Earth Science

God's World, Our Home

A Mastery-Oriented Curriculum

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Contents

Chapter 1

Earth In Space

In December 1968, three astronauts went into orbit around the moon in the Apollo 8 spacecraft. This was the first time humans had gone further from Earth than just a few hundred kilometers above the surface. As they circled the moon, the Apollo 8 crew were the first people to have a direct, close-up view of the desolate craters, plains, and mountains of another world. Since radio signals cannot go through or around the solid sphere of the moon, they were out of radio contact with Earth for about thirty minutes each time they went behind the moon. As they came back from their fourth journey behind the moon, they saw something that caught their attention far more than the unexplored surface of the moon—they saw Earth rising above the lunar horizon. The moon was gray and barren; Earth on the other hand hung brilliantly in the sky with its blue oceans, white clouds and ice caps, and variously-hued continents. They journeyed 384,000 kilometers to the moon, but then realized that the most important object in their view was not the moon, but Earth.

Objectives

After studying this chapter and completing the exercises, you should be able to do each of the following tasks, using supporting terms and principles as necessary.

1. Define and describe the four major Earth systems.
2. Give examples of specialties practiced by different kinds of Earth scientists.
3. Describe Earth's location in the solar system, galaxy, and universe.
4. Define what a habitable zone is, and apply this definition to Earth's place in the solar system and the solar system's place in the Milky Way galaxy.
5. Give examples of ways in which Earth seems to be "just right" for complex life.
6. Describe Earth's orbit around the sun.
7. Explain how the tilt of Earth's axis causes the seasons.
8. Explain why it is hot in the summer and cold in the winter in the Northern Hemisphere.
9. List, in order, the phases of the moon throughout the lunar cycle.
10. Describe the position of the sun, Earth, and moon for each phase of the lunar cycle.
11. Explain what causes partial and total solar eclipses and explain why they do not occur every month.
12. Explain the cause of lunar eclipses.
13. Explain how solar, lunar, and lunisolar calendars work and give an example of each.
14. Compare the Julian and Gregorian calendars, explaining how the Gregorian calendar corrected a flaw in the Julian calendar.

Vocabulary Terms

You should be able to define or describe each of these terms in a complete sentence or paragraph.

1. Antarctic Circle
2. aphelion
3. Arctic Circle
4. atmosphere
5. autumnal equinox
6. biosphere
7. ecliptic
8. first quarter
9. full moon
10. galaxy
11. geocentric model
12. geology
13. Gregorian calendar
14. habitable zone
15. heliocentric model
16. hydrosphere
17. Julian calendar
18. last quarter
19. lithosphere
20. lunar calendar
21. lunar phase
22. lunisolar calendar
23. meteorology
24. Milky Way galaxy
25. new moon
26. oceanography
27. partial solar eclipse
28. penumbra
29. perihelion
30. solar calendar
31. solar eclipse
32. summer solstice
33. total lunar eclipse
34. total solar eclipse
35. Tropic of Cancer
36. Tropic of Capricorn
37. umbra
38. universe
39. vernal equinox
40. waning crescent
41. waning gibbous
42. waxing crescent
43. waxing gibbous
44. winter solstice

1.1 An Introduction to Earth Science

The image on the opening page of this chapter is a picture taken by astronauts on the spacecraft Apollo 17, the final mission to the moon in 1972. From space, one can see that Earth is not a monotonous place. Some of its land surface is brown and barren, and other parts are covered with lush vegetation. Greater than 70% of the surface is covered by oceans. Both land and the oceans near the poles are covered with water in a different form: snow and ice. Forming a thin layer on top of all these is the atmosphere, with its ever-changing patterns of clouds.

1.1.1 Earth Systems

What you see from space can be categorized into different Earth systems, illustrated in Figures 1.1 through 1.5. Scientists think of these systems as concentric spheres, with the solid Earth at the center, then water, then the air. Living organisms are present in all three. This gives us four primary Earth systems: the lithosphere, the hydrosphere, the atmosphere, and the biosphere.

The *lithosphere* is the rigid outer layer of Earth, composed mostly of solid rock. The lithosphere includes Earth's crust and the upper part of the underlying mantle. The rocks of the crust are exposed in many places at the surface of Earth. There are two basic types of crust: continental crust and oceanic crust. The continental crust is composed largely of a lighter-colored rock called granite and averages about 30 to 40 km (20–30 mi) in thickness. On the other hand, the oceanic crust is typically about 5 km (3 mi) thick and composed of a dark, dense igneous rock (that is, formed from molten rock) called basalt. Beneath the lithosphere is the rest of Earth's rocky mantle, and beneath the mantle is Earth's iron core. You will learn more about Earth's crust, mantle, and core in Chapter 7.

The *hydrosphere* is the part of Earth that is made out of water. This water is present as a liquid in the oceans, seas, lakes, and rivers, and as groundwater in pores in rocks and soil. Additionally, water is present as a solid—snow and ice—on land and the polar oceans, and as a gas in the atmosphere. Most of Earth's water is present as salt water in the oceans. The greatest amount of fresh water—that is, non-salty water—is contained in ice, primarily in the ice caps that cover Greenland and Antarctica. Compared to the oceans and ice caps,

Figure 1.1. Lithosphere—the solid, rigid outer layer of Earth. This quarry is in Australia.

there is only a tiny amount of water in lakes and streams.

