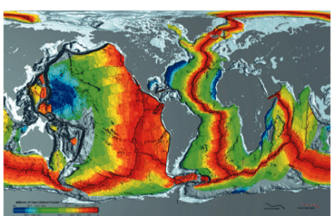


FIGURE 2.9
Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

The Mechanism for Continental Drift

Seafloor spreading is the mechanism for Wegener's drifting continents. When new oceanic crust is brought to the surface of the ocean floor at mid-oceanic ridges it pushes old crust outward. The continents weren't moving through the ocean floor but more ocean floor was being formed in between them.

The history of the seafloor spreading hypothesis and the evidence that was collected to develop it are the subject of this video:

- http://www.youtube.com/watch?v=6CsTTmvX6mc&feature=rec-LGOUT-exp_fresh+div-1r-2

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178207

The Theory of Plate Tectonics—What is a Plate?

During the 1950s and early 1960s, scientists set up seismograph networks to see if enemy nations were testing atomic bombs. These seismographs also recorded all of the earthquakes around the planet. The seismic records were used to locate an earthquake's epicenter, the point on Earth's surface directly above the place where the earthquake occurs.

Why is this relevant? It turns out that the locations of earthquake epicenters are concentrated along areas which outline specific land chunks or "plates" on the Earth. In addition to this, a vast number of volcanoes from around the world are also located in along these plate boundary areas. With this evidence and the combined evidences about Sea Floor Spreading, magnetic striping of the ocean floor, and more, the answer to what could cause the Continents to Drift apart became real.

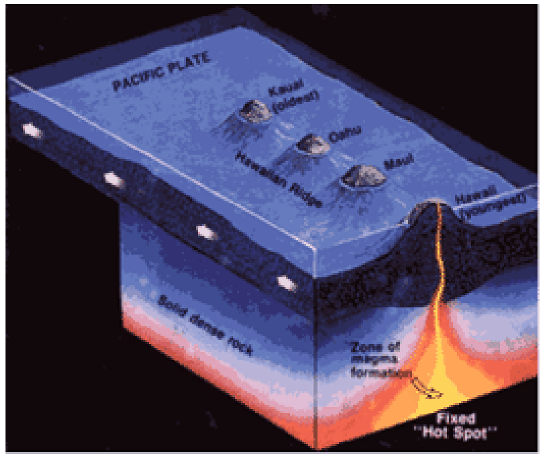
With the addition of this new information, Wegener's theory of Continental Drift has been modified and is now known as the Plate Tectonics theory. This theory provides the answers to the two questions that Alfred Wegener could not explain.

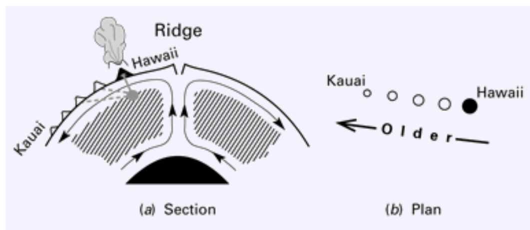
1. What causes plates to move, and
2. What force could cause this to happen?

Today, our general understanding about the Plate Tectonic Theory is that the Earth is divided into several crustal plates composed of oceanic lithosphere and thicker continental lithosphere, Tectonic plates are able to move because the Earth's lithosphere has a higher strength and lower density than the underlying asthenosphere. Along convergent boundaries, (where two plates are moving toward one another) subduction (the more dense oceanic plate moves under the less dense continental plate) carries plates into the mantle; the material lost is roughly balanced by the formation of new (oceanic) crust along mid-ocean ridges by seafloor spreading. In this way, the total surface of the globe remains the same. Plate movement is thought to be driven by a combination of the motion of the seafloor moving away from the mid-ocean ridges and a drag, downward of plates at the subduction zones.

Mantle Plumes and Hotspots

The portion of the mantle below specific parts of the lithosphere is hotter than normal. This is known as a mantle plume or hotspot. These hot spots can be used to determine the direction and rate at which tectonic plates are moving. One example of this is the Hawaiian islands. As the hot spot melts the plate above it, it melts the crust and causes new magma to rise and volcanoes to form- as it cools it turns to rock. Over time, these rocks build until they are above the surface of the ocean and an island is formed. As the plate moves the island is carried away from the hotspot, magma no longer rises and the volcano stops erupting. Magma begins to rise and form a new island under the hot spot. Over even longer periods of time, the islands move in the direction the plates are moving over the hot spot thus creating the chain of islands we see in present day Hawaii.



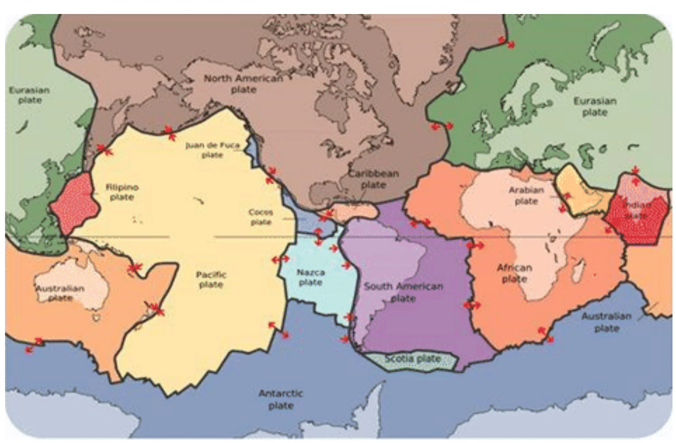


Check out this video for more information on hot spots:

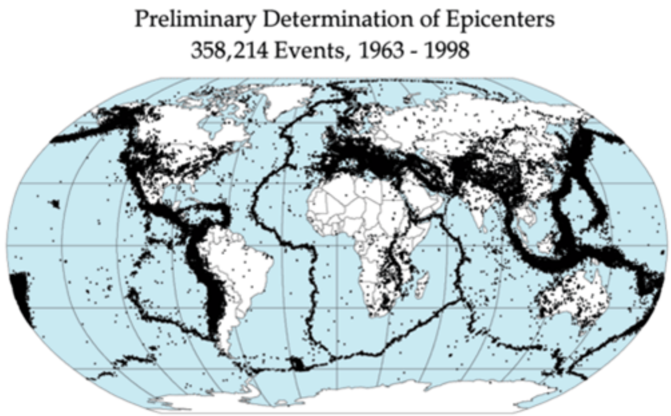
- http://www.ck12.org/earth-science/Volcanoes-at-Hotspots/enrichment/Hawaiian-Hot-Spots%3A-Undersea-Volcanic-Studies/

Earth's Tectonic Plates

The lithosphere is divided into a dozen major and several minor plates (Figure below). The plates' edges can be drawn by connecting the dots that mark earthquakes' epicenters. A single plate can be made of all oceanic lithosphere or all continental lithosphere, but nearly all plates are made of a combination of both.



The lithospheric plates and their names are shown in the figure above. The arrows show whether the plates are moving apart, moving together, or sliding past each other.



Movement of the plates over Earth's surface is termed plate tectonics. Plates move at a rate of a few centimeters a year, about the same rate fingernails grow.

Volcanoes

During a volcano, the heat energy is transferred through lava to the Earth's surface. The magma may come up to the surface as lava bringing heat energy with it. The volcanoes which erupt on the island of Hawaii are an example of this transfer of heat energy. Notice, the lava is very hot as it comes up to the surface. The lava immediately begins to cool. As the heat escapes, the lava hardens to dark black rock.

Magma which becomes trapped below the surface can build up pressure that must be released as mechanical energy. An example of this release of mechanical energy was the eruption of Mt. Saint Helens in Washington State. As the heat energy in the magma built up below the surface of the mountain, the pressure increased. This pressure was released in a gigantic explosion which blew off the top of the mountain.

Earthquakes

The transfer of earthquake energy happens in the form of waves. These waves can happen in a couple of different ways.

The energy from an earthquake arrives in three distinct waves. The fastest and therefore the first to arrive was named the Primary wave or p-wave. The second to arrive was named the secondary wave or s-wave. The slowest and last to arrive was named the surface wave.

P-wave: P-waves are a form of longitudinal waves. These waves vibrate in a direction parallel to the direction in which the energy is transferred. For example, in an east moving p-wave objects vibrate in an east-west direction.

S-wave: S-waves are a form of transverse waves. These waves vibrate in a direction perpendicular to the direction in which the energy is transferred. For example, in an east moving s-wave, objects vibrate in a north-south direction. This is more destructive than the vibrations in a p-wave.

Surface Wave: A surface wave is much slower than the p-wave or s-wave. A surface wave is a combination of a transverse and a longitudinal wave in which the particles vibrate both perpendicularly and parallel to the direction of energy transfer. An object struck by a surface wave would vibrate both north-south and east-west. The result is that the objects move in a circle. This is the most destructive of the three types of wave. A surface wave is similar to the ripples you see when an object is dropped into a body of water.

Summary

- Alfred Wegener did some background reading and made an observation. Wegener then asked an important question and set about to answer it. He collected a great deal of evidence to support his idea. Wegener's evidence included the fit of the continents, the distribution of ancient fossils, the placement of similar rocks and structures on the opposite sides of oceans, and indicators of ancient climate found in locations where those climates do not exist today.
- Data from magnetometers dragged behind ships looking for enemy submarines in WWII discovered magnetic patterns on the seafloor.
- Rocks of normal and reversed polarity are found in stripes symmetrically about the mid-ocean ridge axis.
- The age of seafloor rocks increases from the ridge crest to rocks the farthest from the ridges. Still, the rocks of the ocean basins are much younger than most of the rocks of the continents.
- Seafloor spreading brought together the mantle convection idea of Holmes, the continental drift idea of Wegener, based on new bathymetric and magnetic data from the seafloor, improved Wegener's theory of Continental Drift and led to the formation of the theory of Plate Tectonics, made a coherent single idea.
- Large chunks of lithosphere are called tectonic plates. These plates are separated by boundaries that can be marked by earthquake epicenters and volcanoes.

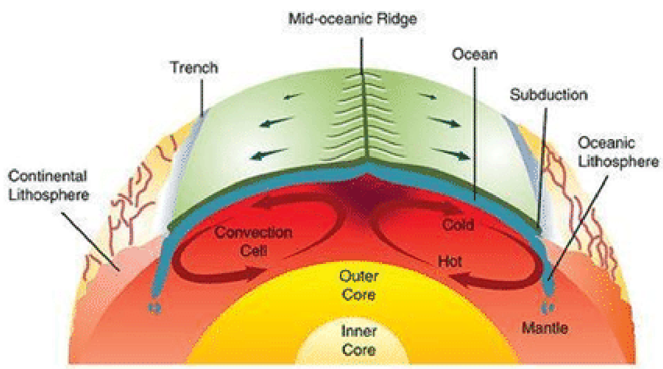
Think like a Geologist

1. How did Wegener use fossil evidence to support his Continental Drift theory?
2. How did Wegener use climate evidence from rocks to support his Continental Drift theory?
3. How does the pattern of magnetic stripes give evidence for seafloor spreading?
4. How does the topography of the sea floor give evidence for seafloor spreading?
5. How does sea-floor spreading fit into the Theory of Plate Tectonics?

2.3 Does the movement of Earth's plates affect all living things?

How Plates Move

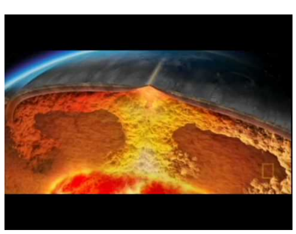
- If seafloor spreading drives the plates, what drives seafloor spreading? Picture two convection cells side-by-side in the mantle, similar to the illustration in Figure below.
- Hot mantle from the two adjacent cells rises at the ridge axis, creating new ocean crust.
- The top limb of the convection cell moves horizontally away from the ridge crest, as does the new seafloor.
- The outer limbs of the convection cells plunge down into the deeper mantle, dragging oceanic crust as well. This takes place at the deep sea trenches.
- The material sinks to the core and moves horizontally.
- The material heats up and reaches the zone where it rises again.



Mantle convection helps drive plate tectonics. Hot material rises at mid-ocean ridges and sinks at deep sea trenches, which keeps the plates moving along the Earth's surface.

Mantle convection is shown in these animations:

- http://www.youtube.com/watch?v=p0dWF_3PYh4



MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/176318

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_convection2.html

Plate Boundaries

Plate boundaries are the edges where two plates meet. Most geologic activities, including volcanoes, earthquakes, and mountain building, take place at plate boundaries. How can two plates move relative to each other?

- **Divergent Plate Boundaries:** the two plates move away from each other.
- **Convergent Plate Boundaries:** the two plates move towards each other.
- **Transform Plate Boundaries:** the two plates slip past each other.

The type of plate boundary and the type of crust found on each side of the boundary determines what sort of geologic activity will be found there.

Divergent Plate Boundaries

Plates move apart at mid-ocean ridges where new seafloor forms. Between the two plates is a rift valley. Lava flows at the surface cool rapidly to become basalt (a type of rock), but deeper in the crust, magma cools more slowly to form gabbro (another type of rock).

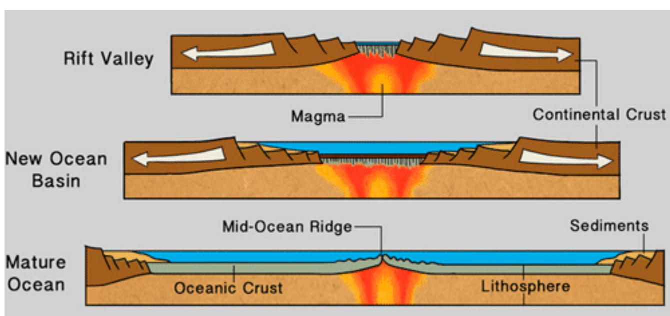
USGS animation of divergent plate boundary at mid-ocean ridge:

- http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Divergent+Boundary&flash_file=divergent&flash_width=500&flash_height=200

Divergent plate boundary animation:

- http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Divergent_480.mov

See the images below for examples of divergent plate boundaries:



Can divergent plate boundaries occur within a continent? What is the result? In continental rifting, magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, creating an ocean between continents.

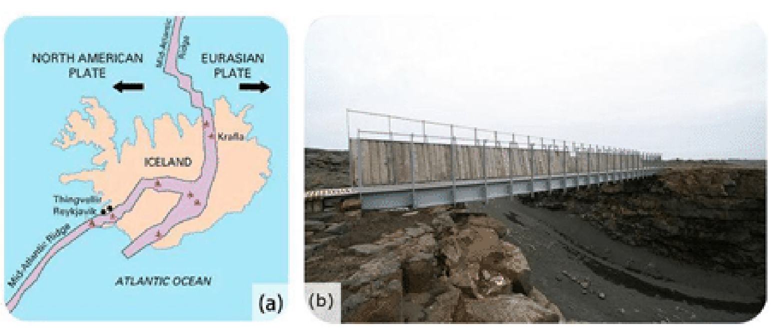


FIGURE 2.10
(a) Iceland is the one location where the ridge is located on land: the Mid-Atlantic Ridge separates the North American and Eurasian plates; (b) The rift valley in the Mid-Atlantic Ridge on Iceland.

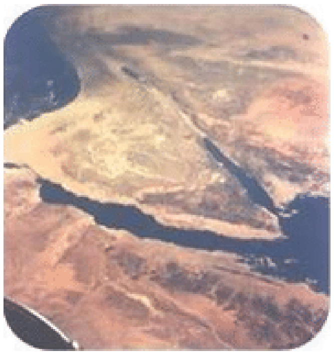


FIGURE 2.11
The Arabian, Indian, and African plates are rifting apart, forming the Great Rift Valley in Africa. The Dead Sea fills the rift with seawater.

Convergent Plate Boundaries

When two plates converge, the result depends on the type of lithosphere the plates are made of. No matter what, smashing two enormous slabs of lithosphere together results in magma generation and earthquakes.

Ocean-continent: When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process, called subduction, occurs at the oceanic trenches (Figure 2.12). The entire region is known as a subduction zone. Subduction zones have a lot of intense earthquakes and volcanic eruptions. The subducting plate causes melting in the mantle. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate (Figure 2.12). The volcanoes are known as a continental arc.

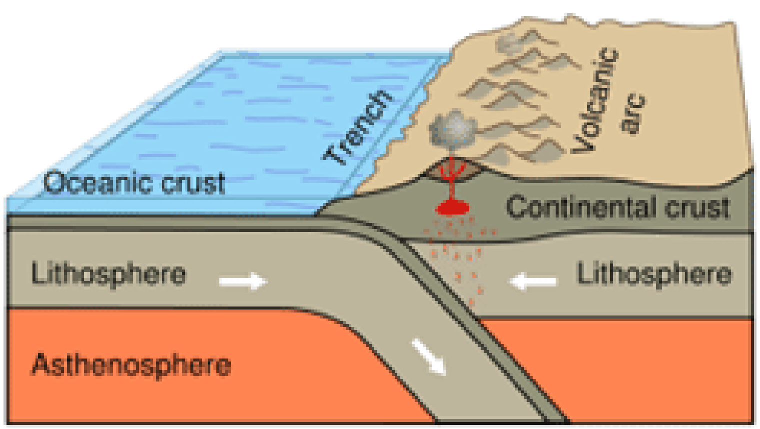


FIGURE 2.12
Subduction of an oceanic plate beneath a continental plate causes earthquakes and forms a line of volcanoes known as a continental arc.

This animation shows the relationship between subduction of the lithosphere and creation of a volcanic arc:

- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html

Ocean-ocean: When two oceanic plates converge, the older, denser plate will subduct into the mantle. An ocean trench marks the location where the plate is pushed down into the mantle. The line of volcanoes that grows on the upper oceanic plate is an island arc. Earthquakes are common in these regions.

Continent-continent: Continental plates are less dense than oceanic plates and do not easily undergo subduction. The rock builds up on top of the plates as they collide. This results in the creation of some of the world's largest mountains ranges. (Figure 2.15). Magma cannot penetrate this thick crust so there are no volcanoes, although

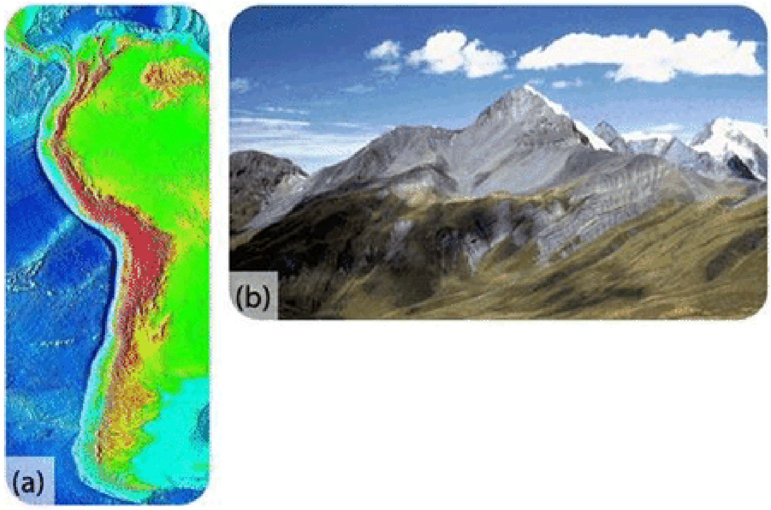


FIGURE 2.13
(a) At the trench lining the western margin of South America, the Nazca plate is subducting beneath the South American plate, resulting in the Andes Mountains (brown and red uplands); (b) Convergence has pushed up limestone in the Andes Mountains where volcanoes are common.

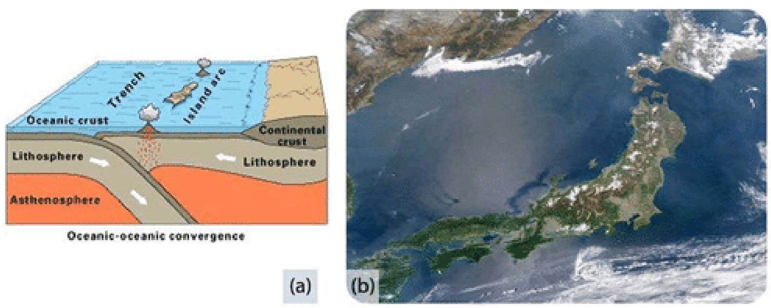


FIGURE 2.14
(a) Subduction of an ocean plate beneath an ocean plate results in a volcanic island arc, an ocean trench and many earthquakes. (b) Japan is an arc-shaped island arc composed of volcanoes off the Asian mainland, as seen in this satellite image.

the magma stays in the crust. Metamorphic rocks are common because of the stress the continental crust experiences. With enormous slabs of crust smashing together, continent-continent collisions bring on numerous and large earthquakes.

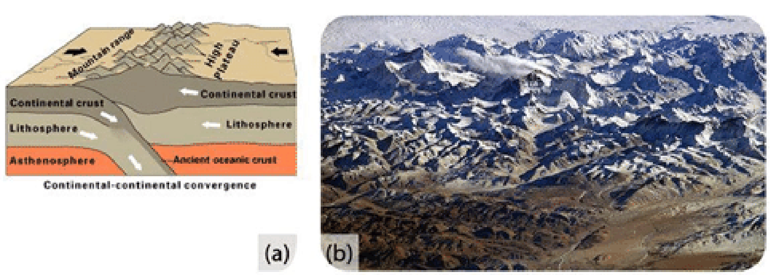
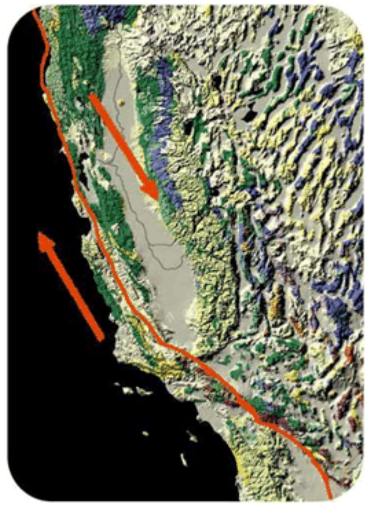


FIGURE 2.15
(a) In continent-continent convergence, the plates push upward to create a high mountain range. (b) The world's highest mountains, the Himalayas, are the result of the collision of the Indian Plate with the Eurasian Plate, seen in this photo from the International Space Station.

Transform Plate Boundaries

Transform plate boundaries are seen as transform faults, where two plates move past each other in opposite directions. Transform faults on continents bring massive earthquakes (Figure below).



At the San Andreas Fault in California, the Pacific Plate is sliding northeast relative to the North American plate, which is moving southwest.

A brief review of the three types of plate boundaries and the structures that are found there is the subject of this video:

- https://www.youtube.com/watch?v=_hKosm0h3kI

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178284

Use this simulator to improve your understanding of how plate boundaries affect Earth's Geography:

- http://sepuplhs.org/middle/iaes/students/simulations/sepup_plate_motion.html

Think like a Geologist

1. Describe a lithospheric plate.
2. Draw and identify the major tectonic plates of Earth.
3. How does a volcano transfer energy from Earth's interior to the surface?
4. What is a convergent boundary and what are the results of its movement?
5. What is a divergent boundary and what are the results of its movement?
6. What is a transform boundary and what are the results of its movement?
7. Explain how gravity, density and convection cause tectonic plates to move.

2.4 References

1. http://oceanexplorer.noaa.gov/edu/learning/2_midocean_ridges/activities/seafloor_spreading.html#none. .

Chapter 3 Standard III: Atmosphere

Chapter Outline

3.1 Is the Greenhouse Effect a good thing or a bad thing?
3.2 Why is it winter in the Southern Hemisphere when it is summer in the Northern Hemisphere?
3.3 What makes the wind blow?
3.4 Why were winds so important to the early explorers?
3.5 What is ozone and why are we concerned about a hole in the ozone?
3.6 What causes the change in the weather?
3.7 How do they forecast the weather?
3.8 What causes severe weather?
3.9 What are short-term climate changes?
3.10 How has Earth's climate changed?
3.11 What causes climate change?
3.12 How are fossil fuels formed?

Standard 3: Students will understand the atmospheric processes that support life and cause weather and climate.

Objective 1: Relate how energy from the Sun drives atmospheric processes and how atmospheric currents transport matter and transfer energy.

1. Compare and contrast the amount of energy coming from the Sun that is reflected, absorbed or scattered by the atmosphere, oceans, and land masses.
2. Construct a model that demonstrates how the greenhouse effect contributes to atmospheric energy.
3. Conduct an investigation on how the tilt of Earth's axis causes variations in the intensity and duration of sunlight striking Earth.
4. Explain how uneven heating of Earth's atmosphere at the equator and polar regions combined with the Coriolis effect create an atmospheric circulation system including, Hadley cells, trade winds, and prevailing westerlies, that moves heat energy around Earth.
5. Explain how the presence of ozone in the stratosphere is beneficial to life, while ozone in the troposphere is considered an air pollutant.

Objective 2: Describe elements of weather and the factors that cause them to vary from day to day.

1. Identify the elements of weather and the instruments used to measure them (e.g., temperature-thermometer; precipitation-rain gauge or Doppler radar; humidity-hygrometer; air pressure-barometer; wind-anemometer; cloud coverage-satellite imaging).
2. Describe conditions that give rise to severe weather phenomena (e.g., thunderstorms, tornados, hurricanes, El Niño/La Niña).
3. Explain a difference between a low pressure system and a high pressure system, including the weather associated with them.

4. Diagram and describe cold, warm, occluded, and stationary boundaries (weather fronts) between air masses.
5. Design and conduct a weather investigation, use an appropriate display of the data, and interpret the observations and data.

Objective 3: Examine the natural and human-caused processes that cause Earth's climate to change over intervals of time ranging from decades to millennia.

1. Explain differences between weather and climate and the methods used to investigate evidence for changes in climate (e.g., ice core sampling, tree rings, historical temperature measurements, changes in the extent of alpine glaciers, changes in the extent of Arctic sea ice).
2. Explain how Earth's climate has changed over time and describe the natural causes for these changes (e.g., Milankovitch cycles, solar fluctuations, plate tectonics).
3. Describe how human activity influences the carbon cycle and may contribute to climate change.
4. Explain the differences between air pollution and climate change and how these are related to society's use of fossil fuels. Investigate the current and potential consequences of climate change (e.g., ocean acidification, sea level rise, desertification, habitat loss) on ecosystems, including human communities.

3.1 Is the Greenhouse Effect a good thing or a bad thing?

Objectives

- Compare and contrast the amount of energy coming from the Sun that is reflected, absorbed or scattered by the atmosphere, oceans, and land masses.
- Construct a model that demonstrates how the greenhouse effect contributes to atmospheric energy.
- Conduct an investigation on how the tilt of Earth's axis causes variations in the intensity and duration of sunlight striking Earth.
- Explain how uneven heating of Earth's atmosphere at the equator and polar regions combined with the Coriolis effect create an atmospheric circulation system including, Hadley cells, trade winds, and prevailing westerlies, that moves heat energy around Earth.
- Explain how the presence of ozone in the stratosphere is beneficial to life, while ozone in the troposphere is considered an air pollutant.

Introduction

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

The Atmosphere and the Sun's Rays

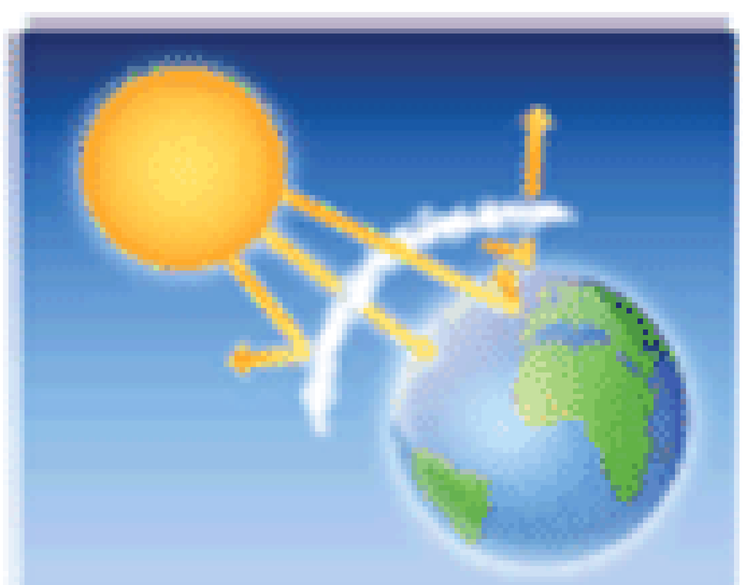


FIGURE 3.1
The atmosphere shields Earth from harmful solar rays.

The atmosphere protects living things from the sun's most harmful rays. Atmospheric gases reflect or absorb the strongest rays of sunlight.

Look at the image 3.2, what happens to the Sun's energy as it enters Earth's atmosphere?

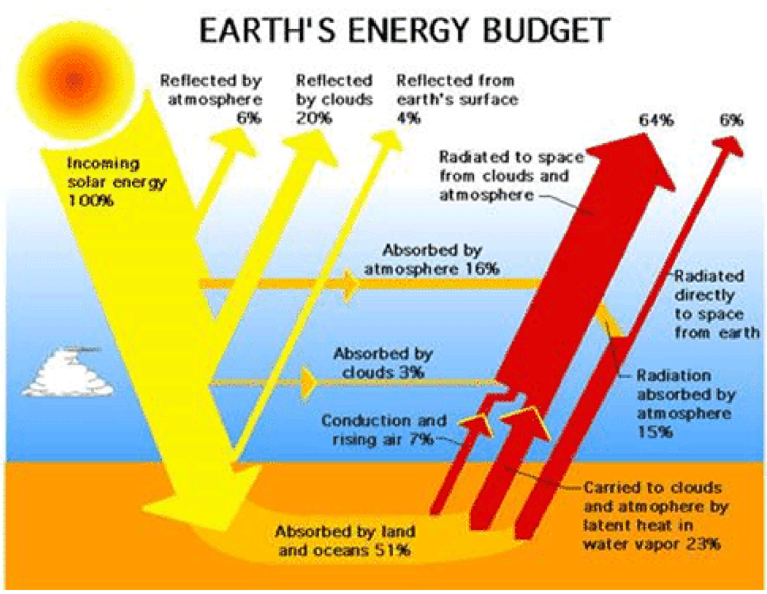


FIGURE 3.2
The Earth's heat budget shows the amount of energy coming into and going out of the Earth's system and the importance of the greenhouse effect. The numbers indicate a measurement of energy and the arrows depict the direction of the movement of the energy.

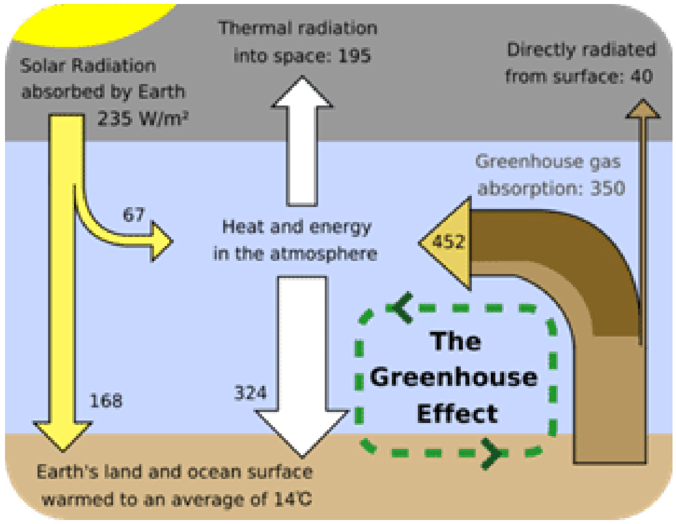
The Atmosphere and Earth's Temperature

How does the atmosphere resemble a greenhouse?

To extend the growing season, many farmers use greenhouses. A greenhouse traps heat so plants can continue to grow in cooler weather. Similar to, but not exactly like, a greenhouse, the greenhouse gasses in our atmosphere don't trap but absorb energy that is emitted by the Earth and then radiate the energy back to the Earth at a different wavelength - thus keeping the Earth at a habitable temperature.

The Greenhouse Effect

The role of **greenhouse gases—(gases that absorb and emit heat)**—in the atmosphere is very important in balancing Earth's temperature. **Greenhouse gases** warm the atmosphere by absorbing and re-emitting heat. Some of the heat that radiates out from the ground is absorbed and re-emitted by greenhouse gases in the troposphere layer of the atmosphere. Like a blanket on a sleeping person, greenhouse gases act as insulation for the planet. The warming of the atmosphere because of insulation by greenhouse gases is called the **greenhouse effect** (see Figure below). Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.



Greenhouse Gases

Greenhouse gases include carbon dioxide (CO_2), water vapor (H_2O), methane (CH_4), ozone (O_3), nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs.

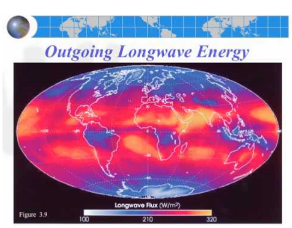
Human Activity and Greenhouse Gas Levels

Human activity has significantly raised the levels of many of greenhouse gases in the atmosphere. Methane levels are about 250% higher as a result of human activity. Carbon dioxide has increased more than 35%. CFCs have only recently existed.

What do you think happens as atmospheric greenhouse gas levels increase? More greenhouse gases trap more heat and warm the atmosphere. The increase or decrease of greenhouse gases in the atmosphere affect climate and weather the world over.

This video explains how the greenhouse effect works to keep temperatures more stable.

- http://www.youtube.com/watch?v=p6xMF_FFUU0



MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/177902

An additional diagrams and information can be found at:

- http://www.amnh.org/explore/ology/climatechange
- http://www3.epa.gov/climatechange/kids/basics/today/greenhouse-effect.html

Summary

- Not all of the energy from the Sun reaches Earth's surface. Some of the energy is absorbed, scattered or reflected by the atmosphere.

- Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs).
- Tropospheric greenhouse gases trap heat in the atmosphere and stabilize Earth's temperatures Levels of greenhouse gases in the atmosphere are increasing due to human activities.
- Increased levels of greenhouse gases lead to increased average global temperatures.

Practice

Use this resource to answer the questions that follow.

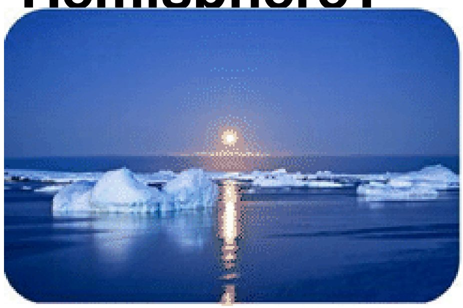
- http://www.hippocampus.org

Science choose Environmental Science click on choose all content then search for Greenhouse Effects and watch the first option listed.

Think like an Environmental Scientist

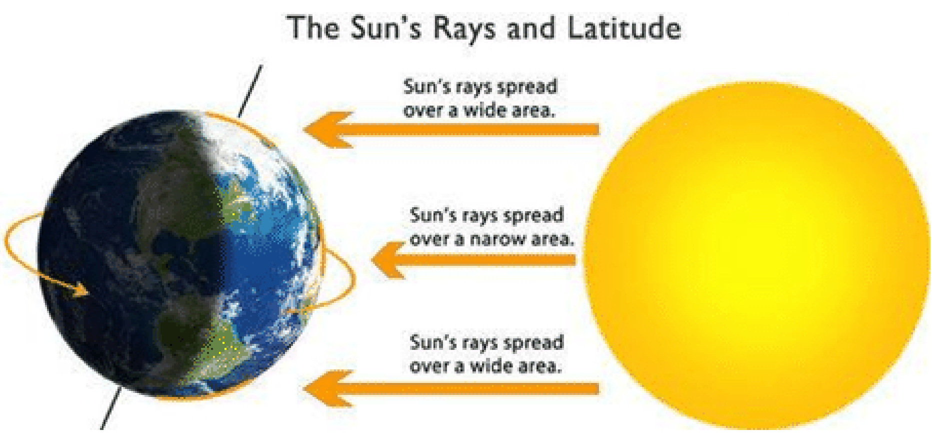
1. What percentage of solar radiation is absorbed by the surface of the Earth?
2. What is reflection and how does it affect the amount of energy in the atmosphere?
3. In what form does most of the sun's energy reach the earth's surface? How is it re-emitted?
4. What are the main greenhouse gases? How do greenhouse gases affect life on Earth?
5. Is greenhouse effect a good thing or a bad thing? Defend your answer.

3.2 Why is it winter in the Southern Hemisphere when it is summer in the Northern Hemisphere?




The sun is always up, even in the middle of the night in Antarctica during the summer. The photo on the left is Antarctica during the night in the summer. The photo on the right is Antarctica during the day in summer. Similarly, in the winter Antarctica is mostly dark all day. If Earth received the same amount of light from the Sun, why are there differences in temperatures and other atmospheric conditions around the globe? **Why is Earth heated unevenly?**

Different parts of Earth's surface receive different amounts of sunlight. You can see this in the figure below. The sun's rays strike Earth's surface most directly at the equator. This focuses the rays on a small area. Near the poles, the sun's rays strike the surface at a slant. This spreads the rays over a wider area. The more focused the rays are, the more energy an area receives and the warmer it is. Another way to word this is that towards the poles the same amount of sunlight is spread over a larger area.



Earth also tilts on its axis and that tilt changes. The tilt of Earth also impacts the concentration of light. In the above figure, North America is tilted toward the Sun and will receive even more concentrated light. If you guessed summer, you are correct! The difference in solar energy received at different latitudes drives atmospheric circulation. Places that get more concentrated solar energy have more heat. Places that get less concentrated solar energy have less heat. Warm air rises and cool air sinks. These principles mean that air moves around the planet. The heat moves around the globe in certain ways. This determines the way the atmosphere moves.

Summary

- Earth's surface is not heated evenly by the Sun.
- Solar energy that reaches Earth near the equator is more direct and therefore, more concentrated.
- Solar energy that reaches Earth near the poles is at an angle and therefore, less concentrated.

- Light from the Sun is more concentrated when a hemisphere is tilted toward the Sun. (hint: think summer)
- The difference in the amount of solar energy drives atmospheric circulation.

Practice

Use this resource to answer the questions that follow.

- http://www.kidsgeo.com/geography-for-kids/0074-latitude-effects-temperature.php

Think like a Climatologist

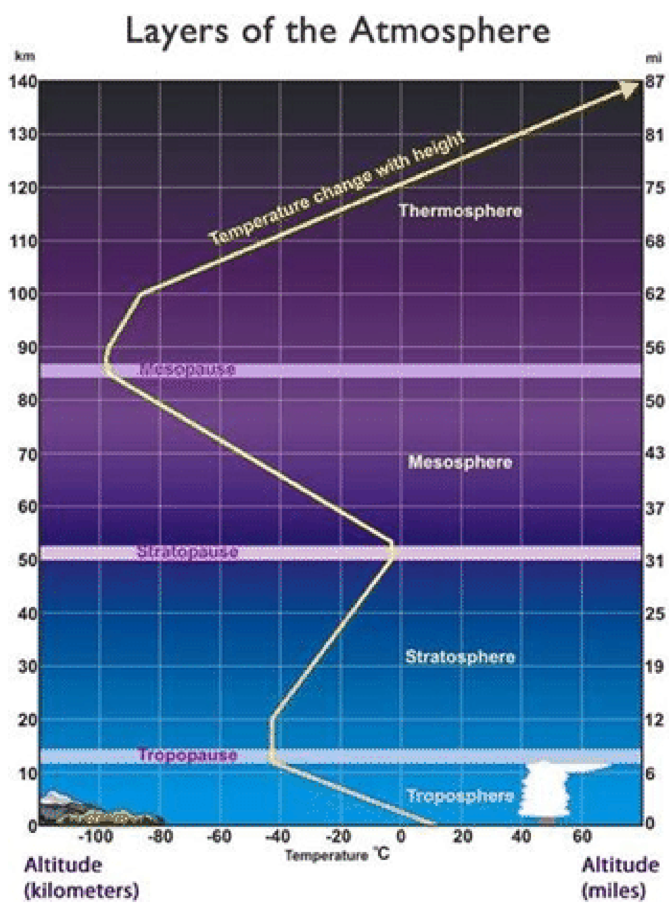
1. What is latitude?
2. How does latitude affect global temperatures?
3. What part of Earth receives the most solar radiation in a year?
4. Why do cities near the Arctic Circle (70°N) rarely have temperatures above 36°C (96°F) even though the sun shines almost 24 hours a day?
5. How does uneven heating of the earth affect global circulation?
6. The North Pole receives sunlight 24 hours a day in the summer but less solar radiation than the equator. Explain why.

3.3 What makes the wind blow?

Why do we say Earth's temperature is moderate? It may not look like it, but various processes work to moderate Earth's temperature across the latitudes. Atmospheric circulation brings warm equatorial air toward the poles and frigid polar air toward the equator. If the planet had an atmosphere that was stagnant (not moving), the difference in temperature between the two regions would be much greater.

Layers of the Atmosphere

The atmosphere is divided into various layers (as seen below). Weather happens in the lowest layer or the Troposphere.



Air Pressure Zones

Within the troposphere are convection cells (similar to the convection currents found inside Earth) (see Figure 3.3). Air heated at the ground rises, creating a low pressure zone. Air from the surrounding area is sucked into the space left by the rising air. Air flows horizontally at the top of the troposphere. The air cools until it descends. When the air reaches the ground, it creates a high pressure zone. Air flowing from areas of high pressure to low pressure creates winds. The greater the pressure difference between the pressure zones, the faster the wind blows.

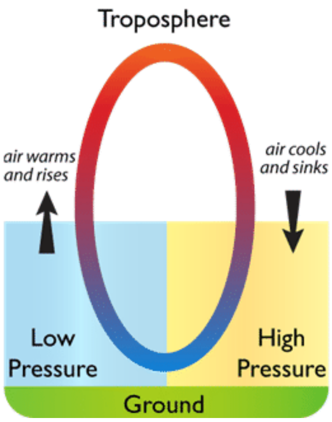


FIGURE 3.3
Warm air rises, cool air sinks, and air moves vertically.

Two Convection Cells

Because more solar energy hits the equator, the air warms and forms a low pressure zone. At the top of the troposphere, half moves toward the North Pole and half toward the South Pole. As it moves along the top of the troposphere it cools. The cool air is dense, and it sinks to the ground. The air is sucked back toward the equator. This describes the convection cells north and south of the equator.

Coriolis Effect

If the Earth did not rotate, there would be one convection cell in the northern hemisphere and one in the southern with the rising air at the equator and the sinking air at each pole. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the **Coriolis effect (apparent deflection of a moving object because of earth's rotation)** must be taken into account.

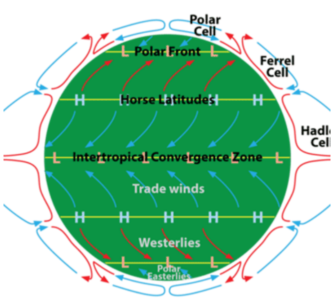


FIGURE 3.4
The atmospheric circulation cells, showing direction of winds at Earth's surface.

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the **Coriolis effect** (see Figure 3.4). Air rises at the equator, but as it moves toward the pole at the top of the troposphere, it deflects to the right. (In reality, it just appears to deflect to the right because the ground beneath it moves.) At about 30°N latitude, the air from the equator meets air flowing toward the equator from the higher latitudes. This air is cool because it has come from higher latitudes. Both batches of air descend. Once on the ground, the air returns to the equator. This convection cell is called the Hadley Cell and is found between 0° and 30°N. Mirror image convection cells are also found in the Southern Hemisphere.

Summary

- Uneven heating of the Earth's surface causes convection cells in the atmosphere.
- Coriolis effect results in there being three convection cells per hemisphere rather than one.
- Coriolis effect make it so that global winds deflect to the right in the Northern Hemisphere and deflect to the left in the Southern Hemisphere.
- Winds blow at the base of the atmospheric convection cells.

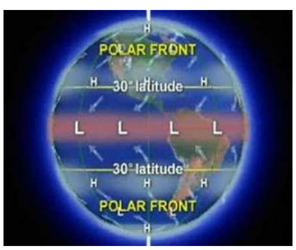
Think like a Meteorologist

1. In what atmospheric layer does weather occur?
2. Draw a diagram, label, and explain the north and south convection cells.
3. What are Hadley cells?
4. Where does convection occur?
5. How do surface winds move?
6. Describe how air moves at high altitudes?
7. Diagram and label the parts of a convection cell in the troposphere.
8. How does Coriolis effect atmospheric convection?

Practice

Watch the following video and answer the questions that follow.

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



MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/177908

3.4 Why were winds so important to the early explorers?

Global Wind Belts

When Columbus sailed the ocean blue, and for centuries before and after, ocean travel depended on the wind. Mariners knew how to get where they were going and at what time of the year based on experience with the winds. Winds were named for their usefulness to sailors, such as the trade winds that enabled commerce between people on opposite shores.

Global winds blow in belts encircling the planet. Air blowing at the base of the circulation cells creates the global wind belts. The global wind belts are enormous and the winds are relatively steady (see Figure 3.5).

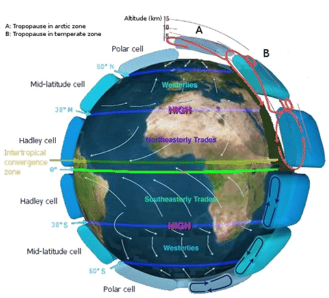


FIGURE 3.5

The direction of major wind belts.

The Global Winds

Let's look at the global wind belts in the Northern Hemisphere.

- In the Hadley cell air should move north to south, but it is deflected to the right by the Coriolis effect. So the air blows from northeast to the southwest. This belt is called the **trade winds** because they helped sailing ships and were good for trade.

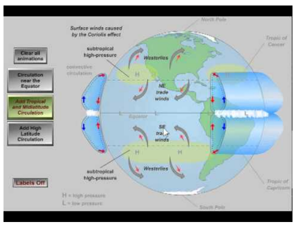
- In the Ferrel cell air should move south to north, but the winds actually blow from the southwest (mostly west to east). This belt is also known as the **westerly winds or westerlies**. Utah sits within the westerly belt.

Check out this "real-time" Global Winds animation:

- http://earth.nullschool.net/

This video discusses the uneven heating of Earth's surface and the resulting global wind belts and surface wind currents:

- https://youtu.be/Ye45DGkqUkE



MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178123

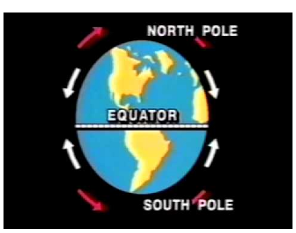
Summary

- Global wind patterns are similar around the world.
- The trade winds blow east to west but bend due to the Coriolis effect.
- The westerlies blow west to east and are also bent because of the Coriolis effect.

Think like a Meteorologist

Use this resource to answer the questions that follow.

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



MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/177912

1. Describe the process that creates wind?
2. What are local and regional winds?
3. What are the global wind patterns?
4. In what direction does the Earth rotate?
5. What is the Coriolis effect?
6. What are the Westerlies?
7. Explain global wind patterns.

3.5 What is ozone and why are we concerned about a hole in the ozone?

Ozone 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 (UV) radiation 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 highest concentration of ozone is in the ozone layer in the lower stratosphere. Ozone is also a greenhouse gas, so it helps stabilize Earth's temperatures.

At this point you might be saying to yourself, "So ozone is in the upper atmosphere and it protects me from scary solar radiation. How is that a bad thing?" There is no simple answer to that question: It depends on where the ozone is located (see Figure 3.6).

- In the troposphere, ozone is a pollutant.
- In the ozone layer in the stratosphere, ozone screens out high energy ultraviolet radiation and makes Earth habitable.

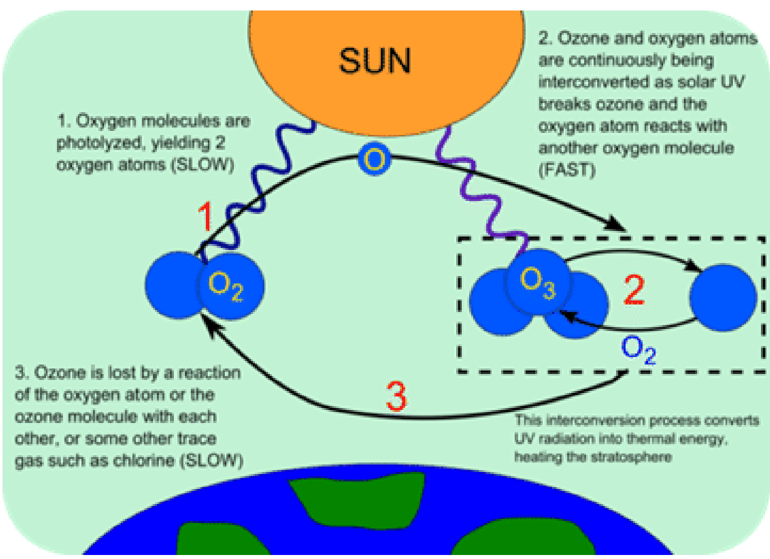


FIGURE 3.6

Solar energy breaks apart oxygen molecules into two oxygen atoms. (2) Ozone forms when oxygen atoms bond together as O_3. UV rays break apart the ozone molecules into one oxygen molecule (O_2) and one oxygen atom (O). These processes convert UV radiation into heat, which is how the Sun heats the stratosphere. (3) Under natural circumstances, the amount of ozone created equals the amount destroyed. When O_3 interacts with chlorine or some other gases the O_3 breaks down into O_2 and O and so the ozone layer loses its ability to filter out UV.

So how is ozone harmful?

Ozone can form in the troposphere (lower atmosphere) and is considered a type of air pollution. Certain respiratory conditions can be made worse in people who live closer to or in large cities. Some studies have shown that people in urban areas suffer lower levels of lung function and more chronic bronchitis and emphysema. If you live in a city, you have seen **smog**. It is a low-hanging, fog-like cloud that seems to never leave the city (Figure 3.7). Smog is caused by coal burning and by **ozone** produced by motor vehicle exhaust. Smog can cause eye irritation and respiratory problems. Smog is common in many areas of Utah during the summer.