Earth is surrounded by a layer of gases called the *atmosphere*. The thickness of the atmosphere compared to the rest of the planet is like the peel of an apple compared to the rest of the fruit. The most abundant gas in the atmosphere is nitrogen (78%), followed by oxygen (21%). The remaining 1% is made up of argon, carbon dioxide, and a number of gases that are present in small proportions. The atmosphere also contains a variable amount of water vapor—water in its gaseous state.

Figure 1.2. Hydrosphere—Earth's water. Havasu Falls is in the Grand Canyon in Arizona.

The atmosphere serves a number of functions. The oxygen in the atmosphere is necessary for respiration for most living things, and the carbon dioxide is necessary for photosynthesis. The atmosphere also helps to maintain the temperature of the surface of Earth in a range that is suitable for advanced organisms such as plants and animals. In addition, the gases of the atmosphere help prevent various types of harmful radiation from the sun and deep space from reaching Earth's surface.

The *biosphere* is made up of all organisms that live on Earth, together with the environments in which they live. Life exists in almost every environment on Earth:

Figure 1.3. Atmosphere—The gaseous layer that surrounds Earth. This thunderstorm occurred over New Mexico.

Figure 1.4. Biosphere—All living things on Earth. This temperate rainforest is in Redwood National Park in California.

Figure 1.5. All four Earth systems—lithosphere, hydrosphere, atmosphere, and biosphere—are interacting along this Atlantic Ocean coastline in Maine.

the surface, the soil, the air, the deep sea, hot springs, ice, and even cracks in hot rocks thousands of meters beneath the surface.

These four systems all interact with each other. It is obvious that organisms in the biosphere are dependent on the lithosphere, hydrosphere, and atmosphere for oxygen, water, nutrients, and space to live. However, not only does the biosphere use resources from the other systems, the biosphere in turn affects those systems as well. Plants have changed the atmosphere by producing oxygen. Plants also help to break down minerals in the soil by removing nutrients and exchanging water with the hydrosphere. Likewise, there are interactions between the lithosphere, hydrosphere, and atmosphere. For example, water—coming from the atmosphere—falls on Earth and causes erosion of the soil, which is part of the lithosphere. Many of the interactions between the solid Earth, water, air, and life are extraordinarily complex and are not fully understood.

1.1.2 Subdivisions of Earth Science

Figure 1.6. A geologist sampling 1150°C (2100°F) lava at Kilauea, a volcano in Hawaii.

Earth scientists work in a number of specialties. Traditionally, these are broken down into three major subdivisions: geology, oceanography, and meteorology, illustrated in Figures 1.6 through 1.8.

Geology is the study of the materials that make up Earth and the processes that change Earth over time. Geologists, of course, study rocks, but they also study a range of materials and processes that will be covered in this book, such as volcanoes, earthquakes, fossils, streams, glaciers, water resources, mineral resources, and energy resources.

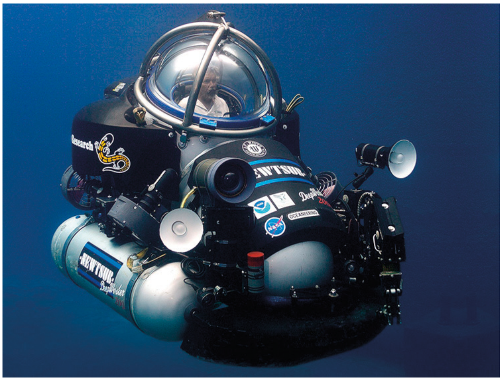


Figure 1.7. Oceanographers use submersibles such as DeepWorker *to explore the ocean's depths.*

Figure 1.8. Meteorologists using radar to study a tornado.

Oceanography is the study of the oceans. An oceanographer might study ocean currents, processes that occur on beaches, mineral resources on or beneath the ocean floor, or organisms that live in the ocean.

Meteorology is the study of the atmosphere. Meteorologists not only make weather observations and forecasts. They are also interested in studying air pollution and understanding long-term trends and changes in climate at various places.

1.1.3 Further Specializations

Due to the explosive growth of scientific knowledge, it is impossible for a geologist, oceanographer, or meteorologist to have complete knowledge of his or her subject. Usually, Earth scientists have a broad knowledge of the sciences and a specialty that is the focus of their work. Some specialties of Earth sciences include:

- Climatology — The study of climate, which is the long-term average of weather conditions in an area.
- Ecology — The study of the interactions between organisms and their environments. Ecology is often considered to be a topic in biology, but it is also an important topic in Earth sciences. Organisms affect Earth, and Earth affects the organisms that live on it.
- Geochemistry — The use of chemistry to understand Earth processes.
- Geophysics — The use of physics to understand Earth, including its shape, interior, magnetism, and surrounding space.
- Hydrology — The study of the movements and quality of water, either on Earth's surface or under it.
- Marine biology — The study of life and ecosystems in the oceans.
- Mineralogy — The study of the formation, composition, and distribution of minerals.
- Paleontology — The study of past life on Earth and how it has changed over time.
- Petroleum geology — The study of the location, migration, and production of oil and gas resources.

- Petrology — The study of rocks.
- Planetary geology — The application of geological principles to other worlds, such as planets, moons, and asteroids.
- Volcanology — The study of volcanoes.

This list represents only some of the many specializations within the Earth sciences. Even within these specialties, a scientist usually focuses on an even narrower topic. A climatologist might be most interested in desert climates, a paleontologist might specialize in coral fossils of the Jurassic Period, or a volcanologist might focus on the chemical composition of volcanic rocks produced from volcanoes like the ones in Hawaii. However, even within these specializations the best scientists are those who can relate their data to work being done by workers in other specializations. Because of this, scientists often work in teams and attend meetings with other scientists so they can exchange ideas and look for interactions and relationships between their work and that of others.

Learning Check 1.1

1. Distinguish among the lithosphere, hydrosphere, atmosphere, and biosphere.
2. Suggest two ways that the biosphere interacts with each of the other Earth systems.
3. Give a definition for each of the three major subdivisions of Earth science that you will be learning about in this course.

1.2 Earth in the Solar System, Galaxy, and Universe

We cannot completely understand Earth without having an understanding of Earth's place in the solar system, galaxy, and universe. After all, things that happen at a great distance from Earth can greatly influence our planet. Energy from the sun, produced by nuclear fusion of hydrogen and helium in the sun's core, constantly bathes Earth's land, water, and air in the form of electromagnetic radiation. There is gravitational attraction between Earth and the sun, moon, and other planets in the solar system. Rare astronomic events can influence Earth as well, such as the collision of large meteorites or even asteroids with Earth.

1.2.1 Earth in the Solar System

Until the 16th and 17th centuries, most scientists believed that Earth was at the center of the physical universe. It was thought that the sun, moon, and five planets known at the time (Mercury, Venus, Mars, Jupiter, and Saturn) all orbited around Earth in perfectly circular orbits, as illustrated in Figure 1.9. In this model, the stars were points of light that also revolved around Earth. This Earth-centered picture of the universe is known as a *geocentric* model. The story of how scientists changed their minds about this model of the universe is fascinating and was an important turning point in the history of science, but it is a topic for another course. It took about one hundred years from the work of Nicolaus Copernicus (1473–1543) until after the death of Galileo (1564–1642) for most scientists to abandon the geocentric model of the universe.

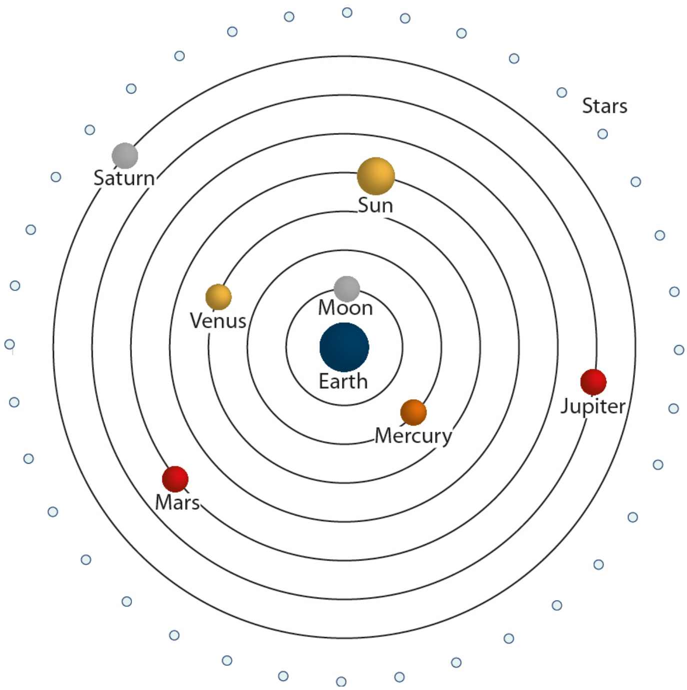


Figure 1.9. In the geocentric model, Earth is at the center of the universe, and all other bodies orbit Earth.

Today we have a very different picture of the place of Earth in the solar system and of the universe as a whole, illustrated in Figure 1.10. We now understand that the sun, not Earth, is at the center of the solar system. This model of the solar system is known as a *heliocentric* model. Earth is one of eight planets that orbit the sun. The four innermost plan-