FIGURE 3.7
A layer of smog in Salt Lake City, Utah. Environmental Protection Agency, 1970

Summary

- Ozone is a molecule made of 3 oxygen atoms. There is a layer of ozone in the stratosphere that absorbs harmful ultraviolet (UV) radiation.
- Ozone in the stratosphere blocks harmful solar radiation, while Ozone in the troposphere is a pollutant and is harmful to humans and other living things.

Think like a Climatologist

1. What is ozone and why is it important?
2. What are some health issues associated with ozone in the troposphere?
3. How is ozone helpful to living things?
4. How is ozone pollution formed?

3.6 What causes the change in the weather?

Objectives

- Identify the elements of weather and the instruments used to measure them (e.g., temperature—thermometer; precipitation—rain gauge or Doppler radar; humidity— hygrometer; air pressure—barometer; wind—anemometer; cloud coverage—satellite imaging).
- Describe conditions that give rise to severe weather phenomena (e.g., thunderstorms, tornados, hurricanes, El Niño/La Niña).
- Explain a difference between a low pressure system and a high pressure system, including the weather associated with them.
- Diagram and describe cold, warm, occluded, and stationary boundaries (weather fronts) between air masses.
- Design and conduct a weather investigation, use an appropriate display of the data, and interpret the observations and data.

Now that we have looked at the atmosphere let's bring it a little closer to home and talk about weather. For an overview of air masses, see:

- http://www.srh.noaa.gov/crp/?n=education-airmasses

Air Masses

An air mass is a large body of air that has nearly the same temperature and humidity throughout. For example, an air mass might have cold dry air. Another air mass might have warm moist air. The conditions in an air mass depend on where the air mass formed.

Formation of Air Masses

Most air masses form over polar or tropical regions and they may form over continents or oceans. Air masses are moist if they form over oceans. They are dry if they form over continents. Air masses that form over oceans are called maritime air masses. Those that form over continents are called continental air masses. Figure 3.8 shows air masses that form over or near North America.

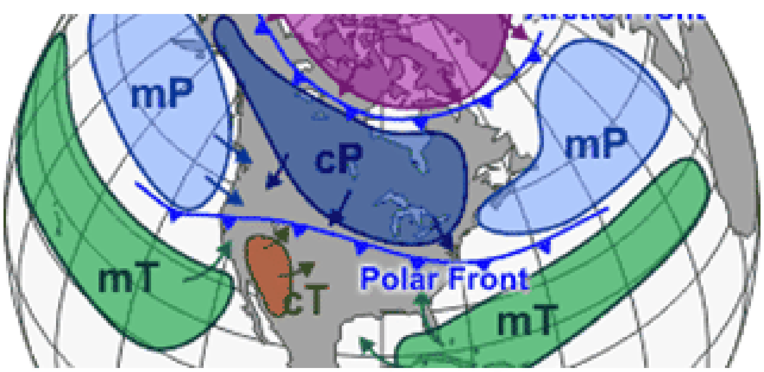


FIGURE 3.8
North American air masses.

An air mass takes on the conditions of the area where it forms. For example, a continental polar (cP) air mass has cold dry air. A maritime polar (mP) air mass has cold moist air. Which air masses have warm moist air? Where do they form?

Movement of Air Masses

When a new air mass goes over a region it brings its characteristics to the region. This may change the area's temperature and humidity. Moving air masses cause the weather to change when they contact different conditions. For example, a warm air mass moving over cold ground may cause an inversion (cold air is trapped close to the ground and cannot rise).

Why do air masses move? Winds push them along. Cold air masses tend to move toward the equator. Warm air masses tend to move toward the poles. Coriolis Effect causes them to move on a diagonal. Many air masses travel with the westerly winds in the U.S.

Fronts

When cold air masses move south from the poles, they run into warm air masses moving north from the tropics. The boundary between two air masses is called a front. Air masses usually don't mix at a front. The differences in temperature and pressure cause clouds and precipitation. Types of fronts include cold, warm, occluded, and stationary fronts.

Cold Fronts

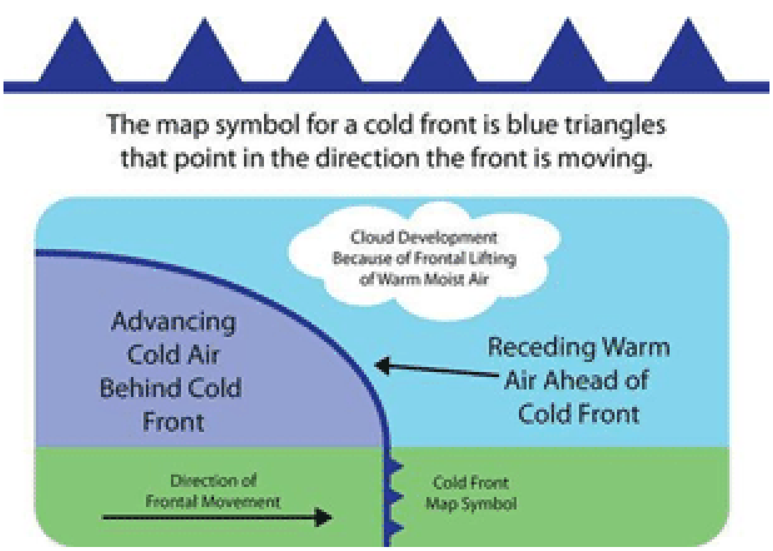


FIGURE 3.9
Cold fronts often bring stormy weather.

A cold front occurs when a cold air mass runs into a warm air mass. This is shown in Figure 3.9. The cold air mass moves faster than the warm air mass and lifts the warm air mass out of its way. As the warm air rises, its water vapor condenses. Clouds form, and precipitation falls. If the warm air is very humid, precipitation can be heavy. Temperature and pressure differences between the two air masses cause winds. Winds may be very strong along a cold front.

As the fast-moving cold air mass keeps advancing, so does the cold front. Cold fronts often bring sudden changes in the weather. There may be a thin line of storms right at the front that moves as it moves. In the spring and summer, these storms may be thunderstorms and tornadoes. In the late fall and winter, snow storms may occur. After a cold front passes, the cold air mass behind it brings cooler temperatures. The air is likely to be less humid as well.

Warm Fronts

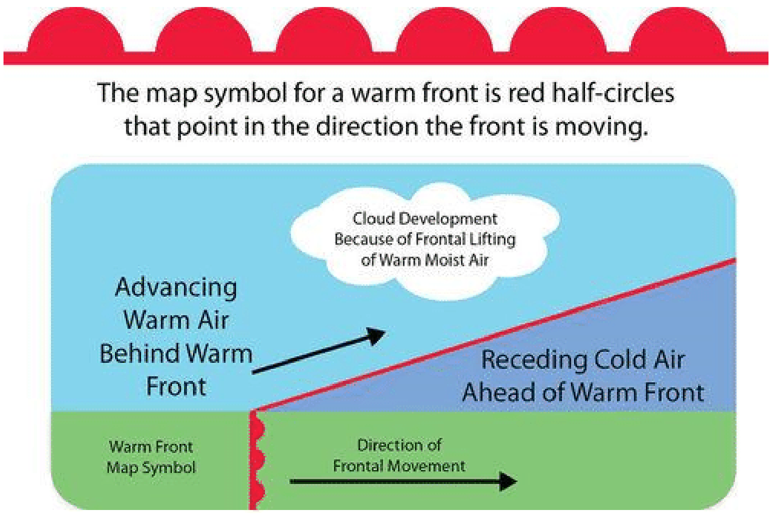
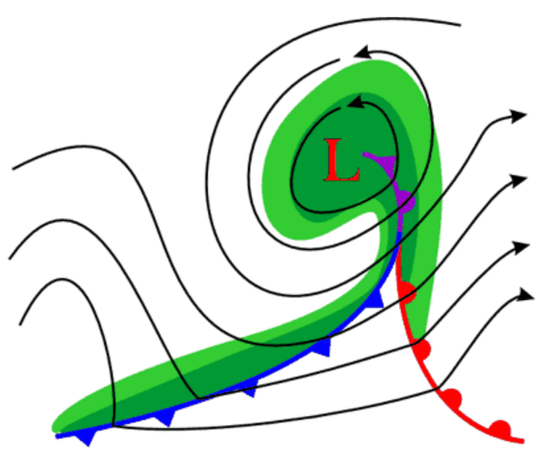


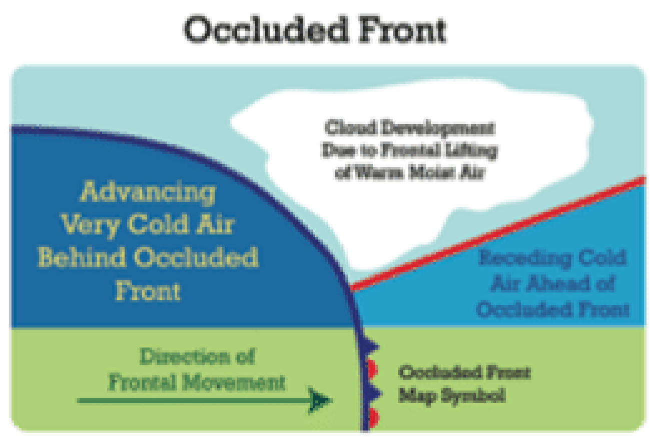
FIGURE 3.10
Warm fronts generally bring cloudy weather.

When a warm air mass runs into a cold air mass it creates a warm front. The warm air mass is moving faster than the cold air mass, so it flows up over the cold air mass. As the warm air rises, it cools, resulting in clouds and sometimes light precipitation. Warm fronts move slowly and cover a wide area. After a warm front passes, the warm air mass behind it brings warmer temperatures. The warm air is also likely to be more humid.

Occluded Fronts



With an occluded front, a warm air mass becomes trapped between two cold air masses. The warm air is lifted up above the cold air as in Figure below. The weather at an occluded front is especially fierce right at the occlusion. Precipitation and shifting winds are typical.

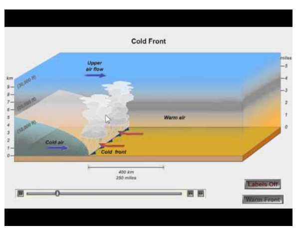


Stationary Fronts

Sometimes two air masses stop moving when they meet. These stalled air masses create a stationary front. Such a front may bring clouds and precipitation to the same area for many days.

View this video for more information on warm and cold fronts:

- https://youtu.be/huKYKykjcm0



MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178288

Summary

- An air mass is a large body of air that has about the same conditions throughout. Air masses take on the conditions of the area where they form. Winds and air currents cause air masses to move. Moving air masses cause changes in the weather.
- A front forms at the boundary between two air masses. Types of fronts include cold, warm, occluded, and stationary fronts. Clouds, precipitation, and storms commonly occur along fronts.

Think like a Climatologist

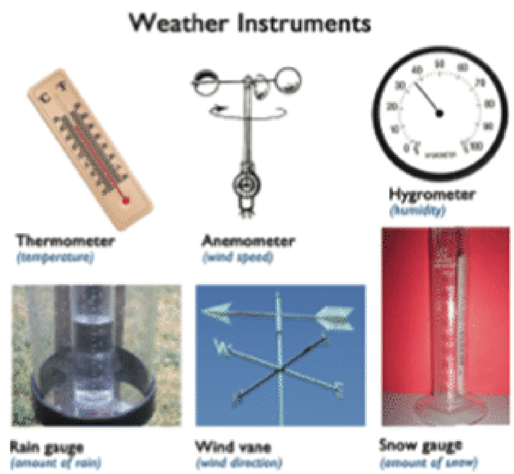
1. What is an air mass?
2. Describe continental polar and maritime tropical air masses.
3. What causes air masses to move?
4. What is a front?

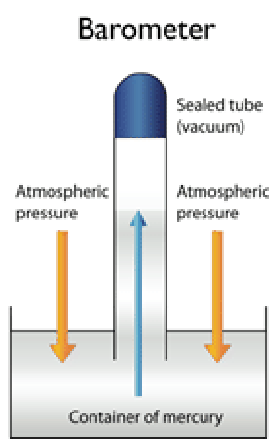
3.7 How do they forecast the weather?

Weather instruments measure weather conditions:

- A thermometer measures temperature.
- An anemometer measures wind speed.
- A rain gauge measures the amount of rain (precipitation).
- A hygrometer measures humidity.
- A wind vane shows wind direction.
- A snow gauge measures the amount of snow (precipitation).
- A Doppler radar system measures movement and amount of precipitation.
- A satellite measures and records cloud coverage.
- A barometer measures air pressure.

Weather instruments collect data from all over the world at thousands of weather stations. Many are on land but some float in the oceans on buoys.





Other weather devices are needed to collect weather data in the atmosphere. They include weather balloons, satellites, and radar.

Weather stations contain many instruments for measuring weather conditions. The weather balloon will rise into the atmosphere until it bursts. As it rises, it will gather weather data and send it to the surface. Many weather satellites orbit Earth. They constantly collect and transmit weather data from high above the surface. A radar device sends out radio waves in all directions. The waves bounce off water in the atmosphere and then return to the sender. The radar data shows where precipitation is falling.

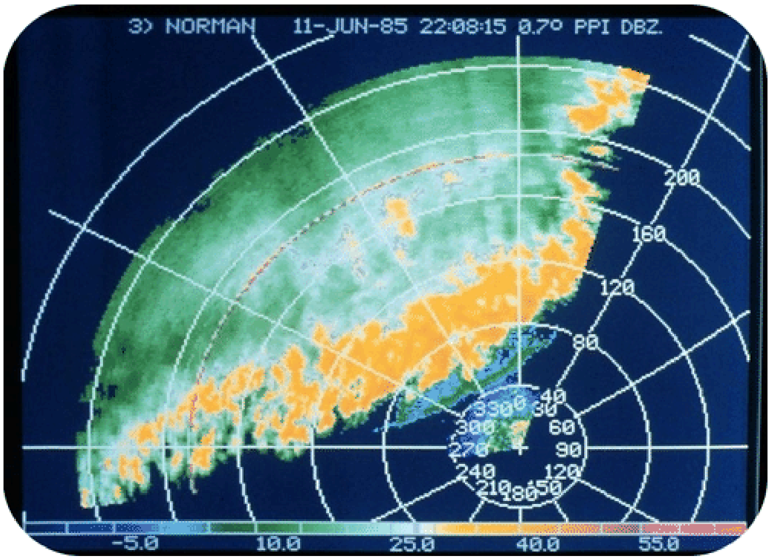


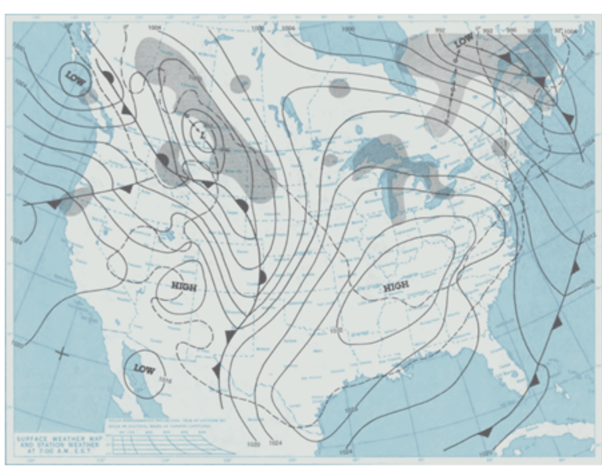
FIGURE 3.11
Radar image of a line of thunderstorms

Using computers to track the weather

What do meteorologists do with all that weather data? They use it in weather models. The models analyze the data and predict the weather. The models require computers. That's because so many measurements and calculations are involved.

Weather Maps

Because weather is an important part of everyday life, meteorologists use weather maps on the news to show what is happening nationwide or even globally. The weather map figure below is an example of this.



Summary

- Weather is very complex. This makes it hard to predict. Certain "rules" can help. For example, low pressure brings stormy weather.
- Weather instruments measure weather factors. Weather stations collect data on Earth's surface. Weather balloons, satellites, and radar collect data in the atmosphere. Computer models analyze the data and help predict the weather.
- A shows the weather for a certain area. It can show actual or predicted weather. It may show a single weather condition or more than one.

Think like a Meteorologist

1. Why is weather difficult to predict?
2. List three weather instruments, and state what they measure.
3. What is the role of weather balloons and weather satellites?
4. What does a weather map show?

How to read a weather map

Check out this tutorial from CK-12 on how to read a weather map:

- http://www.ck12.org/earth-science/Weather-Maps/lecture/How-To-Read-A-Surface-Analysis-Of-A-Weather-Map/?referrer=featured_content

3.8 What causes severe weather?

Sometimes weather can change drastically. Have you ever been out on a nice sunny day and suddenly you see large billowing clouds overhead? There are several types of severe weather than can happen around the globe. What is happening in your neighborhood?

Thunderstorms

Thunderstorms form when ground temperatures are high, typically during late afternoons and early evenings in the summer.

Thunderstorms: Thunder and Lightning

- Thunderstorms can form individually or as part of a squall line along a cold front.
- Large amounts of energy collected within cumulonimbus clouds is released as electricity called lightning.
- The rapid heating of the air surrounding a lightning strike produces a loud clap of thunder, which is a result of the rapidly expanding air.

Tornadoes

Characteristics:

- Tornadoes form at the front of severe thunderstorms.
- Tornadoes generally last only a few minutes.
- When tornadoes form over water, they are referred to as waterspouts.

Formation:

- Tornadoes are typically products of severe thunderstorms.
- As air in a thunderstorm rises, the surrounding air races in to fill the gap.
- This forms a funnel-shaped whirling column of air that extends down to the earth from the thundercloud.

Destruction:

- Damages a small area but can destroy everything it passes.
- An average of 90 people are killed by tornadoes each year.

Location:

- Tornadoes form during the spring where maritime tropical and continental polar air masses meet.

Hurricanes

Hurricanes are special types of cyclones that form in the tropics. They are also referred to as tropical cyclones.

Hurricanes: Formation

- Hurricanes arise in the tropical latitudes in summer and autumn when sea surface temperatures are over 28ºC.
- Warm seas create a large humid air mass.
- Warm air rises and forms a low pressure cell called a tropical depression.
- Air begins to rotate around the low pressure.
- As air rises, water vapor condenses, releasing energy from latent heat.
- If wind shear is low, the storm will build into a hurricane within 2-3 days.

Blizzards

Blizzards are large snowstorms with high winds.

Conditions:

- Temperatures below -7ºC (20ºF); -12ºC (10ºF) 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 $\frac{2}{5}$ km ($\frac{1}{4}$ mile) or less for at least three hours; near zero visibility for a severe blizzard.

Blizzards: Formation

- Occur across the middle latitudes and towards the poles.
- Usually part of a mid-latitude cyclone.
- Commonly occurs when the jet stream has traveled south and a cold, northern air mass comes into contact with a warmer, semitropical air mass.
- Pressure gradient between the low-pressure and high-pressure parts of the storm create strong winds.

Blizzards: Lake-Effect Snow

- Lake effect snow occurs when an air mass reaches the leeward side of a lake. The air mass is very unstable and drops a tremendous amount of snow.

Heat Waves and Droughts

Heat Wave:

- According to the World Meteorological Organization a region is in a heat wave if it has more than five consecutive days of temperatures that are more than 9ºF (5ºC) above average.
- A high-pressure area sitting over a region with no movement is the likely cause of a heat wave.

Drought:

- When a region gets significantly less precipitation than normal for an extended period of time, it is in drought.
- Consequences to droughts include dust storms, blown over soil, and wildlife disturbance.

Summary

- A storm is an episode of severe weather. It is caused by a major disturbance in the atmosphere. Types of storms include thunderstorms, tornadoes, and hurricanes.
- A thunderstorm is a storm with heavy rains and lightning. It may also have hail and high winds. Thunderstorms are very common. They occur when the air is very warm and humid.

- A tornado is a storm with a funnel-shaped cloud. It has very strong, whirling winds. Tornadoes are small but powerful. They occur with thunderstorms and hurricanes.
- A hurricane is a large storm with high winds and heavy rains. Hurricanes develop from tropical cyclones. They form over warm ocean water. Much of the damage from hurricanes may be caused by storm surge.
- Winter storms develop from cyclones at higher latitudes. They include blizzards and lake-effect snowstorms.

Think like a Scientist

1. Define storm. List three types of storms.
2. Why do thunderstorms occur?
3. What is lightning? What causes it?
4. Where is tornado alley? Why do so many tornadoes occur there?
5. Where do hurricanes form? Where do they get their energy?

3.9 What are short-term climate changes?

El Niño and La Niña bring about dramatic changes in climate for a year or two. In some locations one brings rain and the other brings drought. In California, for example, El Niño years are full of snow and rain. La Niña years tend towards drought. These variations can bring tremendous changes to living creatures. Humans are also affected; for example, erosion from storms may be very high some years.

Short-Term Climate Change

You've probably heard of El Niño and La Niña. These terms refer to certain short-term changes in climate. The changes are natural and occur in cycles, lasting from days to years. El Niño and La Niña are not the only short-term climate changes. Others include the Pacific decadal oscillation and the North Atlantic oscillation. El Niño and La Niña are the most noticeable and discussed.

El Niño and La Niña

To understand El Niño and La Niña, you first need to know what happens in normal years. This is shown in the Figure 3.12.

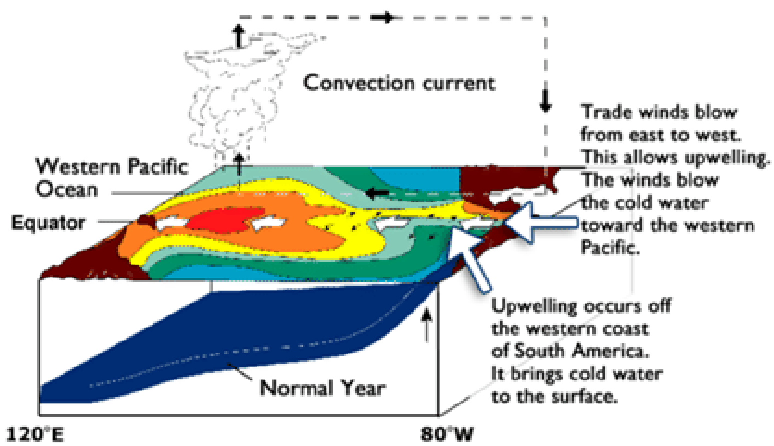


FIGURE 3.12
This diagram represents the Pacific Ocean in a normal year. North and South America are the found at the lower left and upper right of the image.

El Niño

During an El Niño, the western Pacific Ocean is warmer than usual. This causes the trade winds to change direction. The winds blow from west to east instead of east to west. This is shown in Figure 3.13. The change in the trade winds also causes the jet streams to be north of their normal location. The warm water travels east across the equator, too. Warm water piles up along the western coast of South America. This prevents upwelling. Why do you think this is true?

These changes in water temperature, winds, and currents affect climates worldwide. The changes usually last a year or two. Some places get more rain than normal. Other places get less. In many locations, the weather is more severe.

How do you think El Niño affects climate on the western coast of South America?

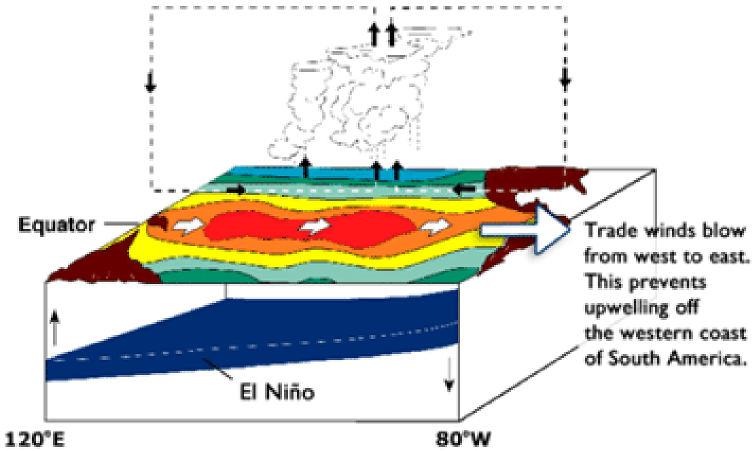


FIGURE 3.13
El Nino Year

This ABC News video explores the relationship of El Niño to global warming. El Niño is named as the cause of strange weather across the United States in the winter of 2007 in this video:

- http://www.youtube.com/watch?v=5uk9nwtAOio&feature=related

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178286

La Niña

La Niña generally follows El Niño. It occurs when the Pacific Ocean is cooler than normal (see the Figure 3.14). The trade winds are like they are in a normal year. They blow from east to west. But in a La Niña the winds are stronger than usual. More cool water builds up in the western Pacific. These changes can also affect climates worldwide.

How do you think La Niña affects climate on the western coast of South America?

Some scientists think that global warming is affecting the cycle of El Niño and La Niña. These short-term changes seem to be cycling faster now than in the past. They are also more extreme.

An online guide to El Niño and La Niña events from the University of Illinois is found here:

- http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/eln/home.rxml

El Niño and La Niña are explained in a National Geographic videos found at National Geographic Video, Natural disaster, Landslides, and More: El Niño.