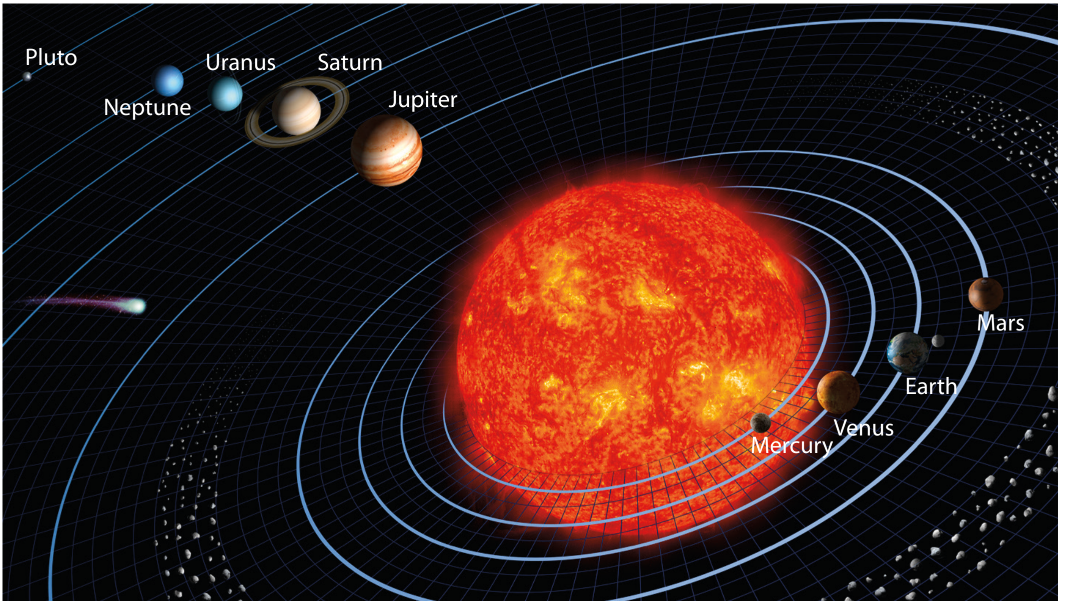


Figure 1.10. In the heliocentric model, planets, asteroids, comets, and other solar system bodies orbit the sun. Our sun is just one of over 100 billion stars in the Milky Way galaxy.

ets—Mercury, Venus, Earth, and Mars—are composed largely of rock and are known as the terrestrial (Earth-like) planets. As Figure 1.11 suggests, we can apply what we know about Earth to the study of the other terrestrial planets because they have similar compositions. Similarly, we can apply what we learn about Mercury, Venus, and Mars back to our study of Earth. The outer four planets—Jupiter, Saturn, Uranus, and Neptune—are much more massive. They are composed largely or entirely of gas and known as the gas giants.

Figure 1.11. The Curiosity rover on Mars, one of the four terrestrial planets. Many of the geologic features that occur on Earth, such as volcanoes, sand dunes, and stream channels, can also be studied on Mars.

1.2.2 Earth—A "Just Right" Planet

Most places in the solar system—and in the universe as a whole—are quite hostile to complex life. Complex life is life that is more sophisticated than bacteria, and includes all plants and animals. In most places in the universe, the temperatures are too hot or too cold, or there isn't water, or the right elements—such as carbon—aren't present, or there is too much damaging electromagnetic radiation for living organisms to thrive.

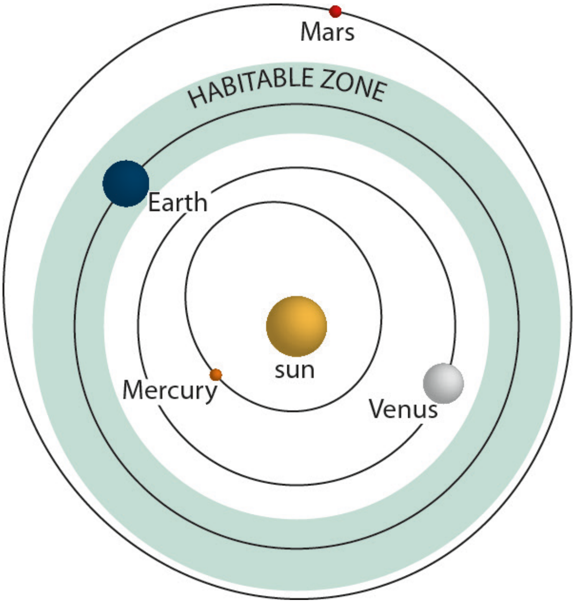


Figure 1.12. Our solar system's habitable zone, tinted in BLUE. There is debate about exactly where the inner and outer limits of the habitable zone are. The sun and planets are not drawn to scale.

Within the solar system, Earth occupies a special location. If Earth were somewhat closer to the sun, the temperature would be hot enough to boil the oceans. Living organisms, from bacteria to humans, are dependent on liquid water to exist. Even on Venus, the next planet closer to the sun, the temperature on the surface is around 460°C (860°F)! On the other hand, if Earth were farther away from the sun, it would be cold enough to freeze all water on the surface. As an example, consider Mars, with an average surface temperature of around –55°C (–67°F), though temperatures can rise above freezing (0°C) on a summer day near the Equator. So far as we know, Mars is currently a lifeless planet. It certainly cannot support the abundance of life that exists on Earth.

The region around a star in which liquid water can exist on the surface of planets—and which therefore can support advanced life—is known as the *habitable zone*, illustrated in Figure 1.12. Determining the inner and outer limits of the habitable zone is not a straightforward task, but certainly Venus is too close to the sun, and Mars is at or near the outer edge of our solar system's habitable zone. Sometimes astronomers refer to planets in the habitable zone as "Goldilocks planets," where the temperature is neither too hot, nor too cold, but just right. There may be places outside of the habitable zone where conditions are just right for life—such as in warm water beneath the surface of some of the moons of Jupiter—but it is considered unlikely by most scientists that these environments could support life more sophisticated than microscopic bacteria.