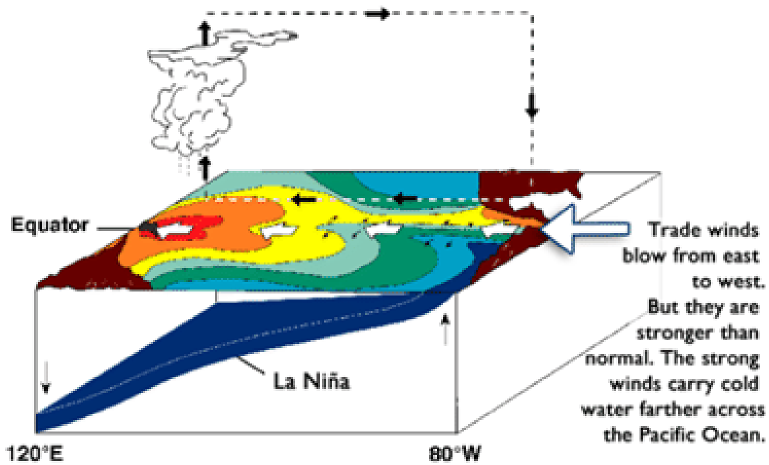


FIGURE 3.14
La Nina year

3.10 How has Earth's climate changed?

- Explain differences between weather and climate and the methods used to investigate evidence for changes in climate (e.g., ice core sampling, tree rings, historical temperature measurements, changes in the extent of alpine glaciers, changes in the extent of Arctic sea ice).
- Explain how Earth's climate has changed over time and describe the natural causes for these changes (e.g., Milankovitch cycles, solar fluctuations, plate tectonics).
- Describe how human activity influences the carbon cycle and may contribute to climate change.
- Explain the differences between air pollution and climate change and how these are related to society's use of fossil fuels.

Sometimes you hear about what the weather is like in an area. You also hear about what the climate is like in an area. What is the difference?

Weather vs. Climate

Weather

- Weather describes what the atmosphere is like at a specific time and place.
- Weather is made up of factors including air temperature, pressure, fog, humidity, cloud cover, precipitation, and wind.
- Most of the time, the weather is different every day.

Climate

- The climate of a region is the long-term average weather of a particular spot. It is often more predictable than the weather.
- The climate usually changes slowly, and is usually affected by factors like the angle of the Sun and the amount of cloud cover in the region.
- The weather changes all the time. It can change in a matter of minutes. Changes in climate occur more slowly. They also tend to be small changes. But even small changes in climate can make a big difference for Earth and its living things.

How Earth's Climate Has Changed

Earth's climate has changed many times. It's been both hotter and colder than it is today.

The Big Picture

Over much of Earth's past, the climate was probably a little warmer than it is today. But ice ages also occurred many times. An ice age is a period when temperatures are cooler than normal. This causes glaciers to spread to lower latitudes. Scientists think that ice ages occurred at least six times over the last billion years alone. How do scientists learn about Earth's past climates?

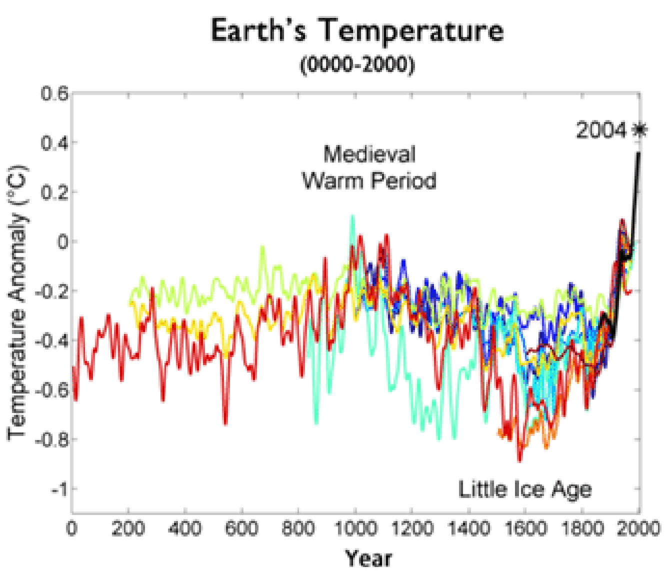
Pleistocene Ice Age

The last major ice age took place in the Pleistocene. This epoch lasted from 2 million to 14,000 years ago. Earth's temperature was only 5°C (9°F) cooler than it is today. But glaciers covered much of the Northern Hemisphere. In the Figure 3.15, you can see how far south they went. Clearly, a small change in temperature can have a big impact on the planet. Humans lived during this ice age.

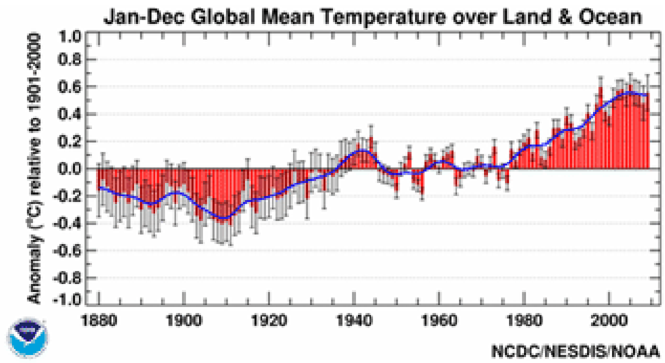
FIGURE 3.15
Pleistocene Glaciers. Chicago would have been buried under a glacier if it existed during the Pleistocene.

Earth's Recent Temperature

Since the Pleistocene, Earth's temperature has risen. Figure below shows how it changed over just the last 2000 years. There were minor ups and downs. But each time, the anomaly (the difference from average temperature) was less than 1°C (1.8°F).



Since the mid-1800s, Earth has warmed up quickly. Look at the Figure below. The 14 hottest years on record occurred since 1900. Eight of them occurred since 1998. This is what is usually meant by global warming.


Jan-Dec Global Mean Temperature over Land & Ocean
Anomaly (°C) relative to 1901-2000
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1880
1900
1920
1940
1960
1980
2000
NCDC/NESDIS/NOAA

3.11 What causes climate change?

- Several natural processes may affect Earth's temperature. They range from sunspots to Earth's wobble.
- Sunspots are storms on the sun. When the number of sunspots is high, the sun gives off more energy than usual. This may increase Earth's temperature.
- Plate movements cause continents to drift. They move closer to the poles or the equator. Ocean currents also shift when continents drift. All these changes affect Earth's temperature.
- Plate movements trigger volcanoes. A huge eruption could spew so much gas and ash into the air that little sunlight would reach the surface for months or years. This could lower Earth's temperature.
- A large asteroid hitting Earth would throw a lot of dust into the air. This could block sunlight and cool the planet.
- Earth goes through regular changes in its position relative to the sun. Its orbit changes slightly. Earth also wobbles on its axis. Both of these changes can affect Earth's temperature.

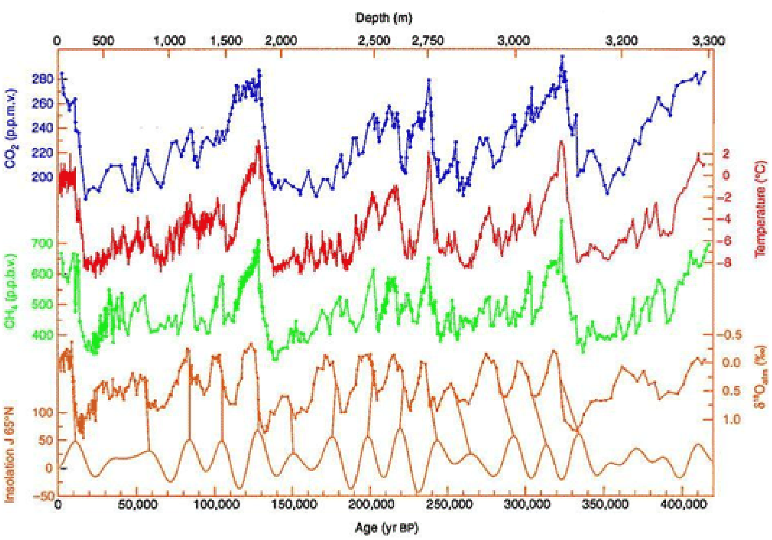


FIGURE 3.16

Vostok Ice Core. Why do the blue, green and red lines go in the same direction at the same time?

This is a complicated graph, but extremely interesting. The data are from the 3600 meter-long Vostok ice core, which gave climate scientists an unprecedented look into the history of Earth's climate. The red line is temperature. You can see that carbon dioxide and methane are correlated with temperature. When these greenhouse gases are high, temperature is high. This holds true for the 440,000 years revealed in the core.

Causes of Long-term Climate Change

Many processes can cause climate to change. These include changes:

- In the amount of energy the Sun produces over years.
- In the positions of the continents over millions of years.
- In the tilt of Earth's axis and orbit over thousands of years.
- That are sudden and dramatic because of random catastrophic events, such as a large asteroid impact.
- In greenhouse gases in the atmosphere, caused naturally or by human activities.

Solar Variation

The amount of energy the Sun radiates is variable. Sunspots are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle (Figure 3.17). 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.

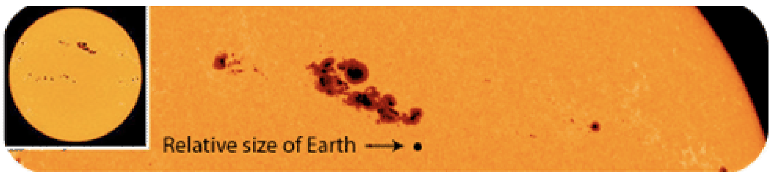


FIGURE 3.17
Sunspots on the face of the Sun.

Plate Tectonics

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

Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather (Figure 3.18). Massive eruptions of the fluid lavas that create lava plateaus release much more gas and dust, and can change climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

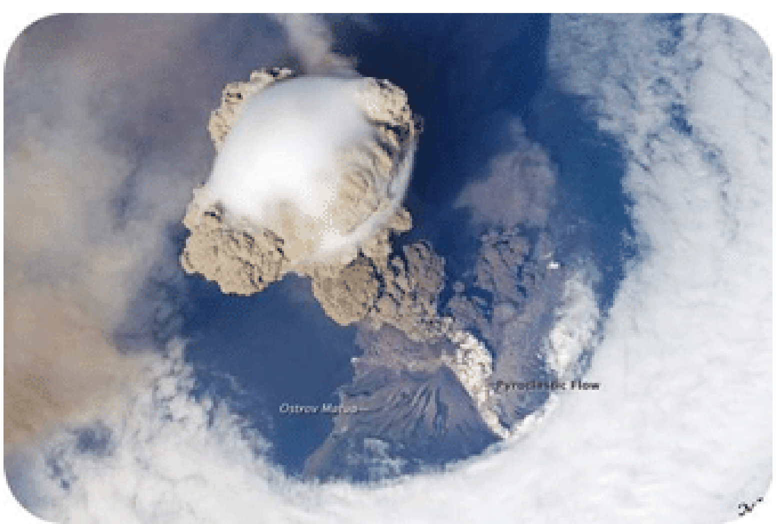


FIGURE 3.18
An eruption like Sarychev Volcano (Kuril Islands, Japan) in 2009 would have very little impact on weather.

Milankovitch Cycles

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

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

1. The shape of the Earth's orbit changes slightly as it goes around the Sun. The orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.
2. The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun. 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 form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Changes in Atmospheric Greenhouse Gas Levels

Since greenhouse gases trap the heat that radiates off the planet's surfaces, what would happen to global temperatures if atmospheric greenhouse gas levels decreased? What if greenhouse gases increased? A decrease in greenhouse gas levels decreases global temperature and an increase raises global temperature.

Greenhouse gas levels have varied throughout Earth history. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods (Figure 3.19).

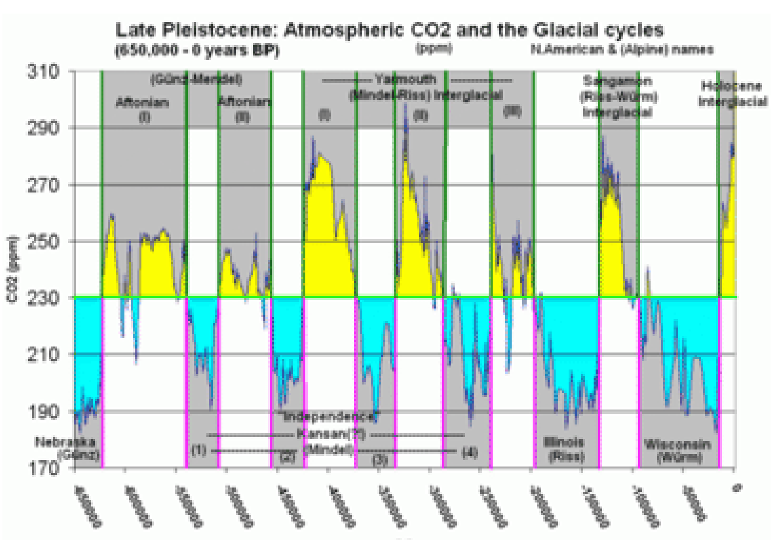


FIGURE 3.19

CO_2 levels during glacial (blue) and interglacial (yellow) periods. Are CO_2 levels relatively high or relatively low during interglacial periods? Current carbon dioxide levels are at 387 ppm, the highest level for the last 650,000 years. BP means years before present.

Natural processes add and remove CO_2 from the atmosphere

Processes that add CO_2:

- volcanic eruptions
- decay or burning of organic matter.

Processes that remove CO_2:

- absorption by plant and animal tissue.

When plants are turned into fossil fuels, the CO_2 in their tissue is stored with them. So CO_2 is removed from the atmosphere. What does this do to Earth's average temperature?

What happens to atmospheric CO_2 when the fossil fuels are burned? What happens to global temperatures?

Summary

- The positions of continents, the sizes of oceans and the amount of volcanic activity that takes place are all ways that plate tectonics processes can affect climate.
- Milankovitch cycles affect the way Earth relates to the sun due to the shape of the planet's orbit, its axial tilt, and its wobble.
- Atmospheric greenhouse gas levels correlate with average global temperatures.

3.12 How are fossil fuels formed?

Fossil fuels are made from plants and animals that lived hundreds of millions of years ago. The plants used energy from the Sun to form energy-rich carbon compounds. As the plants and animals died, their remains settled onto the ground and at the bottom of the sea. Layer upon layer of organic material was laid down. Eventually, the layers were buried very deeply. They experienced intense heat and pressure. Over millions of years, the organic material turned into fossil fuels.

Fossil fuels are compounds of carbon and hydrogen, called hydrocarbons.

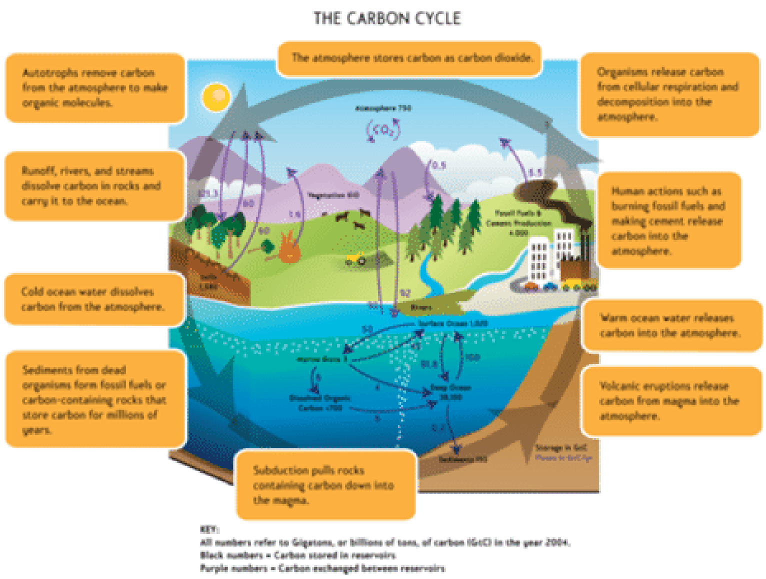


FIGURE 3.20
Human Actions Impact the Carbon Cycle

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO_2 when they form, but they are a source for CO_2 when they are burned.

The equation for combustion of propane, which is a simple hydrocarbon looks like this (Figure below):

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\,O_2} \rightarrow \underset{\text{carbon dioxide}}{3\,CO_2} + \underset{\text{water}}{4\,H_2O}$$

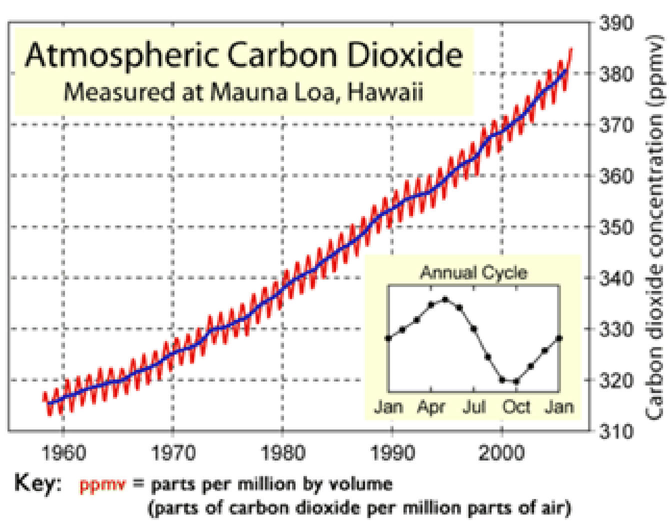
The equation shows that when propane burns, it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas, the amount of CO_2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO_2, the result is the increase in atmospheric CO_2 seen in the graph above.

The second largest source of atmospheric CO_2 is deforestation (Figure 3.21). Trees naturally absorb CO_2 while they are alive. Trees that are cut down lose their ability to absorb CO_2. If the tree is burned or decomposes, it becomes a source of CO_2. A forest can go from being a carbon sink to being a carbon source.

FIGURE 3.21
This forest in Mexico has been cut down and burned to clear forested land for agriculture.

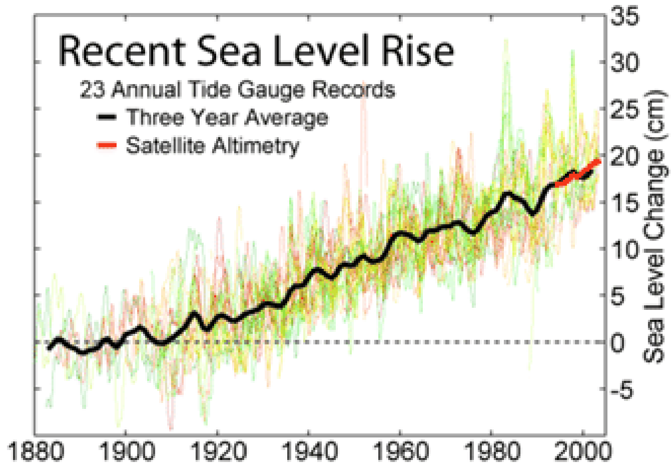
Causes of Global Warming

Recent global warming trends. Figure below shows the increase in carbon dioxide since 1960. Carbon dioxide is a greenhouse gas. It's one of several gases in the air. This has created a greater greenhouse effect.



Effects of Global Warming

As Earth has gotten warmer, sea ice has melted. This has raised the level of water in the oceans. Figure below shows how much sea level has risen since 1880.



Other effects of global warming may include more extreme weather. Many living things may not be able to adjust to the changing climate. For example, coral reefs are dying out in all the world's oceans due to climate change and other factors.

How Will Climate Change in the Future?

Look at the projections in Figure 3.22. The temperature in 2100 may be as much as 5°C (9°F) higher than it was in 2000. A 5°C decrease in temperature led to the Pleistocene ice age. How might a 5°C increase in temperature affect Earth in the future?

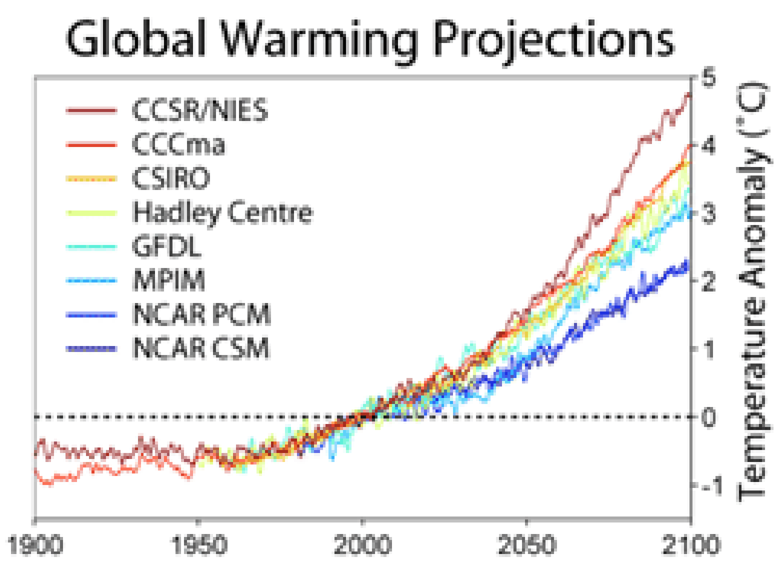


FIGURE 3.22
Projections of several different models are shown here. They all predict a warmer future.

One effect of higher temperatures will be more melting of sea ice. The Figure 3.23 shows how much less sea ice there may be in 2050 if temperatures keep going up. This would cause sea level to rise even higher. Some coastal cities could be under water. Millions of people would have to move inland. How might other living things be affected?

Why is the atmosphere important?

Well, it contains all of the air that we breathe. The atmosphere also has other roles and functions, so when we interfere with the atmosphere, we interfere with some important biological processes. And this can have

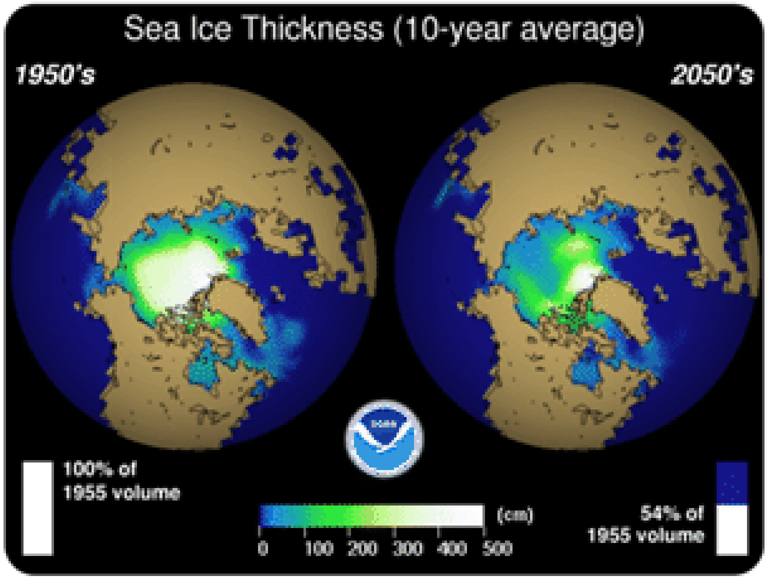


FIGURE 3.23
In the 2050s, there may be only half as much sea ice as there was in the 1950s.

consequences.

The Atmosphere

The atmosphere plays an important part in maintaining Earth's freshwater supply. It is part of the water cycle. It refills lakes and rivers with precipitation. The atmosphere also provides organisms with gases needed for life. It contains oxygen for cellular respiration and carbon dioxide for photosynthesis.

Air Pollution

Earth's atmosphere is vast. However, it has been seriously polluted by human activities. Air pollution consists of chemical substances and particles released into the atmosphere, mainly by human actions. The major cause of outdoor air pollution is the burning of fossil fuels. Power plants, motor vehicles, and home furnaces all burn fossil fuels and contribute to the problem (see Table below). Ranching and using chemicals such as fertilizers also cause air pollution. Erosion of soil in farm fields and construction sites adds dust particles to the air as well. Fumes from building materials, furniture, carpets, and paint add toxic chemicals to indoor air.

In humans, air pollution causes respiratory and cardiovascular problems. In fact, more people die each year from air pollution than automobile accidents. Air pollution also affects ecosystems worldwide by causing acid rain, ozone depletion, and global warming. Ways to reduce air pollution from fossil fuels include switching to nonpolluting energy sources (such as solar energy) and using less energy.

Acid Rain

All life relies on a relatively narrow range of pH, or acidity. That's because protein structure and function are very sensitive to pH. Air pollution can cause precipitation to become acidic. Nitrogen and sulfur oxides, mainly from motor vehicle exhaust and coal burning, create acids when they combine with water in the air. The acids lower the pH of precipitation, forming acid rain. If acid rain falls on the ground, it may damage soil and soil organisms. If it falls on plants, it may kill them (see Figure 3.24). If it falls into lakes, it lowers the pH of the water and kills aquatic organisms.

FIGURE 3.24

Effects of Acid Rain. These trees in a European forest were killed by acid rain.

Chapter 4 Standard IV: Hydrosphere

Chapter Outline

4.1 Why can't we drink most of the water on Earth?

4.2 How do we use water?

4.3 What makes H2O unique?

4.4 What is a freshwater ecosystem?

4.5 Was there always water on Earth?

4.6 What causes water to move in the ocean?

Standard 4: Students will understand the dynamics of the hydrosphere.

Objective 1: Characterize the water cycle in terms of its reservoirs, water movement among reservoirs and how water has been recycled throughout time.

1. Identify oceans, lakes, running water, frozen water, groundwater, and atmospheric moisture as the reservoirs of Earth's water cycle, and graph or chart the relative amounts of water in each.
2. Describe how the processes of evaporation, condensation, precipitation, surface runoff, ground infiltration and transpiration contribute to the cycling of water through Earth's reservoirs.
3. Model the natural purification of water as it moves through the water cycle and compare natural purification to processes used in local sewage treatment plants.

Objective 2: Analyze the characteristics and importance of freshwater found on Earth's surface and its effect on living systems.

1. Investigate the properties of water: exists in all three states, dissolves many substances, exhibits adhesion and cohesion, density of solid vs. liquid water.
2. Plan and conduct an experiment to investigate biotic and abiotic factors that affect freshwater ecosystems.
3. Using data collected from local water systems, evaluate water quality and conclude how pollution can make water unavailable or unsuitable for life.
4. Research and report how communities manage water resources (e.g., distribution, shortages, quality, flood control) to address social, economic, and environmental concerns.

Objective 3: Analyze the physical, chemical, and biological dynamics of the oceans and the flow of energy through the oceans.

1. Research how the oceans formed from outgassing by volcanoes and ice from comets.
2. Investigate how salinity, temperature, and pressure at different depths and locations in oceans and lakes affect saltwater ecosystems.
3. Design and conduct an experiment comparing chemical properties (e.g., chemical composition, percent salinity) and physical properties (e.g., density, freezing point depression) of freshwater samples to saltwater samples from different sources.
4. Model energy flow in the physical dynamics of oceans (e.g., wave action, deep ocean tides circulation, surface currents, land and sea breezes, El Niño, upwellings).
5. Evaluate the impact of human activities (e.g., sediment, pollution, overfishing) on ocean systems.

4.1 Why can't we drink most of the water on Earth?

Objectives

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

Introduction

Water is simply two atoms of hydrogen and one atom of oxygen bonded together. Despite its simplicity, water has remarkable properties. Water expands when it freezes, has high surface tension (because of the polar nature of the molecules, they tend to stick together), and others. Without water, life might not be able to exist on Earth and it certainly would not have the tremendous complexity and diversity that we see.

Distribution of Earth's Water

Earth's oceans contain 97% of the planet's water, just 3% is fresh water, water with low concentrations of salts (See diagram 4.1). Most fresh water is ice, in polar ice caps and glaciers. Storage locations for water are known as reservoirs. Earth's reservoirs are oceans, glaciers, groundwater, lakes, rivers and the atmosphere. A water molecule may pass through a reservoir very quickly or may remain for much longer.

How is the 3% of freshwater divided into different reservoirs? How much of that water is useful for living creatures? How much is available for people?

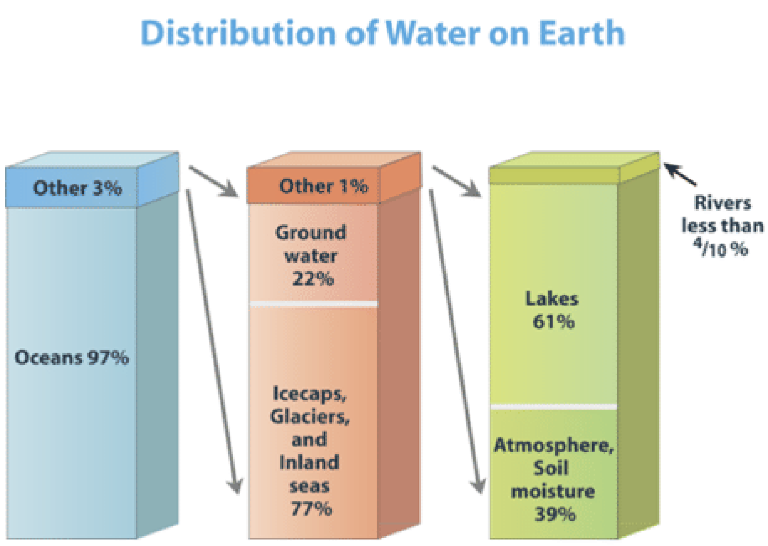
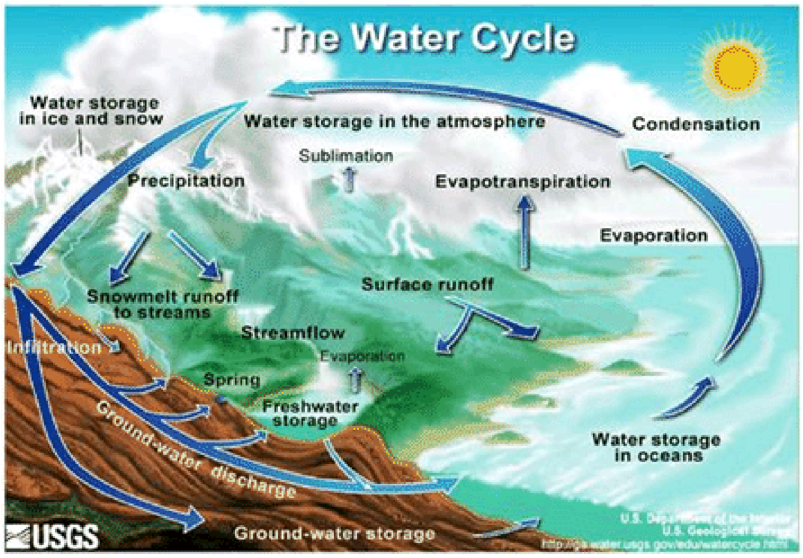


FIGURE 4.1
The Hydrologic (Water) Cycle - (the cycle of processes by which water circulates between Earth's reservoirs)

Because of the unique properties of water, water molecules can cycle through almost anywhere on Earth. The water molecule found in your glass of water today could have erupted from a volcano early in Earth history. In the intervening billions of years, the molecule probably spent time in a glacier or far below the ground. The molecule surely was high up in the atmosphere and maybe deep in the belly of a dinosaur. Where will that water molecule go next?

Because Earth's water is present in all three states, it can get into a variety of environments around the planet. The movement of water around Earth's surface is called the Hydrologic (water) cycle.



Because it is a cycle, the **hydrologic (or water) cycle** has no beginning and no end. It has been an ongoing process since well before the dinosaurs.

The Sun, which is 149,600,000 kilometers away, provides the energy that drives the water cycle. Our nearest star directly impacts the water cycle by supplying the energy needed for **evaporation** - (the process of going from a liquid to a gas).

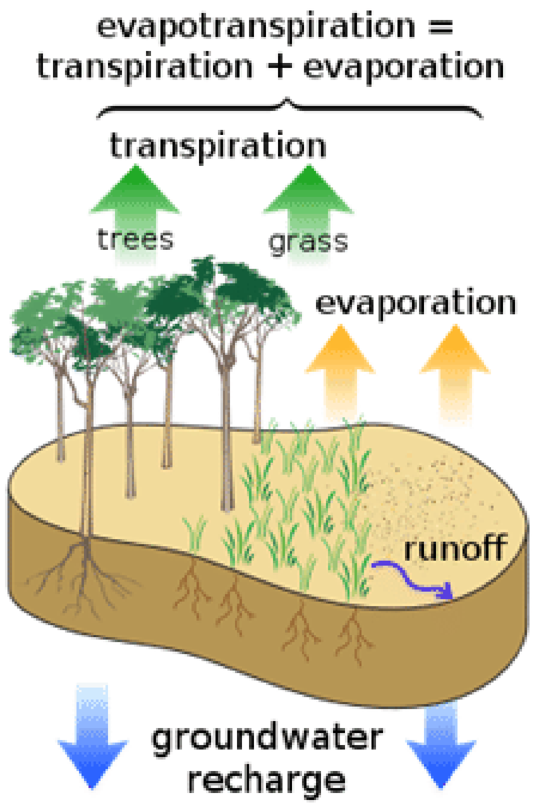
Most of Earth's water is stored in the oceans where it can remain for hundreds or thousands of years. The oceans are discussed in detail in the chapter Earth's Oceans.

Water changes from a liquid to a gas by **evaporation** to become **water vapor** (water in a gas state that is diffused in the atmosphere). The Sun's energy can evaporate water from the ocean surface or from lakes, streams, or puddles on land. Only the water molecules evaporate; the salts remain in the ocean or a freshwater reservoir.

The water vapor remains in the atmosphere until it undergoes **condensation** (the process of changing phase from a gas to a liquid) to become tiny droplets of liquid. The droplets gather in clouds, which are blown about the globe by wind. As the water droplets in the clouds collide and grow, they fall from the sky as **precipitation** (water that falls to the ground as rain, hail, snow, etc).

Plants and animals depend on water to live, and they also play a role in the water cycle. The interaction between plants and the atmosphere is a process known as **transpiration** (Plants take up water from the soil and release large amounts of water vapor into the air through their leaves).

Precipitation can be rain, sleet, hail, or snow. Sometimes precipitation falls into the ocean and sometimes it falls onto the land surface.



When water falls from the sky as rain it may enter streams and rivers that flow downward to oceans and lakes. Water that falls as snow may sit on a mountain for several months. Snow may become part of the ice in a glacier, where it may remain for hundreds or thousands of years. Snow and ice may go directly back into the air by **sublimation**, the process in which a solid changes directly into a gas without first becoming a liquid. Although you probably have not seen water vapor sublimating from a glacier, you may have seen dry ice sublimate in air.

Snow and ice slowly melt over time to become liquid water. This provides a steady flow of fresh water to streams, rivers, and lakes below. A water droplet falling as rain could also become part of a stream or a lake. At the surface, the water may eventually evaporate and reenter the atmosphere.

Reservoirs

A reservoir can be any storage place for water and can be local or global. Local reservoirs might include a nearby lake or stream or tiny droplets of water in the soil. Global reservoirs of water would be **all** lakes, groundwater, oceans, water in the atmosphere, all glaciers and ice caps etc.

A significant amount of water is called **groundwater** - water that filters into the ground. Soil moisture is an important reservoir - (a place where water is stored for a certain period of time) for water. Water trapped in soil is important for plants to grow. Although this may seem surprising, water beneath the ground is commonplace. Usually groundwater travels slowly and silently beneath the surface, but in some locations it bubbles to the surface at springs and geysers.

Water becomes groundwater by seeping through dirt and rock below the surface of the soil through tiny spaces between tiny bits of rock and dirt, infiltrating the ground. Groundwater storage is called an **aquifer** (porous rock and sediment with water trapped in between). Aquifers may store fresh water for centuries. The water may come to the surface through springs or find its way back to the oceans.

Groundwater is the largest reservoir of liquid freshwater on Earth and is found in **aquifers** (porous rock and sediment with water in between).

Contaminants are filtered out as water moves through the soil. Evaporation also purifies water as minerals and salts are left behind.

Aquifers are found at different depths. Some are just below the surface and some are found much deeper below the land surface. A region may have more than one aquifer beneath it and even most deserts are above aquifers. The source region for an aquifer beneath a desert is likely to be far from where the aquifer is located; for example, it may be in a mountain area.

Water can be in an aquifer can be from minutes to thousands of years. Groundwater is often called "fossil water" because it has remained in the ground for so long, often since the end of the ice ages. Why? Groundwater escapes solar radiation so it cannot evaporate very easily. When coastal aquifers are overused, salt water from the ocean may enter the aquifer, contaminating the aquifer and making it less useful for drinking and irrigation. Salt water incursion is a problem in developed coastal regions, such as on Hawaii.

Summary

- Although Earth's surface is mostly water covered, only 3% is freshwater.
- Water travels between phases and reservoirs as part of the hydrologic (water) cycle.
- The major processes of the water cycle include evaporation, transpiration, condensation, precipitation, and return to the oceans via runoff and groundwater supplies.
- Groundwater is the largest reservoir of fresh water.
- The water table is the top of an aquifer below which is water and above is rock or soil mixed with air.
- Aquifers are underground areas of sediment or rock that hold groundwater.
- An aquifer needs good porosity and permeability.
- People dig or drill wells to access groundwater.
- Evaporation and infiltration naturally filter and purify water as it travels to the aquifer.
- Water treatment performed at sewage treatment plants mimics natural processes. Sewage plants also employ biological and chemical purification processes.

Think like a Hydrologist

1. About what percent of the Earth's water is freshwater?
2. What powers the water cycle? How?
3. Define the words condensation and evaporation.
4. Sketch the water cycle.
5. What is transpiration? How is it like evaporation?
6. How is groundwater different from surface water? What is the water table?
7. What are aquifers and why are they so important?
8. What process does groundwater go through that makes it usable by living things? Since groundwater is largely unseen from the surface, how might you monitor the amount of groundwater in an aquifer?
9. Is water from a river or from a well more likely to be clean to drink?
10. Why is overuse of groundwater a big concern?
11. What policies might people put in place to conserve water levels in lakes and aquifers?

Going Further

This animation shows porosity and permeability. The water droplets are found in the pores between the sediment grains, which is porosity. When the water can travel between pores, that's permeability.

- http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/POROS_3.MPG

4.2 How do we use water?

Objectives

- List ways that humans use water.
- State why some people don't have enough water.
- Explain why poor quality water is a problem.

Introduction

All forms of life need water to survive. Humans are no exception. We can survive for only a few days without it. We also need water for agriculture, industry, and many other uses. Clearly, water is one of Earth's most important natural resources. It's a good thing that water is recycled in the water cycle.

Many crops are grown where there isn't enough rainfall for plants to thrive. For example, crops are grown in deserts of the United States, such as Utah. How is this possible? The answer is irrigation. Irrigation is any way of providing adequate water for plants. Most of the water used in agriculture is used for growing crops. Livestock also use water, but they use much less.

Irrigation can waste a lot of water. The type of irrigation shown in the image 4.2 is the most wasteful. The water is simply sprayed into the air. Then it falls to the ground like rain. But much of the water never reaches the crops. Instead, it evaporates in the air or runs off the fields. Irrigation water may dissolve agricultural chemicals such as fertilizer. The dissolved chemicals could soak into groundwater or runoff into rivers or lakes. Salts in irrigation water can also collect in the soil. The soil may get too salty for plants to grow.

FIGURE 4.2
Overhead irrigation systems like this one are widely used to irrigate crops on big farms. What are some drawbacks of irrigation?

Water in Industry

Almost a quarter of the water used worldwide is used in industry. Industries use water for many purposes. For example, they may use water to cool machines or they may use it in chemical processes. These uses of water may pollute it. Water is also used to generate electricity. This use doesn't pollute the water, but it may dam up streams and rivers. This can bring harm to wildlife and limit our use of the land.

Household Uses of Water

Think about all the ways people use water at home. Besides drinking it, they use it for cooking, bathing, washing dishes, doing laundry, and flushing toilets. The water used inside homes goes down the drain. It usually ends up in a sewer system. This water can be treated and reused.

Households may also use water outdoors. If your family has a lawn or garden, you may water them with a hose or sprinkler. You may also use water to wash the car. Much of the water used outdoors evaporates or runs off. The runoff water may end up in storm sewers. Sewers transport water to treatment plants where water is treated and then carried into a body of water, such as the Great Salt Lake.

Water for Fun

There are many ways to use water for fun, such as white water rafting, swimming, and snorkeling. These uses of water don't actually consume it. If you were to guess which recreational activity consumes the most water, what would you guess? Believe it or not, it's golf! Golf courses require a lot of water to maintain the greens. Much of this water is wasted as it evaporates or runs off the ground.

Water Problems: Not Enough Water

Most Americans have plenty of fresh, clean water. But many people around the world do not. In fact, water shortage is the world's most serious resource problem. How can that be? Water is almost everywhere. More than 70 percent of Earth's surface is covered by water.

Where Is All the Water?

One problem is that only a tiny fraction of Earth's water is fresh, liquid water that people can use. More than 97 percent of Earth's water is salt water in the oceans. Just 3 percent of all water on earth is freshwater. Most of the freshwater is frozen in ice sheets, icebergs, and glaciers.

FIGURE 4.3

This glacier in Patagonia, Argentina stores a lot of frozen freshwater.

Rainfall and the Water Supply

Rainfall varies around the globe. About 40 percent of the land gets very little rain. About the same percentage of the world's people don't have enough water. Drier climates generally have less water for people to use. In some places, people may have less water for an entire year than many Americans use in a single day. How much water do you use in a day? How much water is there where you live?

Wealth and the Water Supply

Richer nations can drill deep wells or supply people with water in other ways. In these countries, just about everyone has access to clean running water in their homes. It's no surprise that people in these countries also use the most water. In poorer nations, there is little money to develop water supplies.

Water Shortages

Water shortages are common in much of the world. They frequently occur during droughts. A drought is a period of unusually low rainfall.

We already use six times as much water today as we did a hundred years ago. As the number of people rises, our need for water will grow. By the year 2025, only half the world's people will have enough. Water is such a vital resource that serious water shortages may cause other problems:

- Crops and livestock may die so people will have nothing to eat.
- Other uses of water, such as industry, may have to stop.
- People may fight over water resources.
- People may die from lack of water.

Water Problems: Poor Quality Water

The water Americans get from their faucets is generally safe. This water has been treated and purified. But at least 20 percent of the world's people do not have clean drinking water. Their only option may be to drink water straight from a river. The river water may be polluted with wastes. It may contain bacteria and other organisms that cause disease. Almost 9 out of 10 cases of disease worldwide are caused by unsafe drinking water. It's the leading cause of death in young children. Is the water from Utah's mountain streams safe to drink? Generally, the answer is no, they are not safe to drink without some treatment (boiling, filtration or iodine tablets).

FIGURE 4.4

This boy is getting drinking water from a hole that has been dug. It may be the only source of water where he lives.

Summary

- People use water for agriculture, industry, and households and gardens. Agriculture uses the most water. Almost all of it goes for irrigation.
- Too little water is a major problem. Places with the least water get little rainfall. They also lack money to develop water resources. Droughts make the problem even worse.
- Poor water quality is also a problem. Many people must drink water that contains wastes. This causes a lot of illness and death.

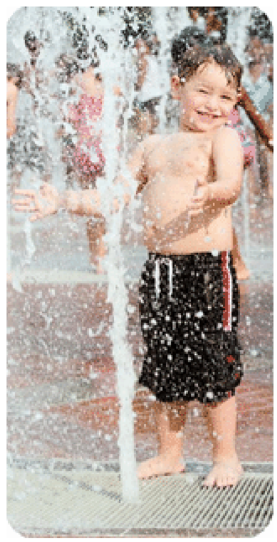
Think like a Hydrologist

1. List and describe the three major ways that humans use water.
2. What is the single biggest use of water in agriculture and why?
3. Give an example of an industrial use of water.
4. What problems may result from serious water shortages?
5. More than 70 percent of Earth's surface is covered by water. Why is scarcity of water the world's most serious resource problem?
6. In this lesson, you learned that many people don't have clean water to drink. They must drink polluted water instead. How does water become polluted? Can polluted water be treated so it is safe to drink?

4.3 What makes H2O unique?

Introduction

Dihydrogen oxide or dihydrogen monoxide. Does this chemical sound dangerous?



Another name for this compound is... water. Water is necessary for life. The importance of water to life cannot be emphasized enough. All life needs water. Life started in water. Essentially, without this simple three atom molecule, life would not exist.

Structure and Properties of Water

No doubt, you are already aware of some of the properties of water. For example, you probably know that water is tasteless and odorless. You also probably know that water is transparent, which means that light can pass through it. This is important for organisms that live in water, because most of them need sunlight to make food.

Chemical Structure of Water

To understand some of water's properties, you need to know more about its chemical structure. As you have seen, each molecule of water consists of one atom of oxygen and two atoms of hydrogen. The oxygen atom in a water molecule attracts negatively-charged electrons more strongly than the hydrogen atoms do. As a result, the oxygen atom has a slightly negative charge, and the hydrogen atoms have a slightly positive charge. A difference in electrical charge between different parts of the same molecule is called polarity, making water a polar molecule.

Opposites attract when it comes to charged molecules. In the case of water, the positive (hydrogen) end of one water molecule is attracted to the negative (oxygen) end of a nearby water molecule. Because of this attraction, weak bonds form between adjacent water molecules, as shown in the diagram 4.5. In water the bonds are strong enough to hold together nearby molecules.

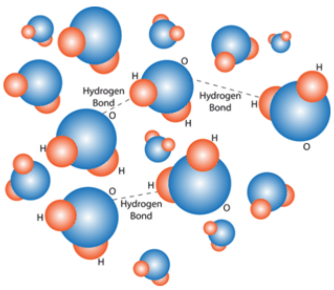


FIGURE 4.5
Hydrogen Bonding in Water Molecules. Hydrogen bonds form between nearby water molecules. How do you think this might affect water's properties?

Properties of Water

Hydrogen bonds are weak bonds between adjacent water molecules. For example, hydrogen bonds explain why water molecules tend to stick together or have **cohesion** where water molecules sticking to other water molecules. Hydrogen bonds are constantly breaking, with new bonds being formed with different molecules. Have you ever watched water drip from a leaky faucet or from a melting icicle? If you have, then you know that water always falls in drops rather than as separate molecules. The dew drops in the diagram 4.6 are another example of water molecules sticking together through cohesion. Water also has high **adhesion** properties which is the ability of water molecules to be attracted to other substances because of its polar nature. On extremely clean/smooth glass, the water may form a thin film because the molecular forces between glass and water molecules (adhesive forces) are stronger than the cohesive forces.

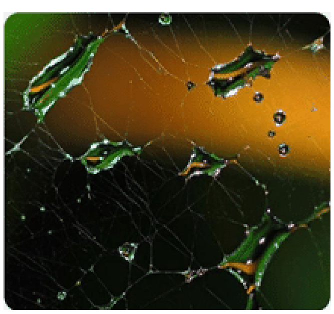
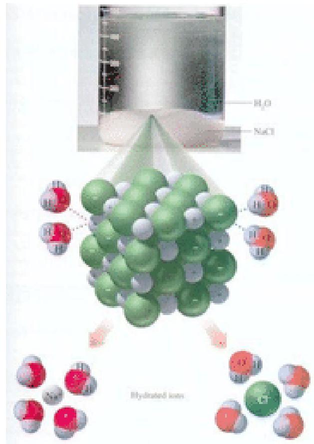


FIGURE 4.6
Droplets of Dew. Drops of dew cling to a spider web in this picture. Can you think of other examples of water forming drops?

(Hint: What happens when rain falls on a newly waxed car?)

Hydrogen bonds cause water to have a relatively high boiling point of 100°C (212°F). Because of its high boiling point, most water on Earth is in a liquid state rather than in a gaseous state. Water in its liquid state is needed by all living things. Hydrogen bonds also cause water to form into a crystalline type structure thus expanding when it freezes. This, in turn, causes ice to have a lower density (mass/volume) than liquid water. The lower density of ice means that it floats on water. For example, in cold climates, ice floats on top of the water in lakes. This allows lake animals such as fish to survive the winter by staying in the liquid water under the ice.

Water as the Universal Solvent



Due to hydrogen bonds, water dissolves more substances than any other common liquid. Most elements have high solubilities in water, which means that even in large concentrations, many things will dissolve into and be suspended in water.

Water is the only substance on Earth that is naturally present in all three states of matter - as a solid, liquid or gas. (And Earth is the only planet where water is present in all three states.) Because of the ranges in temperature in specific locations around the planet, all three phases may be present in a single location or in a region. The three phases are solid (ice or snow), liquid (water), and gas (water vapor). See ice, water, and clouds (Figure 4.7).

FIGURE 4.7
(a) Ice floating in the sea. Can you find all three phases of water in this image? (b) Liquid water. (c) Water vapor is invisible, but clouds that form when water vapor condenses are not.

Summary

- Water is a polar molecule with a more positive charge on one side and a more negative charge on the other side.
- Water is the only substance on Earth that is stable in all three states.
- Earth is the only planet in the Solar System that has water in all three states. Some special properties of water are cohesion (the ability to stick to itself) and adhesion (the ability to stick to other substances).

Think like a Hydrologist

1. List three unique properties that water has due to hydrogen bonding?
2. Water can exist in all three states of matter. Why is water typically in the liquid form?
3. Why is it essential for life that water is less dense when frozen than when liquid?
4. Water always beads up on a freshly waxed car. Is this due to adhesion or cohesion? Both? Explain.
5. Why is water considered a polar molecule?
6. Where in the Solar System is water found in all three states?

4.4 What is a freshwater ecosystem?

Freshwater ecosystems have water that contains little salts and minerals. Freshwater ecosystems include wetlands, such as swamps and marshes as well as ponds, lakes, and rivers. They have diverse ecosystems that depend and are affected by many biotic and abiotic factors.

Biotic factors can include mangroves, water lilies, cattails, black spruce, cypress, fungus, bacteria, and many others. Animal life, another biotic factor, includes many amphibians, reptiles, birds, insects, and mammals. There are also abiotic factors in ecosystems as well. **Abiotic** factors are nonliving components such as temperature, pH, salinity, light, and atmospheric gas.

A freshwater ecosystem is a community of living and non-living things that work together. What may be the most biologically diverse type of freshwater ecosystem?

Notice the abundance of vegetation mixed with water in the picture 4.8? There are many biotic and abiotic factors working together to keep this ecosystem healthy. These are wetland marshes in eastern Finland. Wetlands are a vital part of our water cycle and are very important in cycling nutrients and removing pollutants from our waterways. However, wetlands can only absorb so many pollutants. Once this occurs, biotic factors, such as plants and animals, suffer.