Earth is also "just right" in other ways:

1. Earth seems to be an ideal size. If it were considerably smaller, it would not have strong enough gravity to hold onto most of its atmosphere. Mars has only 10.7 percent of the mass of Earth, and has a very thin atmosphere. If, on the other hand, Earth were considerably larger, it would probably have a much denser atmosphere due to stronger gravity. This would likely lead to much higher surface temperatures.

2. Earth has a good amount of water. There is enough water to support life, but not so much as to completely cover Earth with water.

3. Earth seems to have just the right chemical composition. For example, Earth has a small amount of carbon, an essential element for all the primary molecules of life, such as proteins, sugars, and DNA. But if it had considerably more carbon, the composition of both the solid Earth and the atmosphere would be radically different, and inhospitable to life. Earth also has an iron core, which causes Earth's magnetic field and helps to protect the surface from harmful radiation from space (the solar wind). The chemical composition of Earth's crust also seems to be just right for the long-term maintenance of life.

4. Many scientists believe that gravitational interactions between Earth and the moon—the same interactions that cause ocean tides—keep Earth's axis tilted at a fairly constant angle near 23.5°. If Earth didn't have such a large moon—all other moons in the solar system are small compared to the size of their parent planets—occasional changes in the angle of Earth's tilt could cause catastrophic changes to the climate, which would make the continued existence of complex life difficult. We will take a closer look at Earth's axis in the next section.

5. Earth has plate tectonics, which, as you will learn in Chapter 6, is the process that moves continents and other parts of the lithosphere around on Earth's surface. It turns out that plate tectonics is a process which helps to make Earth a suitable home for the flourishing of life. Geologists believe that a number of factors have

to be just right for plate tectonics to occur, such as the presence of oceans, and having the right amount of radioactivity in the rocks of the lithosphere.

There are many more ways in which the universe as a whole, and our planet in particular, seem to be purposefully designed and fine-tuned for life. Psalm 19:1 states that "The heavens declare the glory of God, and the sky above proclaims his handiwork." To Christian Earth scientists, it is not only the heavens and sky that declare God's glory, but all his creation, including everything in the lithosphere, hydrosphere, atmosphere, and biosphere. All Christians believe the entire universe testifies to its loving and providential creator, our wise God who designed the universe to be inhabited by a spectacular variety of complex life—including us.

1.2.3 Earth in the Galaxy and Universe

On a very dark night, one can see up to two or three thousand stars, only a very tiny fraction of the total number of stars in the galaxy. A galaxy is a massive system of stars gravitationally bound to one another. Our sun is but one of perhaps 200 billion (200,000,000,000) stars in the Milky Way galaxy, the spiral galaxy in which our solar system is located. If we were able to travel outside of the Milky Way galaxy—which would take millions of years to do with our current spacecraft—we would see that it looks something like the galaxy shown in Figure 1.13. As Figure 1.14 illustrates, our solar system is located at the edge of a spiral arm, roughly half way from the center of the galaxy to the outer edge. Our sun is orbiting the center of the galaxy with a velocity of about 800,000 kilometers per hour, but even moving that fast, it takes over 200,000,000 years for the sun to make one revolution around the galactic core.

Just as there is a habitable zone in the solar system, where conditions are right for life to flourish, so there seems to be a galactic habitable zone in spiral galaxies where conditions are right for life to exist. Near the galactic core, stars are closer to each other than they are in our neighborhood of the galaxy, and it is believed that catastrophic events, such as stars passing close to one another and disrupting planetary orbits due to gravitational attraction, would make the entire central region of the galaxy inhospitable for complex life. On the other hand, it appears that solar systems near the edges of spiral galaxies do not contain a high enough proportion of atoms of elements heavier than hydrogen and helium to have terrestrial planets—worlds made of heavier elements such as iron, silicon, and oxygen.

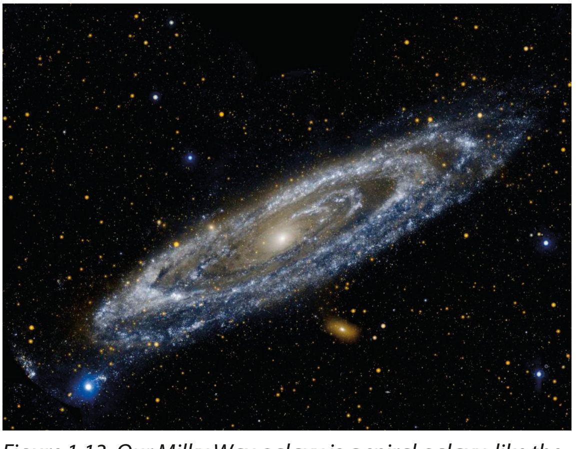


Figure 1.13. Our Milky Way galaxy is a spiral galaxy, like the Andromeda galaxy pictured here.