FIGURE 4.8

The pond above has a thick mat of duckweed plants. They cover the surface of the water and use sunlight for photosynthesis. The cattails grow along a streambed. They have tough, slender leaves that can withstand moving water. What are the biotic and abiotic factors mentioned here? (biotic: plants; abiotic: water, sunlight, moving water)

Natural Purification

As water moves between each stage in the water cycle, water undergoes natural purification. As water evaporates, other non-water and various contaminants are left behind. Sediments and pollutants are filtered out as water moves between layers of soil and loose gravel. This process of ground infiltration brings cleaner water to our aquifers. This natural cycling helps to purify water and has been copied, in part, by modern innovation in our water treatment facilities.

Many of the processes followed by water treatment facilities have been derived from natural purification processes. However, water treatment facilities also make use of biological and chemical purification processes.

Water Treatment

Water treatment is a series of processes that remove unwanted substances from water. It makes water safe to return to the natural environment or to the human water supply. You can see how drinking water is treated in the Figure 4.9. Treating water for other purposes may not include all the same steps. That's because water used in agriculture or industry may not have to be as clean as drinking water.

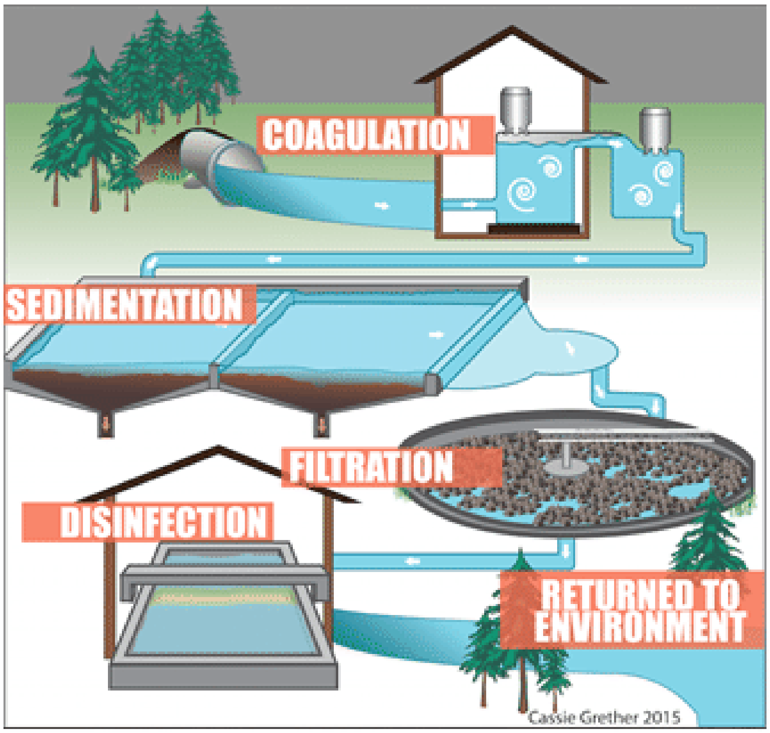


FIGURE 4.9
Four processes are used to treat water to make it safe for drinking.

Conserving Water

Conserving water means using less of it. This applies mostly to people in richer nations. They have the most water and also waste the most. In other countries, people already use very little water. They can't get by with less.

Summary

- Freshwater biomes include standing water and running water biomes.
- Biotic and abiotic factors affect freshwater ecosystems.
- Water treatment is a series of processes that remove unwanted substances from water.
- More processes are needed to purify water for drinking than for other uses.
- There are many ways to use less water. For example, drip irrigation wastes less than other methods. Water-saving toilets and shower heads can save a lot of water at home.

Think like a Scientist

1. Identify three ways that people can reduce water pollution at home.
2. List the four major ways water is used by humans. How is water used differently in the United States compared to the rest of the world?

3. What are the three main sources of water pollution?
4. Why is thermal pollution a problem?
5. Describe three things you can do to help reduce water pollution.
6. Explain the effects changing the temperature of water would have on an ecosystem.

4.5 Was there always water on Earth?

Objectives

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

Introduction

Much of Earth's surface is covered with oceans. That's why Earth is called the "blue planet". Without all that water, Earth would be a very different place. The oceans affect Earth's atmosphere. They also influence its climate. They are home to many living things as well. You might think that oceans have always covered Earth's surface. But you would be wrong!

How the Oceans Formed

When Earth formed 4.6 billion years ago, it would not have been called the "blue planet". There were no oceans then. In fact, there was no liquid water at all. Early Earth was too hot for liquid water to form. It consisted only of molten rock.

Water on Early Earth

Over time, Earth cooled. The surface hardened to become solid rock. But volcanic eruptions, like the one in image 4.10, kept bringing magma and gases to the surface through a process called **outgassing** (release of gas that was trapped in some material, i.e. gasses released during a volcanic eruption). One of the gases was water vapor. More water vapor came from asteroids and **comets** (an icy small solar system body) that crashed into Earth. As Earth cooled still more, the water vapor condensed. This was Earth's first liquid water. At last, the oceans could start to form.

FIGURE 4.10

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

How does the ocean influence the Earth?

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

Oceans and the Atmosphere

Oceans are the major source of water vapor in the atmosphere. Sunlight heats water near the surface, as shown in the diagram 4.11. As the water warms, some of it evaporates. The water vapor rises into the air. It may form clouds and precipitation. Precipitation provides the freshwater needed by plants and other living things.

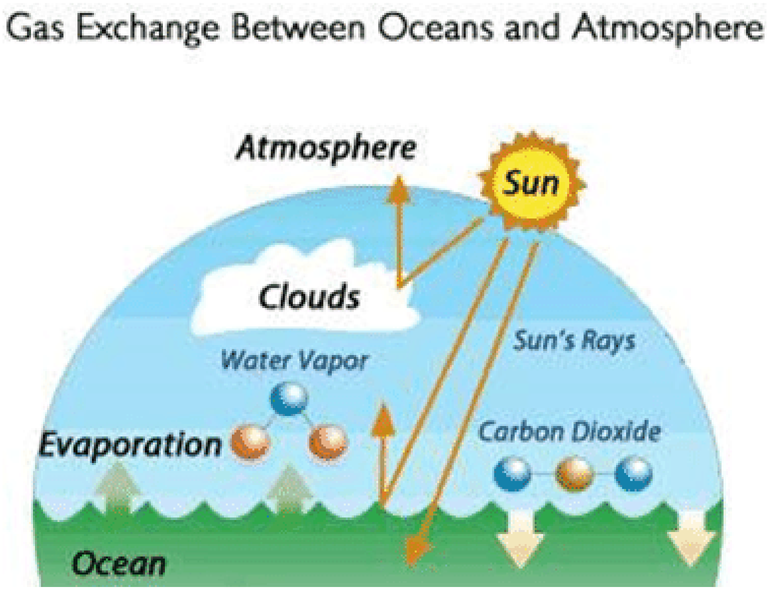


FIGURE 4.11
The oceans and atmosphere exchange gases. Why does water vapor enter the atmosphere from the water?

Ocean water also absorbs gases from the air. It absorbs oxygen and carbon dioxide. Oxygen is needed by living things in the oceans. Much of the dissolved carbon dioxide sinks to the bottom of the water. Carbon dioxide is a major cause of global warming. By absorbing carbon dioxide, the oceans help control global warming. However, by absorbing more carbon dioxide, the oceans become more acidic. The consequence of this acidification negatively impacts marine organisms.

Oceans and Climate

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

- Ocean water is much slower to warm up and cool down than land. As a result, it never gets as hot or cold as land.
- Water flows through all the world's oceans. Therefore, warm water from the equator mixes with cold water from the poles. The warm and cold water tend to "cancel each other out".

Even inland temperatures are milder because of oceans. Without oceans, there would be much bigger temperature swings all over Earth and life would not be able to exist as it does now.

Oceans and Living Things

The oceans also provide a home to many living things. In fact, a greater number of organisms live in the oceans than on land. Coral reefs have more living things than almost anywhere else on Earth.

Why Is Ocean Water Salty?

Ocean water has **salinity** (the amount of salt dissolved in a body of water) or is salty because water dissolves minerals out of rocks. This happens whenever water flows over or through rocks. Much of this water ends up in the oceans. Minerals dissolved in water form salts. Mineral salts become more concentrated in ocean water. That's because a lot of the water evaporates. When it does, it leaves the salts behind. As a result, ocean water is much saltier than other water on Earth.

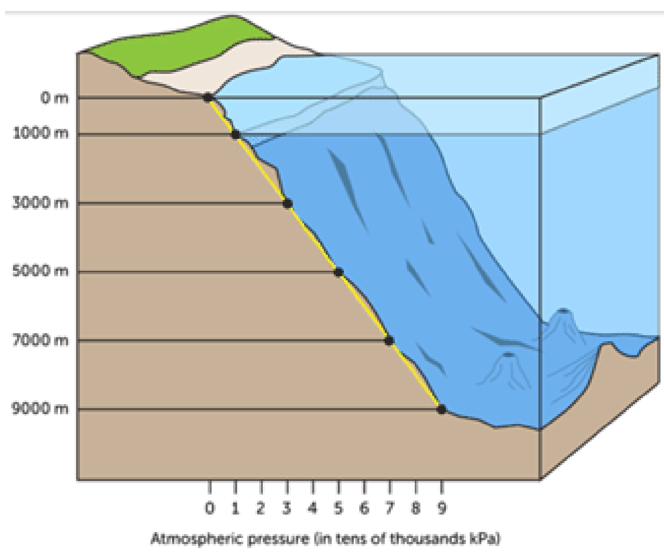
How Salty Is Ocean Water?

Did you ever go swimming in the ocean? If you did, then you probably tasted the salts in the water. By mass, salts make up about 3.5 percent of ocean water.

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

Water Pressure and Depth

Pressure is the amount of force acting on a given area. As you go deeper in the ocean, the pressure exerted by the water increases steadily. That's because there is more and more water pressing down on you from above. The figure below shows how pressure changes with depth. For each additional meter below the surface, pressure increases by 10 kPa. At 30 meters below the surface, the pressure is double the pressure at the surface. At a depth greater than 500 meters, the pressure is too great for humans to withstand without special equipment to protect them. At nearly 11,000 meters below the surface, the pressure is tremendous.



Summary

- Early Earth was too hot for liquid water to form. Eventually Earth cooled. Water vapor from volcanoes and objects in space condensed. Oceans finally formed.
- Oceans have a big influence on Earth. They exchange gases with the atmosphere. They prevent very hot and very cold temperatures. They are home to many living things.
- Dissolved mineral salts wash into the ocean. As ocean water evaporates, it leaves the salts behind. This makes the water saltier. Ocean water is about 3.5 percent salts. The main salt is sodium chloride.

- The ocean is divided into many zones. Some are based on distance from shore. Some are based on depth of water. The ocean floor is another zone.

Think like an Oceanographer

1. State why there was no liquid water on ancient Earth.
2. Describe two ways the oceans influences Earth's atmosphere.
3. Describe how ocean water properties change as you go deeper in the water.
4. Describe how water pressure in the ocean changes as depth increases.

4.6 What causes water to move in the ocean?

Objectives

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

Waves

Most ocean waves are caused by winds. A wave is the transfer of energy through matter. Ocean waves transfer energy from wind through water. The energy of a wave may travel for thousands of miles. However, the water itself moves very little. The Figure 4.12 shows how water molecules move when a wave goes by.

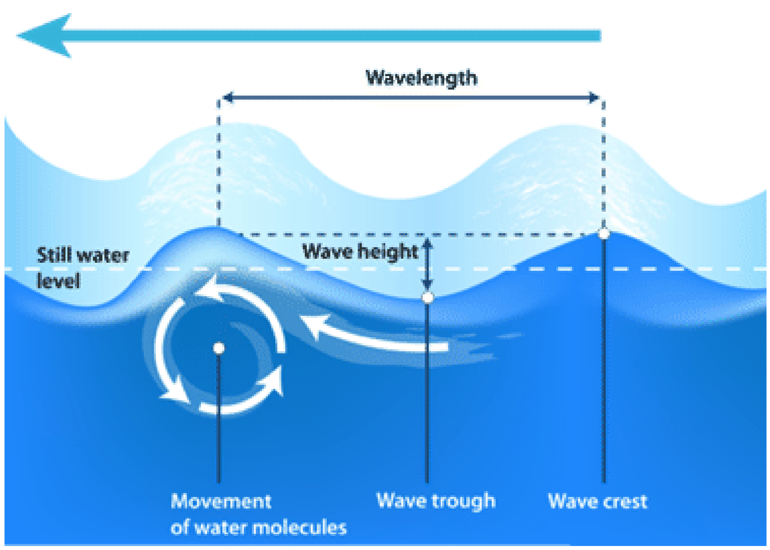


FIGURE 4.12
The energy of a wave travels through the water as a medium.

Tsunamis

Not all waves are caused by winds. Earthquakes also send waves through water. A tsunami is a wave caused by an underwater earthquake. It may be a very big wave, but can also be very small. When a tsunami reaches shallow water near shore, it could potentially flood the land. Tsunamis can cause deaths and destroy property.

Tides

Tides are changes in the rise and fall of sea level caused by the gravitational pull of the Moon and Sun. They occur all around the globe. High tides occur when the water reaches its highest level. Low tides occur when the water reaches its lowest level. Tides keep cycling from high to low and back again. The water level rises and falls twice a day. As a result, in most places there are two high tides and two low tides every 24 hours. In the figure below, you can see the difference between high and low tides. The difference between the high and low tide is the tidal range.

Why Tides Occur

The main reason is the pull of the moon's gravity on Earth and its oceans. The pull is greatest on whatever is closest to the moon.

As a result:

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

Surface Currents

Another way ocean water moves is in currents. A current is a stream of moving water that flows through the ocean. Surface currents are caused mainly by prevailing winds or winds that generally blow the same direction day after day. Major surface currents are shown in the figure below. Because of the Coriolis Effect, they flow in a clockwise direction in the Northern Hemisphere. In the Southern Hemisphere, they flow in the opposite direction.

Coriolis Effect

The Coriolis Effect describes how Earth's rotation deflects winds and surface ocean currents. Coriolis causes freely moving objects to appear to move to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

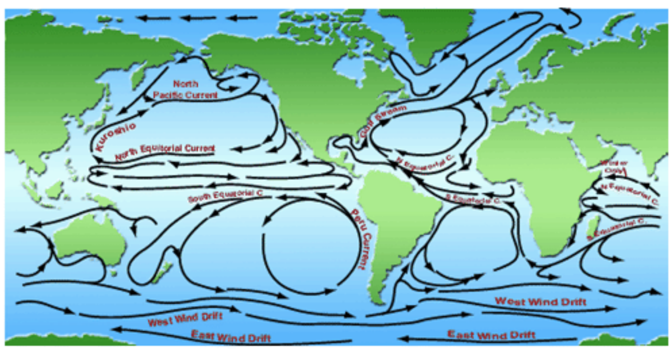
The objects themselves are actually moving straight, but the Earth is rotating beneath them, so they seem to bend or curve. That's why it is incorrect to call Coriolis a force. It is not forcing anything to happen!

To see the Coriolis Effect in action, see:

- http://teachertube.com/viewVideo.php?video_id=195342

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. So to reach his intended destination, the pilot must also veer right while flying north.

As wind or an ocean current moves, the Earth spins 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 to the right in the Northern Hemisphere and left in the Southern Hemisphere.



Surface Currents and Climate

Large ocean currents can have a big impact on the climate of nearby coasts. The Gulf Stream, for example, carries warm water from the Gulf of Mexico up the eastern coast of North America and into Europe. This keep the temperatures in these regions more moderate.

Deep Currents

Currents also flow deep below the surface of the ocean. Deep currents are large convection currents. A convection current is a vertical current that flows because of differences in density at the top and bottom. Density is defined as the amount of mass per unit of volume. More dense water takes up less space than less dense water. It has the same mass but less volume. This makes denser water heavier and so it sinks. Less dense water rises. Rising and sinking water creates a convection current.

Water becomes more dense when it is colder and when it has higher concentration of salt. In the North Atlantic Ocean, cold winds chill the water at the surface. Sea ice forms from fresh water. This leaves behind a lot of salt in the seawater. This cold, dense water sinks to the bottom of the North Atlantic. Downwelling can take place in other places where surface water becomes very dense (see Figure 4.13).

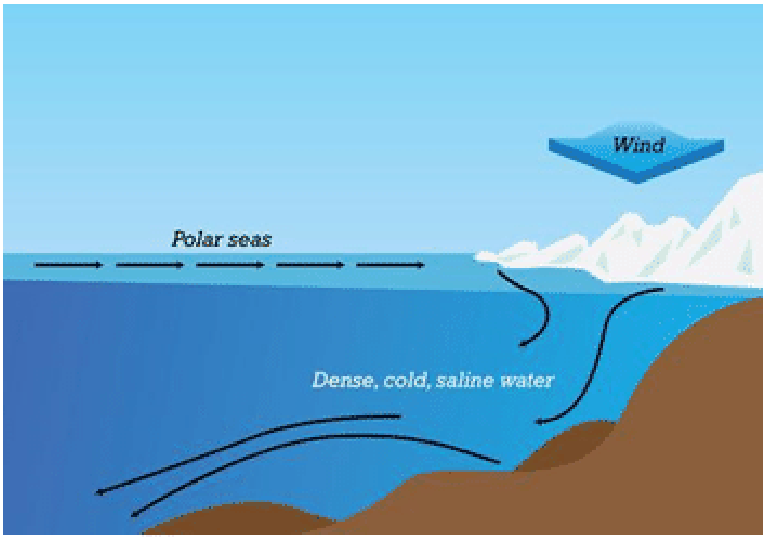


FIGURE 4.13
Deep currents flow because of differences in density of ocean water.

Upwelling

Sometimes deep ocean water rises to the surface. This is called upwelling. This Figure 4.14 shows why it happens. Strong winds blow surface water away from shore. This allows deeper water to flow to the surface and take its place.

When water comes up from the deep, it brings a lot of nutrients with it. That's because nutrients settle to the bottom over time. The nutrients brought to the surface support many living things.

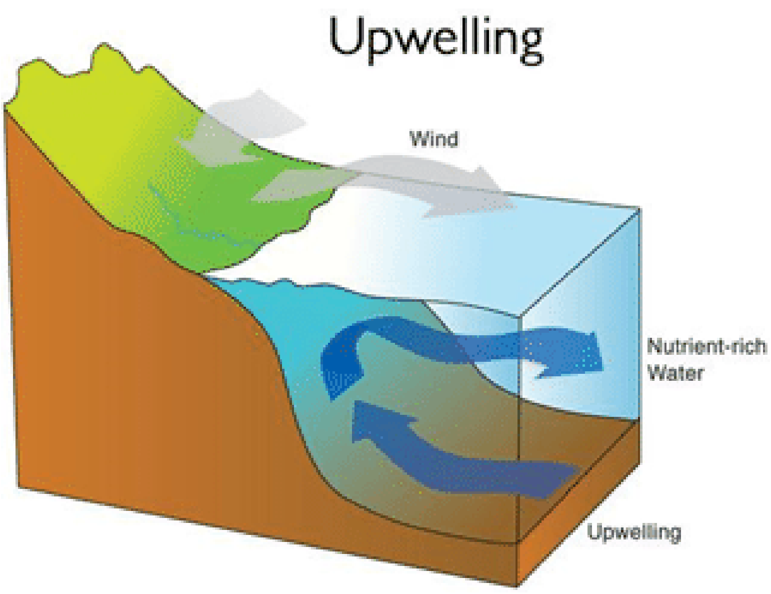


FIGURE 4.14
An upwelling occurs when deep ocean water rises to the surface.

El Niño

During an **El Niño**, (an abnormal weather pattern that starts in the Pacific Ocean) the western Pacific Ocean is warmer than usual. This causes the trade winds to change direction. The winds blow from west to east instead of east to west. The change in the trade winds also causes the jet streams to be north of their normal location. The warm water travels east across the equator, too. Warm water piles up along the western coast of South America. This prevents upwelling. Why do you think this is true?

These changes in water temperature, winds, and currents affect climates worldwide. The changes usually last a year or two. Some places get more rain than normal. Other places get less. In many locations, the weather is more severe. In Utah this can mean an increase in the amount of snow we receive.

La Niña

La Niña generally follows **El Niño**. It occurs when the Pacific Ocean is cooler than normal. The trade winds are like they are in a normal year. They blow from east to west. But in a La Niña, the winds are stronger than usual. More cool water builds up in the western Pacific. These changes can also affect climates worldwide.

Summary

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

Think like an Oceanographer

1. Identify two causes of ocean waves.
2. What is the Coriolis effect?
3. Define density. How is the density of water related to its temperature?
4. Describe upwelling. State why it occurs.
5. Explain how the moon and sun cause Earth's tides.
6. Compare and contrast surface currents and deep currents.
7. Compare and contrast El Niño and La Niña.
8. Why were there no oceans on early Earth?
9. Where did the water come from that formed the oceans?
10. What caused the salinity of the oceans?
11. Describe how ocean currents affect local climates?
12. Upwelling brings nutrients to the surface from the ocean floor. Nutrients are important resources for ocean life. However, they aren't the only resources on the ocean floor. What other resources do you think might be found on the ocean floor?

Going Further

This animation shows the effect of the Moon and Sun on the tides:

- http://www.onr.navy.mil/focus/ocean/motion/tides1.htm

CHAPTER 5 Standard V: People and Planet

Chapter Outline

5.1 HOW DO TECHNOLOGICAL ADVANCES INCREASE HUMAN KNOWLEDGE?

5.2 HOW IS A SEISMOLOGIST LIKE A MEDICAL DOCTOR?

5.3 WILL WATER CAUSE THE NEXT WAR?

5.4 ARE SOIL AND WATER RENEWABLE RESOURCES?

5.5 CAN WE USE UP ALL OF OUR SUNLIGHT?

5.6 WHAT DATA DO SCIENTISTS PROVIDE DATA THAT INFORMS THE DISCUSSION OF EARTH RESOURCE USE?

5.7 CAN WE PREVENT NATURAL HAZARDS?

5.8 WHICH HUMAN ACTIVITIES CONTRIBUTE TO THE FREQUENCY AND INTENSITY OF NATURAL HAZARDS?

5.9 HOW DO HUMANS IMPACT THE CARBON CYCLE?

5.10 HOW DO SCIENTISTS USE TECHNOLOGY TO CONTINUALLY IMPROVE ESTIMATES OF WHEN AND WHERE NATURAL HAZARDS

5.11 REFERENCES

Standard 5: Students will understand how Earth science interacts with society.

Objective 1: Characterize Earth as a changing and complex system of interacting spheres.

1. Illustrate how energy flowing and matter cycling within Earth's biosphere, geosphere, atmosphere, and hydrosphere give rise to processes that shape Earth.
2. Explain how Earth's systems are dynamic and continually react to natural and human caused changes.
3. Explain how technological advances lead to increased human knowledge (e.g., satellite imaging, deep sea ocean probes, seismic sensors, weather radar systems) and ability to predict how changes affect Earth's systems.
4. Design and conduct an experiment that investigates how Earth's biosphere, geosphere, atmosphere, or hydrosphere reacts to human-caused change.
5. Research and report on how scientists study **feedback loops** to inform the public about Earth's interacting systems.

Objective 2: Describe how humans depend on Earth's resources.

1. Investigate how Earth's resources (e.g., mineral resources, petroleum resources, alternative energy resources, water resources, soil and agricultural resources) are distributed across the state, the country, and the world.
2. Research and report on how human populations depend on Earth resources for sustenance and how changing conditions over time have affected these resources (e.g., water pollution, air pollution, increases in population).
3. Predict how resource development and use alters Earth systems (e.g., water reservoirs, alternative energy sources, wildlife preserves).

4. Describe the role of scientists in providing data that informs the discussion of Earth resource use.
5. Justify the claim that Earth science literacy can help the public make informed choices related to the extraction and use of natural resources.

Objective 3: Indicate how natural hazards pose risks to humans.

1. Identify and describe natural hazards that occur locally (e.g., wildfires, landslides, earthquakes, floods, drought) and globally (e.g., volcanoes, tsunamis, hurricanes).
2. Evaluate and give examples of human activities that can contribute to the frequency and intensity of some natural hazards (e.g., construction that may increase erosion, human causes of wildfires, climate change).
3. Document how scientists use technology to continually improve estimates of when and where natural hazards occur.
4. Investigate and report how social, economic, and environmental issues affect decisions about human-engineered structures (e.g., dams, homes, bridges, roads).

5.1 How do technological advances increase human knowledge?

The Earth is made up of 4 main spheres:

- the biosphere (all living/once living things on Earth)
- the geosphere (all the rocks on Earth)
- the atmosphere (all the air on the Earth) and
- the hydrosphere (all the water on the Earth).

These spheres interact with each other as energy and matter cycle through them. These interactions give rise to the processes that shape our Earth.

Earth's systems (all the things that make the Earth work) are dynamic and continually react to natural and human-caused changes. In the following sections you will see examples of this in both the natural world and humans' influence on Earth.

Satellites

Satellites can be used for a number of things to increase human knowledge.