The Milky Way galaxy is just part of the much larger *universe*.

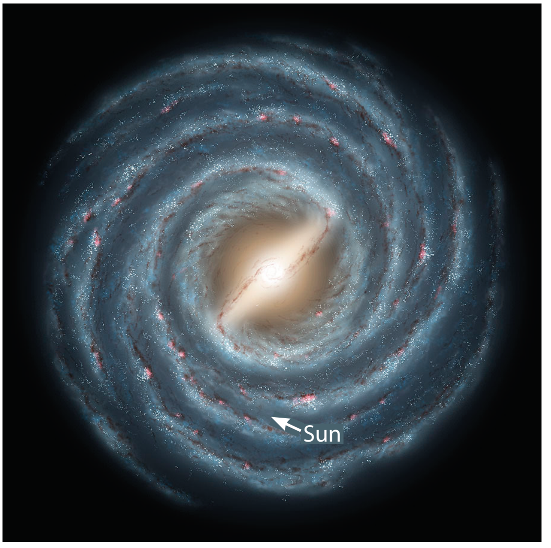


Figure 1.14. An artist's conception of the Milky Way galaxy showing the location of our sun and solar system.

The universe is composed of all the matter and energy that exists, as well as space and time themselves. This includes everything we can see with our most powerful telescopes, such as the distant galaxies shown in Figure 1.15. The Milky Way galaxy is just one of hundreds of billions of galaxies. If there are 200,000,000,000 stars in our galaxy, and at least 100,000,000,000 observable galaxies in the universe, then how many stars are there in the entire universe? At a minimum, that number is 20,000,000,000,000,000,000,000 stars.

This enormous number is virtually incomprehensible to us. It would take over 600 trillion years to count 20,000,000,000,000,000,000,000 stars, taking one second per star. Because the universe is so enormous, and our sun and planet are so small in comparison, it would be easy to conclude that we humans

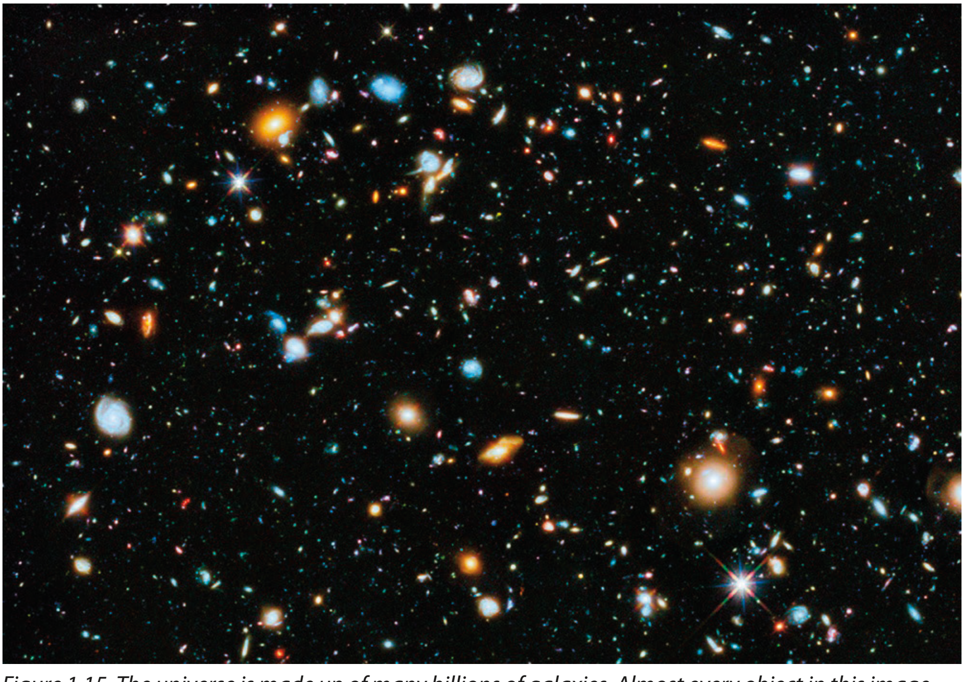


Figure 1.15. The universe is made up of many billions of galaxies. Almost every object in this image, taken by the Hubble Space Telescope, is a galaxy composed of billions of stars.

are rather insignificant. King David, as recorded in Psalm 8:3–4, also looked at the creation and asked,

> *When I look at your heavens, the work of your fingers,*
> *the moon and the stars, which you have set in place,*
> *what is man that you are mindful of him,*
> *and the son of man that you care for him?*

We are, indeed, very small compared to the rest of the creation. But God intended it this way; the vastness of the universe speaks of the bigness of God even more than it speaks of the smallness of the human race. I just stated that it would take many trillions of years for us to count all the stars in the universe, but according to Isaiah 40:26, God has a name for each of those stars. Things that are far beyond our comprehension and capabilities are easy for our powerful creator!

Learning Check 1.2

1. Contrast the geocentric model of the solar system with the heliocentric model.
2. Describe Earth's location in space, relative to the sun and solar system, the galaxy, and the universe.
3. In what ways does Earth seem to be "just right" for complex life?
4. What is meant by a habitable zone, for both the solar system and galaxy as a whole?
5. In what ways does Earth seem to be a very small place in the universe? What does this tell us about ourselves? What does it tell us about God?