Here are just a few things satellites help scientists figure out:

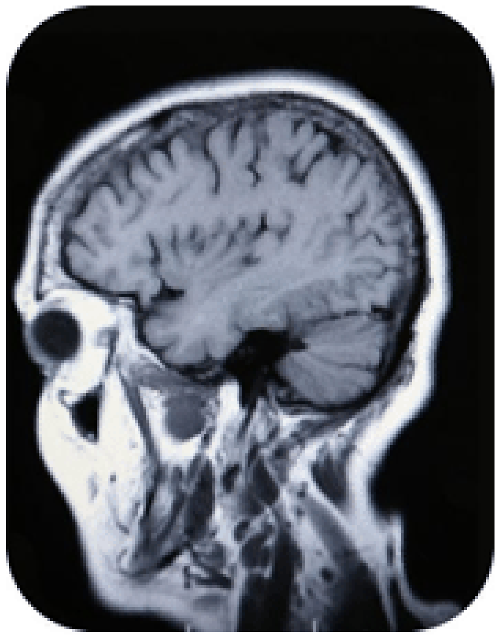
- Imaging satellites take pictures of Earth's surface for military or scientific purposes. Imaging satellites study the Moon and other planets.
- Communications satellites receive and send signals for telephone, television, or other types of communications.
- Navigational satellites are used for navigation systems, such as the Global Positioning System (GPS).
- The International Space Station, the largest artificial satellite, is designed for humans to live in space while conducting scientific research.

Collecting Weather Data can also be refined using technology.

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.

5.2 How is a seismologist like a medical doctor?

Just as a medical doctor uses an MRI, CT scan, or x-ray to see inside a patient's body, seismologists use wave energy to learn about Earth's interior. The difference is that the doctor can run the energy through the patient at any time. Scientists need to wait for an earthquake to get information about Earth's interior.



With these and other technologies we are able to gain more knowledge about the Earth around us and in turn are better able to predict when physical changes will occur here on our planet. With these predictions we can save lives and keep our future safe.

1. Design and conduct an experiment that investigates how Earth's biosphere, geosphere, atmosphere, or hydrosphere reacts to human-caused change.

Try this: think of an experiment where you can investigate how Earth's biosphere, geosphere, atmosphere, or hydrosphere reacts to human-caused change. Keep track of your data in your science journal and share what you learn with a friend.

2. Research and report on how scientists study **feedback loops** to inform the public about Earth's interacting systems.

Once you have seen patterns in what you observed in the above mentioned "try this" take another look at your conclusion. Does it give you any hint as to why you saw what you did? Is there any way to mitigate (take care of) what you observed? Is there something we as humans can do to make the results of the human-caused change not so severe? As you go through this process you are going through the process known as "**feedback loops**". You are able to see the results of some action and by that information you come up with another way to approach the issue you are investigating. Welcome to the process of science! Scientists use these **feedback loops** to inform the public about Earth's interacting systems.

Summary

- The dynamic Earth is made of 4 main spheres (geosphere, hydrosphere, atmosphere and biosphere) which continually interact with one another enabling life on Earth to be possible.
- There are many types of technology that help humans increase their knowledge in various subjects (satellites, weather collecting instruments, seismographs, etc).

5.3 Will water cause the next war?

Earth's resources are distributed

For information about Utah's own resources are distributed check out this website:

- http://naturalresources.utah.gov/about-dnr.html

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

Water Distribution

Water is unevenly distributed around the world. Large portions of the world, such as much of northern Africa, receive very little water relative to their population (see the Figure 5.1). The map shows the relationship between water supply and population by river basin.

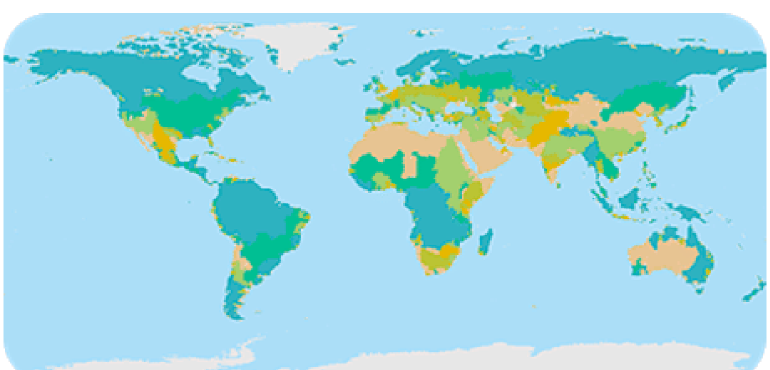


FIGURE 5.1
Blue means there is a lot of river water for each person who lives in the river basin. Salmon pink means there is very little river water for each person who lives in the river basin.

Over time, there will be less water per person within many river basins as the population grows and global temperatures increase so that some water sources are lost. In 2025, many nations, even developed nations, are projected to have less water per person than now (Figure 5.2).

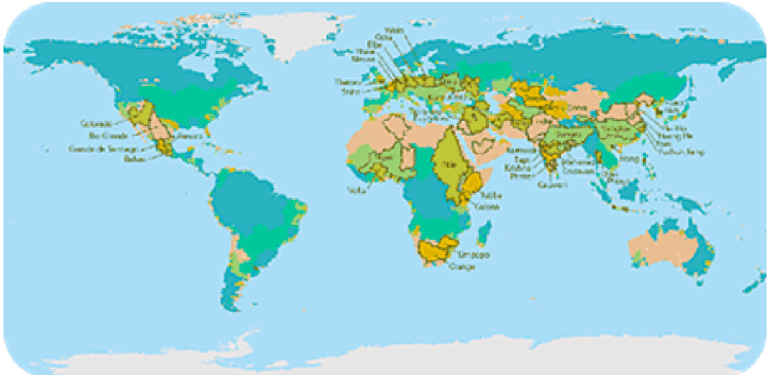


FIGURE 5.2
The same map but projected into 2025.

Droughts

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

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

FIGURE 5.3
Extended periods with lower than normal rainfall cause droughts.

Effect of Changing Climate

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

Summary

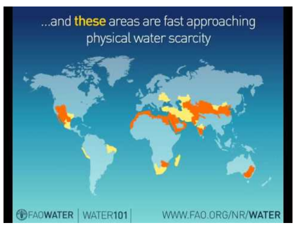
- A lot of the problem with water is that it is not evenly distributed across the planet.
- Many of the world's people live with water scarcity, and that percentage will increase as populations increase and climate changes.

Think like a Scientist

Practice

Use this resource to answer the questions that follow:

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



MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178404

1. What is water scarcity?
2. Why do people take water for granted?
3. How much freshwater is there on Earth?
4. How many people do not have access to clean water?
5. What will occur by 2025?
6. What is physical water scarcity? Where does this occur?
7. What is economic water scarcity? Where does this occur?

Review

8. How will changing climate affect the availability and distribution of water?
9. How do human activities affect the occurrence of droughts?

5.4 Are soil and water renewable resources?

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

Soil

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

Although renewable, soil takes a very long time to form—up to hundreds of millions of years. So, for human purposes, soil is a nonrenewable resource. It is also constantly depleted of nutrients through careless use, and eroded by wind and water. For example, misuse of soil caused a huge amount of it to simply blow away in the 1930s during the Dust Bowl (see the Figure 5.4). Soil must be used wisely to preserve it for the future. Conservation practices include contour plowing and terracing. Both reduce soil erosion. Soil also must be protected from toxic wastes.

FIGURE 5.4

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

Water

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

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

Too much of a Good Thing

Water pollution comes from many sources. One of the biggest sources is runoff. Runoff picks up chemicals such as fertilizer from agricultural fields, lawns, and golf courses. It carries the chemicals to bodies of water. The added nutrients from fertilizer often cause excessive growth of algae, creating algal blooms (see the Figure 5.5). The algae use up oxygen in the water so that other aquatic organisms cannot survive. This has occurred over large areas of the ocean, creating dead zones, where low oxygen levels have killed all ocean life. A very large dead zone exists in the Gulf of Mexico. Measures that can help prevent these problems include cutting down on fertilizer use. Preserving wetlands also helps because wetlands filter runoff water.

FIGURE 5.5

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

Summary

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

5.5 Can we use up all of our sunlight?

No, we have a limitless supply of sunlight. That makes it a renewable resource. Products derived from fossil fuels, like the gasoline we use to drive our cars, are not renewable resources. We will eventually run out of fossil fuels.

Renewable Resources and Alternative Energy Sources

A resource is renewable if it is remade by natural processes at the same rate that humans use it up. Sunlight and wind are renewable resources because they will not be used up (Figure 5.6). The rising and falling of ocean tides is another example of a resource in unlimited supply. A sustainable resource is a resource that is used in a way that meets the needs of the present without keeping future generations from meeting their needs. People can sustainably harvest wood, cork, and bamboo. Farmers can also grow crops sustainably by not planting the same crop in their soil year after year. Planting the same crop each year can remove nutrients from the soil. This means that wood, cork, bamboo, and crops can be sustainable resources.

FIGURE 5.6
Wind power, a renewable resource, shown here in a modern wind energy farm.

Alternative Energy Sources

A nonrenewable resource is one that cannot be replaced as easily as it is consumed. Fossil fuels are an example of nonrenewable resources. They take millions of years to form naturally, and so they cannot be replaced as fast as they are consumed. To take the place of fossil fuel use, alternative energy resources are being developed. These alternative energy sources often utilize renewable resources.

FIGURE 5.7
An example of solar power, using solar cells to convert sunlight into electricity.

The following are examples of sustainable alternative energy resources:

- Solar power, which uses solar cells to turn sunlight into electricity (Figure 5.7). The electricity can be used to power anything that uses normal coal-generated electricity.
- Wind power, which uses windmills to transform wind energy into electricity. It is used for less than 1% of the world's energy needs. But wind energy is growing fast. Every year, 30% more wind energy is used to create electricity.
- Hydropower (Figure 5.8), which uses the energy of moving water to turn turbines (similar to windmills) or water wheels, that create electricity. This form of energy produces no waste or pollution. It is a renewable resource.
- Geothermal power, which uses the natural flow of heat from the earth's core to produce steam. This steam is used to turn turbines which create electricity.
- Biomass is the mass of biological organisms. It is usually used to describe the amount of organic matter in a trophic level of an ecosystem. Biomass production involves using organic matter ("biomass") from plants to create electricity. Using corn to make ethanol fuel is an example of biomass generated energy. Biomass is generally renewable.
- Tides in the ocean can also turn a turbine to create electricity. This energy can then be stored until needed (Figure 5.8).

Summary

- Renewable resources can be replaced by natural processes as quickly as they are used.
- Alternative energy sources include wind power, solar power, hydropower, and geothermal power.

FIGURE 5.8
Dam of the tidal power plant in the Rance River, Bretagne, France

Think like a Scientist

Practice

Use the resource below to answer the questions that follow:

- http://www.youtube.com/watch?v=1cysaOnlv_E

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178993

1. How much of the energy needs of the European Union in 2005 was supplied from renewable resources?
2. What energy producing techniques can be used to produce electricity? What techniques can be used to produce heat?
3. Why is biomass based energy known as the "Sleeping Giant"? What energy could it replace that some of the other techniques (such as tidal power) would have difficulty replacing?
4. What is Biogas? How is it produced? What resources is it targeted to replace?

Review

5. What does sustainable mean?
6. What are some ways that renewable resources can be used to generate energy?

5.6 What data do scientists provide data that informs the discussion of Earth resource use?

Resource Availability

Supply

Nonrenewable resources vary in their availability; some are very abundant and others are rare. Materials, such as gravel or sand, are technically nonrenewable, but they are so abundant that running out is no issue. Some resources are truly limited in quantity: when they are gone, they are gone, and something must be found that will replace them. There are even resources, such as diamonds and rubies that are valuable in part because they are so rare.

Price

Besides abundance, a resource's value is determined by how easy it is to locate and extract. If a resource is difficult to use, it will not be used until the price for that resource becomes so great that it is worth paying for. For example, the oceans are filled with an abundant supply of water, but desalination is costly, so it is used only where water is really limited (Figure 5.9). As the cost of desalination plants comes down, more will likely be built.

FIGURE 5.9
Tampa Bay, Florida, has one of the few desalination plants in the United States.

Politics

Politics is also part of determining resource availability and cost. Nations that have a desired resource in abundance will often export that resource to other countries, while countries that need that resource must import it from one of the countries that produces it. This situation is a potential source of economic and political trouble.

Of course the greatest example of this is oil. 11 countries have nearly 80% of all of the world's oil (Figure 5.10). However, the biggest users of oil, the United States, China, and Japan, are all located outside this oil-rich region. This leads to a situation in which the availability and price of the oil is determined largely by one set of countries that have their own interests to look out for. The result has sometimes been war, which may have been attributed to all sorts of reasons, but at the bottom, the reason is oil.

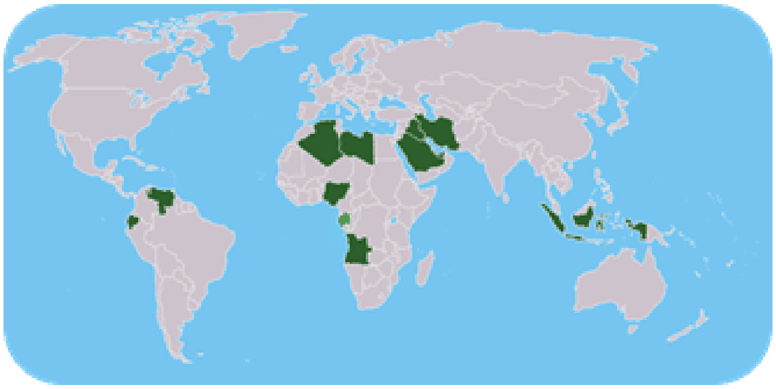


FIGURE 5.10
The nations in green are the 11 biggest producers of oil; they are Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.

Waste

The topic of overconsumption was touched on in Concept Life on Earth. Many people in developed countries, such as the United States and most of Europe, use many more natural resources than people in many other countries. We have many luxury and recreational items, and it is often cheaper for us to throw something away than to fix it or just hang on to it for a while longer. This consumerism leads to greater resource use, but it also leads to more waste. Pollution from discarded materials degrades the land, air, and water (Figure 5.11).

FIGURE 5.11
Pollution from discarded materials degrades the environment and reduces the availability of natural resources.

Natural resource use is generally lower in developing countries because people cannot afford many products. Some of these nations export natural resources to the developed world since their deposits may be richer and the cost of labor lower. Environmental regulations are often more lax, further lowering the cost of resource extraction.

Summary

- The availability of a resource depends on how much of it there is and how hard it is to extract, refine, and transport to where it is needed.
- Politics plays an important role in resource availability since an unfavorable political situation can make a

resource unavailable to a nation.
- Increased resource use generally means more waste; electronic waste from developed nations is a growing problem in the developing world.

Review

1. Why does electronic waste that is generated in developed nations get dumped in developing nations?
2. Why is politics important in the availability of resources?
3. Why do some nations consume more goods and generate more waste than others?

Earth science literacy helps the public make informed choices

Knowledge is power. We have heard that phrase over and over as we are on this journey of gaining knowledge as we attend school. Knowledge about the Earth is key when we, as humans, choose how to use natural resources here on Earth. We are able to gain knowledge about where and when to use natural resources as we pay attention to Earth science literacy. These sources give us the knowledge we need to make informed choices about where to drill for oil, where the best wind plant locations would be, how to clean and conserve water, etc.

5.7 Can we Prevent Natural Hazards?

Natural hazards

Check out this PDF that contains a lot of great info specifically for Utah:

- http://geology.utah.gov/online/pdf/pi-48.pdf

FIGURE 5.12
House damaged by the April 6, 2004 debris flow in Farmington, Utah.

Landslides: Events & Information

Landslides are common natural hazards in Utah. They often strike without warning and can be destructive and costly. Common types of landslides in Utah are debris flows, slides, and rock falls. Many landslides are associated with rising ground-water levels due to rainfall, snowmelt, and landscape irrigation.

Therefore, landslides in Utah typically move during the months of March, April, and May, although debris flows associated with intense thunderstorm rainfall are common in July.

Source: http://geology.utah.gov/utahgeo/hazards/landslide/index.htm

Prevent Wildfires: What can you do?

Building Safe Campfires

- Clear campfire site down to bare soil.
- Circle pit with rocks.
- Build campfires away from overhanging branches, steep slopes, dry grass, and leaves.
- Keep a bucket of water and a shovel nearby.

- Never leave a campfire unattended.
- When putting out a campfire, drown the fire, stir it, and drown it again.
- Always have adult supervision.
- Be careful with gas lanterns, barbeque grills, gas stoves, and anything that can be a source of ignition for a wildfire.

Off-Road Safety

- Never park on or drive through dry grass.
- Grease trailer wheels, check tires, and ensure safety chains are not touching the ground.
- Internal combustion engines on off-road vehicles require a spark arrestor.
- Check and clean the spark arrestor.
- Carry a shovel and fire extinguisher in your vehicle or OHV/ATV.
- Spark from chainsaws, welding torches, and other equipment can cause wildfires.
- Please check local restrictions before using such equipment.

Source: http://www.utahfireinfo.gov/prevention/fire_safety.html

What causes the greatest damage in an earthquake?

This photo shows the Mission District of San Francisco burning after the 1906 earthquake. The greatest damage in earthquakes is usually not from the ground shaking. The greatest damage is caused by the effects of that shaking. In this earthquake, the shaking broke the gas mains and the water pipes. When the gas caught fire, there was no way to put it out. Fire causes the greatest damage in many earthquakes.

Earthquake!

An earthquake is sudden ground movement. This movement is caused by the sudden release of the energy stored in rocks. An earthquake happens when so much stress builds up in the rocks that the rocks break. An earthquake's energy is transmitted by seismic waves.

How can you prepare for an earthquake?

If you live in earthquake country the actions you take before, during, and after a quake could make the difference in your comfort for several days or even your survival.

Protecting Yourself in an Earthquake

There are many things you can do to protect yourself before, during, and after an earthquake.

Before the Earthquake

- Have an engineer evaluate the house for structural integrity. Make sure the separate pieces — floor, walls, roof, and foundation — are all well-attached to each other.
- Bracket or brace brick chimneys to the roof.
- Be sure that heavy objects are not stored in high places.
- Secure water heaters all around and at the top and bottom.
- Bolt heavy furniture onto walls with bolts, screws, or strap hinges.
- Replace halogen and incandescent light bulbs with fluorescent bulbs to lessen fire risk.
- Check to see that gas lines are made of flexible material so that they do not rupture. Any equipment that uses gas should be well secured.
- Everyone in the household should know how to shut off the gas line.
- Prepare an earthquake kit with three days supply of water and food, a radio, and batteries.
- Place flashlights all over the house and in the glove box of your car.
- Keep several fire extinguishers around the house to fight small fires.
- Be sure to have a first aid kit. Everyone should know basic first aid and CPR.
- Plan in advance how you will evacuate and where you will go. Do not plan on driving, as roadways will likely be damaged.

During the Earthquake

- If you are in a building, get beneath a sturdy table, cover your head, and hold on.
- Stay away from windows, mirrors, and large furniture.
- If the building is structurally unsound, get outside as fast as possible.
- If you are outside, run to an open area away from buildings and power lines that may fall.
- If you are in a car, stay in the car and stay away from structures that might collapse, such as overpasses, bridges, or buildings.

After the Earthquake

- Be aware that aftershocks are likely.
- Avoid dangerous areas like hillsides that may experience a landslide.
- Turn off water and power to your home.
- Use your phone only if there is an emergency. Many people will be trying to get through to emergency services.
- Be prepared to wait for help or instructions. Assist others as necessary.

Floods

Why are there so many floods?

Floods are a natural part of the water cycle, but that doesn't make them any less terrifying. Put most simply, a flood is an overflow of water in one place. How can you prepare for a flood? What do you do if you're caught in one?

Causes of Floods

Floods usually occur when precipitation falls more quickly than water can be absorbed into the ground or carried away by rivers or streams. Waters may build up gradually over a period of weeks, when a long period of rainfall or snowmelt fills the ground with water and raises stream levels.

Extremely heavy rains across the Midwestern U.S. in April 2011 led to flooding of the rivers in the Mississippi River basin in May 2011 (Figures 5.13).

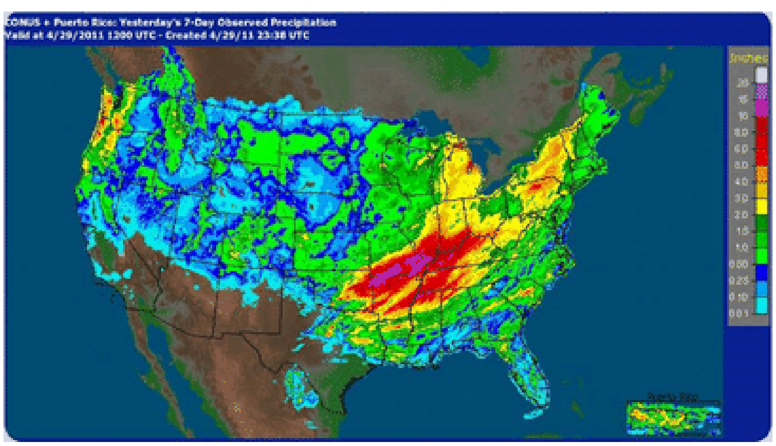


FIGURE 5.13
This map shows the accumulated rainfall across the U.S. in the days from April 22 to April 29, 2011.

Record flow in the Ohio and Mississippi Rivers has to go somewhere. Normal spring river levels are shown in 2010. The flooded region in the image from May 3, 2011 is the New Madrid Floodway, where overflow water is meant to go. 2011 is the first time since 1927 that this floodway was used.

Flash Floods

Flash floods are sudden and unexpected, taking place when very intense rains fall over a very brief period (Figure 5.14). A flash flood may do its damage miles from where the rain actually falls if the water travels far down a dry streambed.

FIGURE 5.14
A 2004 flash flood in England devastated two villages when 3-1/2 inches of rain fell in 60 minutes.

Buffers to Flooding

Heavily vegetated lands are less likely to experience flooding. Plants slow down water as it runs over the land, giving it time to enter the ground. Even if the ground is too wet to absorb more water, plants still slow the water's passage and increase the time between rainfall and the water's arrival in a stream; this could keep all the water falling over a region from hitting the stream at once. Wetlands act as a buffer between land and high water levels and play a key role in minimizing the impacts of floods. Flooding is often more severe in areas that have been recently logged.

Flood Protection

People try to protect areas that might flood with dams, and dams are usually very effective. But high water levels sometimes cause a dam to break and then flooding can be catastrophic. People may also line a river bank with levees, high walls that keep the stream within its banks during floods. A levee in one location may just force the high water up or downstream and cause flooding there. The New Madrid Overflow in the image above was created with the recognition that the Mississippi River sometimes simply cannot be contained by levees and must be allowed to flood.

Effects of Floods

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

Not all the consequences of flooding are negative. Rivers deposit new nutrient-rich sediments when they flood, so floodplains have traditionally been good for farming. Flooding as a source of nutrients was important to Egyptians along the Nile River until the Aswan Dam was built in the 1960s. Although the dam protects crops and settlements from the annual floods, farmers must now use fertilizers to feed their cops.

Floods are also responsible for moving large amounts of sediments about within streams. These sediments provide habitats for animals, and the periodic movement of sediment is crucial to the lives of several types of organisms. Plants and fish along the Colorado River, for example, depend on seasonal flooding to rearrange sand bars.

Summary

- Before an earthquake, be sure that your home is secure and that you have supplies to last a few days.
- During an earthquake, get to a safe place.
- After an earthquake, avoid dangerous situations, wait for instructions, and assist as necessary.
- When the amount of water in a drainage exceeds the capacity of the drainage, there is a flood.
- Floods are made worse when vegetation is cleared, when the land is already soaked, or when hillsides have been logged.
- People build dams and levees to protect from flooding.
- Floods are a source of nutrients on a floodplain.

Think like a Geologist

Practice

Use this resource to answer the questions that follow.

- http://video.nationalgeographic.com/video/environment/environment-natural-disasters/landslides-and-more/floods/

1. Where are floods more likely to occur?
2. Why have farmers relied on floods?
3. What causes floods?

4. At what depth can a flood move a car? Why is this dangerous?
5. What cause the Mississippi Flood of 1993?
6. Why did Hurricane Katrina cause so much damage to New Orleans?
7. What could cause massive flooding today?

Review

8. How does a flash flood differ from another type of flood?
9. What was the role of flooding on the Nile River and what was the consequence of damming the river?
10. Why do floods still occur, even though people build dams and levees?

5.8 Which human activities contribute to the frequency and intensity of natural hazards?

Mining and the Environment

Although mining provides people with many needed resources, the environmental costs can be high. Surface mining clears the landscape of trees and soil, and nearby streams and lakes are inundated with sediment. Pollutants from the mined rock, such as heavy metals, enter the sediment and water system. Acids flow from some mine sites, changing the composition of nearby waterways.

U.S. law has changed in recent decades so that a mine region must be restored to its natural state, a process called reclamation. This is not true of older mines. Pits may be refilled or reshaped and vegetation planted. Pits may be allowed to fill with water and become lakes or may be turned into landfills. Underground mines may be sealed off or left open as homes for bats.