1.3 Earth's Orbit and the Seasons

1.3.1 Earth's Orbit

Earth takes 365.24 days to make one complete orbit around the sun. This orbit, however, is not circular. Instead, Earth's orbit around the sun is slightly elliptical, meaning that Earth is slightly closer to the sun at some times and farther away at others. At its closest, Earth is about 147,000,000 km from the sun and at its farthest it is about 152,000,000 km from the sun, for an average of about 150,000,000 km (93,000,000 mi). As shown in Figure 1.16, the point on the orbit of a planet, asteroid, or comet around the sun where it is closest to the sun is called the *perihelion*, and the point where it is farthest from the sun is called the *aphelion*. The difference between the perihelion and aphelion for Earth's orbit is not all that great and from

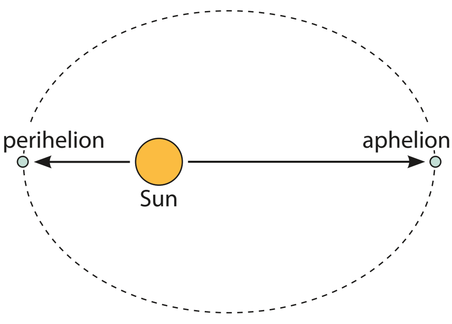


Figure 1.16. For an elliptical orbit, the aphelion is where a planet is farthest from the sun; the perihelion is where it is closest to the sun.

a distance Earth's orbit would appear to be nearly circular. One interesting thing about this elliptical orbit is that Earth is closest to the sun (perihelion) during the first week of January and farthest from the sun (aphelion) the first week of July. This means Earth is actually slightly closer to the sun when it is winter in the Northern Hemisphere and slightly farther away from the sun in the summer. This tells us that the distance from one of Earth's hemispheres to the sun is not the primary cause of seasons. This distance does have a minor effect on seasons—the Northern Hemisphere winter is slightly warmer than it would be if Earth's orbit were circular, and Northern Hemisphere summer is slightly cooler than it would otherwise be—but the main cause of Earth's seasons is the tilt of Earth's axis.

1.3.2 Solstices and Equinoxes

The plane in which Earth orbits the sun is called the *ecliptic*. As Earth orbits the sun, its axis of rotation is not perpendicular to the ecliptic; it is tilted at an angle of about 23.5° as Figure 1.17 shows. As Earth orbits the sun, its axis always points in the same direction. In Figure 1.18, you see that no matter where Earth is in its orbit, its axis is inclined 23.5° to the right. As Earth completes its annual trip around the sun, different parts of the planet receive different amounts of sunlight. At the far left of Figure 1.18, on about June 21, the Northern Hemisphere is tilted towards the sun and receives more direct sunlight than the Southern Hemisphere does. This is the *summer solstice*—the moment of time when the sun is highest in the sky in the hemisphere and regarded as the first day of summer. In general, the summer solstice is the day of the year with the most hours of sunlight. The *winter solstice* occurs on about December 21 in the Northern Hemisphere. This is when the sun is lowest in the sky in the hemisphere, and the day with the least hours of sunlight. At the time the summer solstice occurs in the Northern Hemisphere, the winter solstice occurs in the Southern Hemisphere. About halfway between the solstices are the *equinoxes*, when Earth's axis neither tilts away nor toward the sun, and there is approximately an equal amount of day-

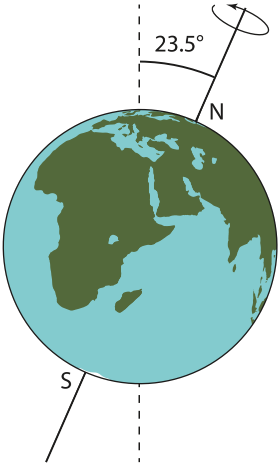


Figure 1.17. Earth's axis is tilted 23.5° from vertical, relative to the ecliptic.

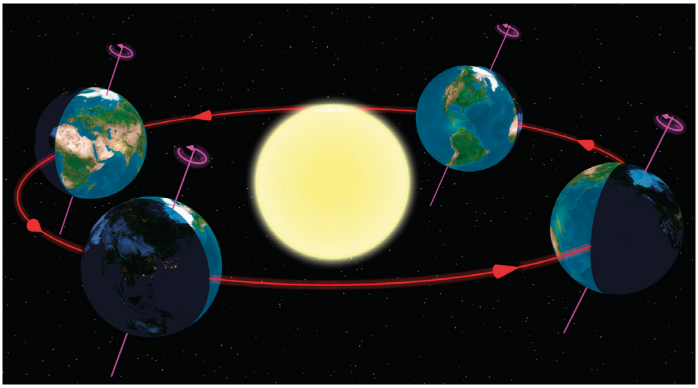


Figure 1.18. As Earth orbits the sun, its axis is always pointed the same direction. This means that for part of the year, the North Pole is pointing more towards the sun; at the opposite part of the year, the North Pole is pointing away from the sun.