- Surface mining clears the land, completely destroying the ecosystems that were found there.
- Mining releases pollutants, which affect the immediate area and may travel downstream or downwind to cause problems elsewhere.
- Reclamation occurs when people attempt to return the mined land to its original state.

Farming

Agriculture is probably the most significant activity that accelerates soil erosion because of the amount of land that is farmed and how much farming practices disturb the ground (Figure 5.15). Farmers remove native vegetation and then plow the land to plant new seeds. Because most crops grow only in spring and summer, the land lies fallow during the winter. Of course, winter is also the stormy season in many locations, so wind and rain are available to wash soil away. Tractor tires make deep grooves, which are natural pathways for water. Fine soil is blown away by wind.

The soil that is most likely to erode is the nutrient-rich topsoil, which degrades the farmland.

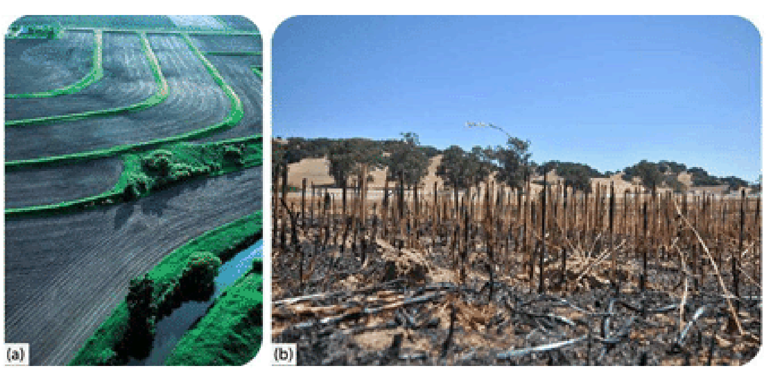


FIGURE 5.15
(a) The bare areas of farmland are especially vulnerable to erosion. (b) Slash-and-burn agriculture leaves land open for soil erosion and is one of the leading causes of soil erosion in the world.

Grazing

Grazing animals (Figure below) wander over large areas of pasture or natural grasslands eating grasses and shrubs. Grazers expose soil by removing the plant cover for an area. They also churn up the ground with their hooves. If too many animals graze the same land area, the animals' hooves pull plants out by their roots. A land is overgrazed if too many animals are living there.

Logging and Mining

Logging removes trees that protect the ground from soil erosion. The tree roots hold the soil together and the tree canopy protects the soil from hard falling rain. Logging results in the loss of leaf litter, or dead leaves, bark, and branches on the forest floor. Leaf litter plays an important role in protecting forest soils from erosion (Figure below).

Much of the world's original forests have been logged. Many of the tropical forests that remain are currently the site of logging because North America and Europe have already harvested many of their trees (Figure 5.16). Soils eroded from logged forests clog rivers and lakes, fill estuaries, and bury coral reefs.

Deforested swatches in Brazil show up as gray amid the bright red tropical rainforest. Surface mining disturbs the land (Figure 5.17) and leaves the soil vulnerable to erosion.

Construction

Constructing buildings and roads churns up the ground and exposes soil to erosion. In some locations, native landscapes, such as forest and grassland, are cleared, exposing the surface to erosion (in some locations the land that will be built on is farmland). Near construction sites, dirt, picked up by the wind, is often in the air. Completed construction can also contribute to erosion (Figure 5.18).

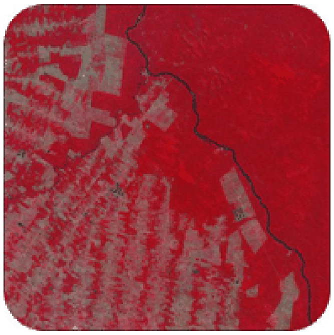


FIGURE 5.16
Logging exposes large areas of land to erosion.

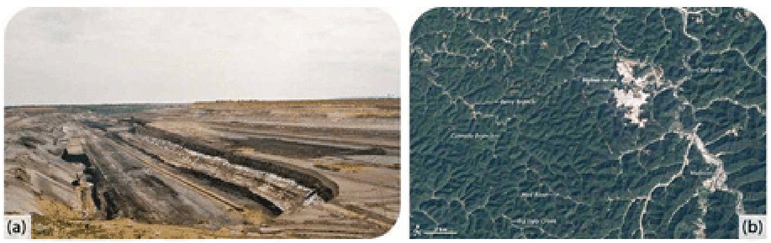


FIGURE 5.17
(a) Disturbed land at a coal mine pit in Germany. (b) This coal mine in West Virginia covers more than 10,000 acres (15.6 square miles). Some of the exposed ground is being reclaimed by planting trees.

FIGURE 5.18
Urban areas and parking lots result in less water entering the ground. Water runs off the parking lot onto nearby lands and speeds up erosion in those areas.

Recreational Activities

Recreational activities may accelerate soil erosion. Off-road vehicles disturb the landscape and the area eventually develops bare spots where no plants can grow. In some delicate habitats, even hikers' boots can disturb the ground, so it's important to stay on the trail (Figure 5.19).

Soil erosion is as natural as any other type of erosion, but human activities have greatly accelerated soil erosion. In some locations soil erosion may occur about 10 times faster than its natural rate. Since Europeans settled in North

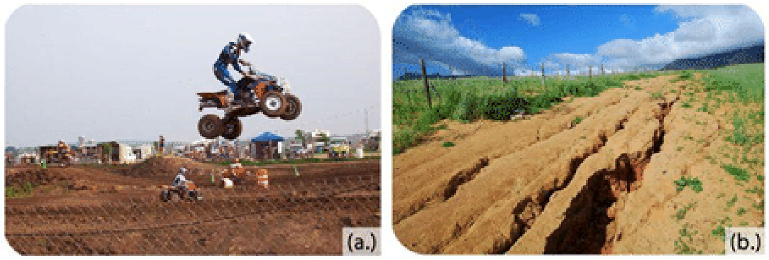


FIGURE 5.19
(a) ATV'S churn up the soil, accelerating erosion. (b) Hiking trails may become eroded.

America, about one-third of the topsoil in the area that is now the United States has eroded away.

Summary

- Although soil erosion is a natural process, human activities have greatly accelerated it.
- The agents of soil erosion are the same as of other types of erosion: water, ice, wind, and gravity.
- Soil erosion is more likely where the ground has been disturbed by agriculture, grazing animals, logging, mining, construction, and recreational activities.

Think like a Geologist

Practice

Use this resource to answer the questions that follow.

- http://www.scalloway.org.uk/phye6.htm

1. What is soil erosion?
2. Where is soil erosion common?
3. How can soil erosion be reduced?
4. What are good farming techniques?
5. What are some natural causes for soil erosion?

Review

6. What is soil erosion? Why did soil erosion accelerate so greatly during the Dust Bowl?
7. How do human activities accelerate soil erosion? Since soil erosion is a natural process, is this bad?
8. What is the consequence of the acceleration of soil erosion?

5.9 How do humans impact the carbon cycle?

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO_2 when they form, but they are a source for CO_2 when they are burned.

The equation for combustion of propane, which is a simple hydrocarbon looks like this:

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\,O_2} \rightarrow \underset{\text{carbon dioxide}}{3\,CO_2} + \underset{\text{water}}{4\,H_2O}$$

The equation shows that when propane burns, it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas, the amount of CO_2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO_2, the result is the increase in atmospheric CO_2 seen in the graph above.

The second largest source of atmospheric CO_2 is deforestation (Figure 5.20). Trees naturally absorb CO_2 while they are alive. Trees that are cut down lose their ability to absorb CO_2. If the tree is burned or decomposes, it becomes a source of CO_2. A forest can go from being a carbon sink to being a carbon source.

Why the Carbon Cycle is Important?

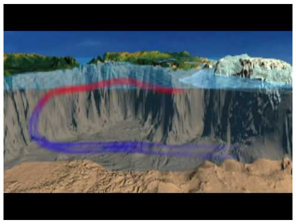
Why is such a small amount of carbon dioxide in the atmosphere even important? Carbon dioxide is a greenhouse gas. Greenhouse gases trap heat energy that would otherwise radiate out into space, which warms Earth.

FIGURE 5.20
This forest in Mexico has been cut down and burned to clear forested land for agriculture.

Atmospheric Processes

This video "Keeping up with Carbon" from NASA, focuses on the oceans. Topics include what will happen as temperature warms and the oceans can hold less carbon, and ocean acidification:

- http://www.youtube.com/watch?v=HrIr3xDhQ0E



MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178527

A very thorough but basic summary of the carbon cycle, including the effect of carbon dioxide in the atmosphere, is found in this video:

- http://www.youtube.com/watch?v=U3SZKJVKRxQ

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/164768

Summary

- Carbon is essential for life as part of proteins, carbohydrates, and fats.
- The amount of carbon dioxide in the atmosphere is extremely low, but it is extremely important since carbon dioxide is a greenhouse gas, which helps to keep Earth's climate moderate.
- The amount of carbon dioxide in the atmosphere is rising, a fact that has been documented on Mauna Loa volcano since 1958.

5.10 How do scientists use technology to continually improve estimates of when and where natural hazards

What if you could predict an earthquake?

What would make a good prediction? Knowing where, when, and the magnitude of the quake would make it possible for people to evacuate.

A Good Prediction

Scientists are a long way from being able to predict earthquakes. A good prediction must be detailed and accurate. Where will the earthquake occur? When will it occur? What will be the magnitude of the quake? With a good prediction authorities could get people to evacuate. An unnecessary evacuation is expensive and causes people not to believe authorities the next time an evacuation is ordered.

Where?

Where an earthquake will occur is the easiest feature to predict. How would you predict this? Scientists know that earthquakes take place at plate boundaries and tend to happen where they've occurred before (Figure above). Fault segments behave consistently. A segment with frequent small earthquakes or one with infrequent huge earthquakes will likely do the same thing in the future.

When?

When an earthquake will occur is much more difficult to predict. Since stress on a fault builds up at the same rate over time, earthquakes should occur at regular intervals (Figure 5.21). But so far scientists cannot predict when quakes will occur even to within a few years.

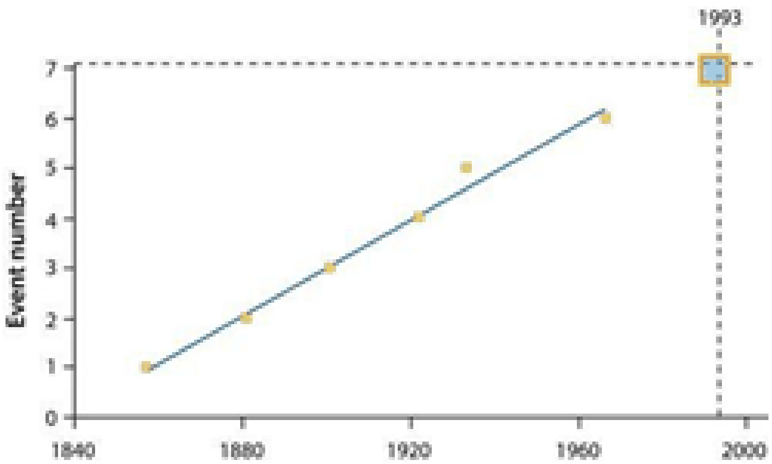


FIGURE 5.21

Around Parkfield, California, an earthquake of magnitude 6.0 or higher occurs about every 22 years. So seismologists predicted that one would strike in 1993, but that quake came in 2004 - 11 years late.

Earthquake Signs

Signs sometimes come before a large earthquake. Small quakes, called foreshocks, sometimes occur a few seconds to a few weeks before a major quake. However, many earthquakes do not have foreshocks, and small earthquakes are not necessarily followed by a large earthquake. Ground tilting, caused by the buildup of stress in the rocks, may precede a large earthquake, but not always. Water levels in wells fluctuate as water moves into or out of fractures before an earthquake. This is also an uncertain predictor of large earthquakes. The relative arrival times of P-waves and S-waves also decreases just before an earthquake occurs.

Folklore tells of animals behaving erratically just before an earthquake. Mostly, these anecdotes are told after the earthquake. If indeed animals sense danger from earthquakes or tsunami, scientists do not know what it is they could be sensing, but they would like to find out.

Earthquake prediction is very difficult and not very successful, but scientists are looking for a variety of clues in a variety of locations and to try to advance the field.

See more at:

- http://science.kqed.org/quest/video/earthquakes-breaking-new-ground/

Summary

- A good prediction must indicate when and where an earthquake will take place with detail and accuracy.
- Fault segments tend to behave the same way over time.
- Signs that an earthquakes may occur include foreshocks, ground tilting, water levels in wells and the relative arrival times of P and S waves.

Think like a Seismologist

1. What magnitude was the 2010 Haiti earthquake?
2. How did scientists recognize that the fault was active?
3. What evidence led to the prediction?
4. What can not be predicted?
5. What type of fault is at the Hayward Fault?
6. Why are earthquakes so hard to predict?
7. Why is it easier to predict where a quake will occur than when?

8. Describe some of the signs that scientists use to predict earthquakes.
9. It's now nine years after the map of earthquake probabilities in the San Francisco Bay area was made. What do you think the fact that no large earthquakes have struck those faults yet does to the probability that one will strike by 2032?

Social, Economic, and Environmental Issues Affect Decisions about Human-Engineered Structures

Use the Internet to investigate and report on a local human engineered structure that is being built (dams, homes, bridges, roads). What kind of social, economic and environmental issues affect the decisions about where these structures are built? Share what you find with a friend.

5.11 References

1. . http://geology.utah.gov/hazards/landslides-rockfalls/ .

CONCEPT 6 Glossary - Earth Science

Chapter 1

- **Astronomical Units:** One astronomical unit is defined as the distance from Earth to the Sun.
- **Big Bang Theory:** the theory that the universe originated sometime between 10 billion and 20 billion years ago from the cataclysmic explosion of a small volume of matter at extremely high density and temperature.
- **Black hole:** a region of space having a gravitational field so intense that no matter or radiation can escape.
- **Doppler Effect:** an increase (or decrease) in the frequency of sound, light, or other waves as the source and observer move toward (or away from) each other. The effect causes the sudden change in pitch noticeable in a passing siren, as well as the redshift seen by astronomers.
- **Dwarf planet:** a celestial body resembling a small planet but lacking certain technical criteria that are required for it to be classed as such.
- **Inner Planet:** closest to the Sun: Mercury, Venus, Earth, and Mars.
- **Main sequence star:** hydrogen nuclei fuse to form helium nuclei.
- **Nebula:** a big cloud of gas and dust.
- **Neutron Star:** celestial object of very small radius (typically 18 miles/30 km) and very high density, composed predominantly of closely packed neutrons.
- **Nuclear Fusion:** a nuclear reaction in which atomic nuclei of low atomic number fuse to form a heavier nucleus with the release of energy.
- **Planet:** a celestial body moving in an elliptical orbit around a star.
- **Red Giant:** a very large star of high luminosity and low surface temperature.
- **Red shift:** the shift of spectral lines toward longer wavelengths (the red end of the spectrum) in radiation from distant galaxies and celestial objects.
- **Solar System:** the collection of eight planets and their moons in orbit around the sun, together with smaller bodies in the form of asteroids, meteoroids, and comets.
- **Star:** A self-luminous celestial body consisting of a mass of gas held together by its own gravity.
- **Supernova:** a star that suddenly increases greatly in brightness because of a catastrophic explosion that ejects most of its mass.
- **Universe:** all existing matter and space considered as a whole; the cosmos.

Try it at Home

Here are some great computer interactives to go along with certain sections of this book:

Standard 1 Objective 2:

This is a tediously accurate map of our solar system. If the moon was the size of a pixel and scaled to that model, you can see the relative size and distances of the planets. Click on the speed of light icon and see how long it takes light from the sun to reach all the planets.

- http://tinyurl.com/l3n3zo

Chapter 2

- **Asthenosphere:** a layer of the Earth just below the lithosphere that has the characteristic of plasticity
- **Composition:** what something is made of

- **Continental drift hypothesis:** the hypothesis that Earth's continents were once all connected together in one mass, and then drifted apart
- **Convection:** the transfer of energy by a warmer, less dense substance rising and a cooler, less dense substance sinking
- **Convergent Boundary:** a place where two or more tectonic plates move towards each other and collide. Also known as a destructive plate boundary
- **Divergent Boundary:** a place where two tectonic plates move away from each other. Also known as a constructive plate boundary
- **Earthquakes:** a shaking or trembling of the earth that is either volcanic or tectonic in origin
- **Geologic record:** the layers of rock deposits laid down by volcanoes or weathering that contain a record of Earth's past history
- **Heat of formation:** the increase in Earth's temperature that resulted from the collisions of smaller particles as the Earth formed.
- **Inner core:** the innermost layer of Earth, it is metallic and solid
- **Lithosphere:** the rigid outer layer of Earth
- **Lithospheric plate:** earth's rigid outer crust that is broken into tectonic plates
- **Magnetic striping:** permanent magnetism in rocks resulting from the orientation of the Earth's magnetic field at the time the rock formed
- **Mantle plumes:** also called hot spots, are a place in the upper mantle of the Earth where hot magma from the lower mantle upwells to melt through the crust
- **Mesosphere:** a layer of Earth's mantle below the asthenosphere but above the outer core,
- **Mid-ocean ridges:** an underwater mountain system formed by plate tectonic movement, the cite of divergent plate boundaries
- **Oceanic trenches:** long narrow depressions on the seafloor, they are the deepest parts of the oceans and occur at convergent plate boundaries
- **Outer core:** a liquid metallic layer of Earth below the mesosphere, but above the inner core
- **Physical Properties:** any property that describes the physical characteristics of a substance
- **Plate Tectonics:** the scientific theory that describes the large scale motions of Earth's crust
- **Radioactive decay:** the process in which the nucleus of an atom becomes unstable and loses particles or begin break apart, forming a new element and releasing energy
- **Sea floor spreading:** a process that occurs at mid-ocean ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge
- **Tectonic plates:** sections of Earth's lithosphere that move around the surface of the Earth
- **Transform boundaries:** a place where two tectonic plates move horizontally in either direction. Also known as a conservative plate boundary.
- **Volcanoes:** an opening, or rupture, in the surface or crust of the Earth which allows hot lava, volcanic ash and gases to escape from the magma chamber below the surface.

Try it at Home

Here are some great computer interactives to go along with certain sections of this book:

Standard 2 Objective 2:

The IRIS Earthquake Browser is an interactive map that provides current and historical earthquake data. Students can use the data map to find evidence of plate boundaries, types of plate interactions, and see a subducting plate with depth. It includes a 3D modeling feature is great for viewing a subducting plate.

- http://tinyurl.com/m3ybe4v

Chapter 3

Try it at Home

Here are some great computer interactives to go along with certain sections of this book:

Standard 3 Objective 2:

The Wundermap is an interactive weather map from weather underground that shows current weather conditions as well as historical weather data. It also includes maps for other features such as flood and fault zones.

- http://tinyurl.com/56juzx

Standard 3 Objective 3:

NOAA provides access to over a hundred years of real climate data from thousands of stations. You can use this data to track and graph changes in multiple variables over time. Data is free to access but is only available upon request. They send the data via email and it can take up to 2 days to process the request. Plan accordingly.

- http://tinyurl.com/ES3-3cd

Standard 3 Objective 3:

This interactive from the Pacific Islands Climate Education Partnership and WGBH shows how carbon dioxide levels influence climate change. Learn about carbon cycle reservoirs, how carbon dioxide flows into and out of the atmosphere have changed in the past 300 years due to human activity, and how this correlates to increased average global temperature.

- http://tinyurl.com/ES3-3c

Chapter 4

- **Abiotic:** non living things
- **Adhesion:** the ability of water molecules to be attracted to other substances
- **Aquifers:** porous rock and sediment with water trapped in between
- **Biotic:** all living or once living things
- **Cohesion:** water molecules sticking to other water molecules
- **Comet:** an icy small solar system body
- **Condensation:** the process of changing phase from a gas to a liquid
- **Ecosystem:** a community of living and non-living things that work together
- **El Niño:** an abnormal weather pattern that starts in the Pacific Ocean
- **Evaporation:** the process of going from a liquid to a gas
- **Groundwater:** water that infiltrates the ground
- **Outgassing:** release of gas that was trapped in some material, i.e. gasses released during a volcanic eruption
- **Precipitation:** water that falls to the ground as rain, hail, snow, etc
- **Reservoir:** a place where a substance is stored for a certain period of time
- **Salinity:** the amount of salt dissolved in a body of water
- **The Hydrologic (Water) Cycle:** the cycle of processes by which water circulates between Earth's reservoirs
- **Transpiration:** Plants take up water from the soil and release large amounts of water vapor into the air through their leaves

- **Water vapor:** water in a gas state that is diffused in the atmosphere

Try it at Home

Here are some great computer interactives to go along with certain sections of this book:

Standard 4 Objective 1:

Earth is covered by water, hence its nickname: the Blue Planet. This interactive resource adapted from Oxford University Press reveals just how much water is saline – the kind that fills the oceans – and how much is fresh water. As you explore these statistics further, you may be surprised to learn just how little water is available to share among Earth's six billion human inhabitants, not to mention all the other organisms that rely on fresh water for their survival.

- http://tinyurl.com/ES4-1a

Standard 4 Objective 1:

Water continuously travels between Earth's surface and the atmosphere via the hydrologic cycle. Through five main processes — condensation, precipitation, infiltration, runoff, and evapotranspiration — water is perpetually recycled. In this interactive resource adapted from NASA, explore the steps of the water cycle.

- http://tinyurl.com/plavkbx

Standard 4 Objective 1:

Learn all about the water filtration process then make your own water filtration system.

- http://tinyurl.com/p6525wb

Standard 4 Objective 2:

The RiverWeb Simulator simulates water quality in both natural environments and those that have been impacted by human. The sim teaches necessary vocab and background to the students. It allows the students to interact and manipulate data. They can compare multiple variables. The sim will graph these variables against each other in a scatter plot graph to check for correlations. It also simulates improvements that can be made at each location and allows you to compare the water quality indicators before and after the improvements have been implemented.

**Sign up is not required. Username and password are "generic".

- http://tinyurl.com/ES4-2c

Chapter 5

- **Atmosphere:** is the layer of gases that may surround a planet of sufficient mass
- **Biomass:** Total mass of organisms at a trophic level.
- **Biomass production:** Use of organic matter (biomass) from plants to create electricity.
- **Biosphere:** the global ecological system integrating all living beings and their relationships.

- **Feedback Loops:** is a process in which information about the past or the present influences the same phenomenon in the present or future. As part of a chain of cause-and-effect that forms a circuit or loop, the event is said to "feed back" into itself.
- **Geosphere:** the solid part of earth including the surface
- **Geothermal power:** Electricity derived from the natural flow of heat from the earth's core.
- **Hydropower:** Electricity derived from the energy of moving water.
- **Hydrosphere:** the combined mass of water found on, under, and over the surface of a planet
- **Natural Hazards:** a threat of a naturally occurring event that will have a negative effect on people or the environment
- **Nonrenewable resource:** Natural resource that is used up faster than it can be made by nature.
- **Renewable resource:** Natural resource that can be replaced as quickly as it is used.
- **Resources:** A useful material that is found in nature sustainable resource: Resources that is used in a way that meets the needs of the present without keeping future generations from meeting their needs.
- **Solar power:** Electricity derived from the sun.
- **Wind power:** Electricity derived from the wind.

Try it at Home

Here are some great computer interactives to go along with certain sections of this book:

Standard 5:

In the game of PowerUp, a free, online, multiplayer game that allows students to experience the excitement and the diversity of modern engineering!

Playing the game, students work together in teams to investigate the rich, 3D game environment and learn about the environmental disasters that threaten the game world and its inhabitants. Players meet Expert Engineer characters and experience the great diversity of the field. Conversations with these experts and engaging interactive activities allow players to explore ways engineers design and build systems to harness renewable energy sources as alternatives to burning fossil fuels. Players take on the role of Engineers, working together designing and building energy solutions to save the world.

- http://powerupthegame.com/home.html

*Could not access online using ASD online server-blocked

Standard 5 Objective 1:

This interactive gives a brief introduction to the spheres of the Earth and how they interact with one another. It also includes a section about human influence on the spheres.

- http://tinyurl.com/ES5-1ab

Standard 5 Objective 1:

This interactive activity adapted from NASA and the U.S. Geological Survey illustrates the concept of albedo—the measure of how much solar radiation is reflected from Earth's surface. The balance between the amount of solar radiation reflected and absorbed by Earth's surface plays an important role in regulating global temperature. Learn about how Earth materials, such as snow, ice, and water, differ in their ability to reflect and absorb the Sun's energy and how melting polar ice creates a positive feedback loop that accelerates global warming. Investigate how the presence of pollution, such as soot, lowers the albedo of ice and further increases melting. In addition, observe the decline in Arctic sea ice cover from 1979-2007 and the effect of melting ice on sea levels.

- http://tinyurl.com/mfc7da7

Standard 5 Objective 2:

This interactive shows human population, and resource availability in all areas of the globe and how those two interact.

- http://tinyurl.com/ES5-2ab

Standard 5 Objective 3:

This page goes through the different processes a scientist uses to be able to predict volcanic eruptions.

- http://tinyurl.com/puoceb2