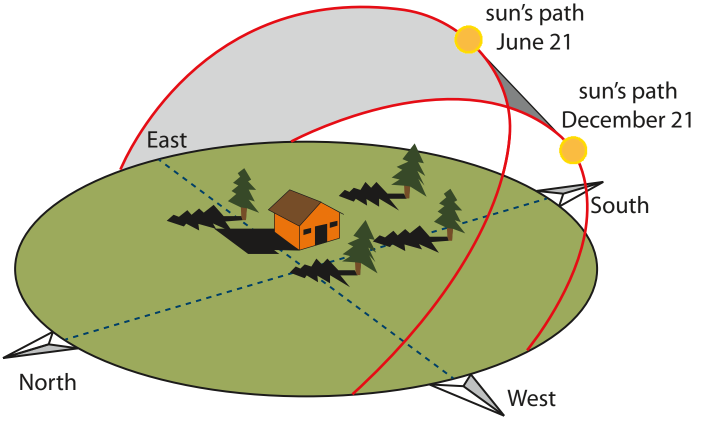


Figure 1.19. The path the sun takes across the sky in the Northern Hemisphere at the latitude of the central United States on the summer solstice (June 21) and winter solstice (December 21).

light and nighttime. The *vernal equinox* is the equinox that occurs between the winter solstice and summer solstice, on about March 22 in the Northern Hemisphere. The *autumnal equinox* occurs between the summer solstice and winter solstice, on about September 22 in the Northern Hemisphere.

The temperature on Earth's surface depends on the amount of heat received from the sun, which is received in the form of electromagnetic radiation. Earth is always gaining energy from the sun, but Earth also loses heat energy into space at the same time. If Earth did not lose heat to balance out the energy it receives from the sun, it would get hotter and hotter and eventually melt! The electromagnetic radiation from the sun is primarily visible light, which is absorbed by Earth's surface and atmosphere, leading to warming. The warm Earth, at the same time, re-radiates electromagnetic radiation back out into space, mainly as infrared radiation. We can see this balance swinging back and forth on a daily basis: the temperature rises as the sun warms Earth's surface during the day, but then drops at night. We also see this happening on a longer time scale, as the Northern Hemisphere warms up through the spring and summer and cools off through fall and winter. It is all about which is greater at the time: energy received from the sun or energy radiated back into space from Earth.

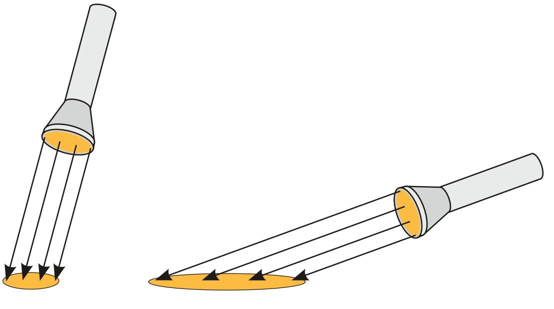


Figure 1.20. The flashlights illustrate the difference between having the sun high in the sky (summer) and low in the sky (winter). In the summer, energy is concentrated in a smaller area, but in winter, energy from the sun is spread out over a larger area, resulting in less heating of the ground.

There are two primary reasons why it is hotter in the summer than in the winter. Both reasons are related to the path the sun takes across the sky. We think of the sun as rising in the east and setting in the west. But as Figure 1.19 shows, in the summer the sun actually rises in the northeast and takes a long, high path across the sky before setting in the northwest (from a Northern Hemisphere perspective). In the winter, on the other hand, the sun rises in the southeast, and takes a much shorter, lower path across the sky before setting in the southwest.

From these observations, it becomes apparent why it is hot in the summer. First, the sun is in the sky for a long time on a summer day, so there is a long period of time for Earth's surface to absorb radiation from the sun. Second, the sun is higher in the sky on a summer day, so sunlight is concentrated on a smaller area than in the winter. The difference in sunlight concentration is illustrated with flashlight beams in Figure 1.20. The opposite is true in winter: the sun is in the sky for a shorter period of time, so there is less time for Earth's surface to absorb sunlight and sunlight hits Earth's surface at a lower angle, spreading out the energy from the sun over a greater area.

1.3.3 The Tropics and Polar Regions

Near Earth's Equator, changes in the sun's position in the sky don't have as great of an effect on temperatures. Whether it is summer solstice, winter solstice, or an equinox, the sun climbs up high in the sky every day and this part of Earth is generally warm year-round. Between latitudes 23.5°N and 23.5°S, there is at least one day in the year when the sun is directly overhead at noon.[1] At latitude 23.5°N, the sun climbs up to directly overhead at noon on the day of the Northern Hemisphere summer solstice. As Figure 1.21 illustrates, this latitude is known as the *Tropic of Cancer*. This latitude is the farthest north that the sun can be seen directly overhead. The southern equivalent, at 23.5°S, is the *Tropic of Capricorn*. The region between the Tropic of Cancer and the Tropic of Capricorn is known as the *tropics*. Except in mountainous areas, this region is warm all year. In the United States, only

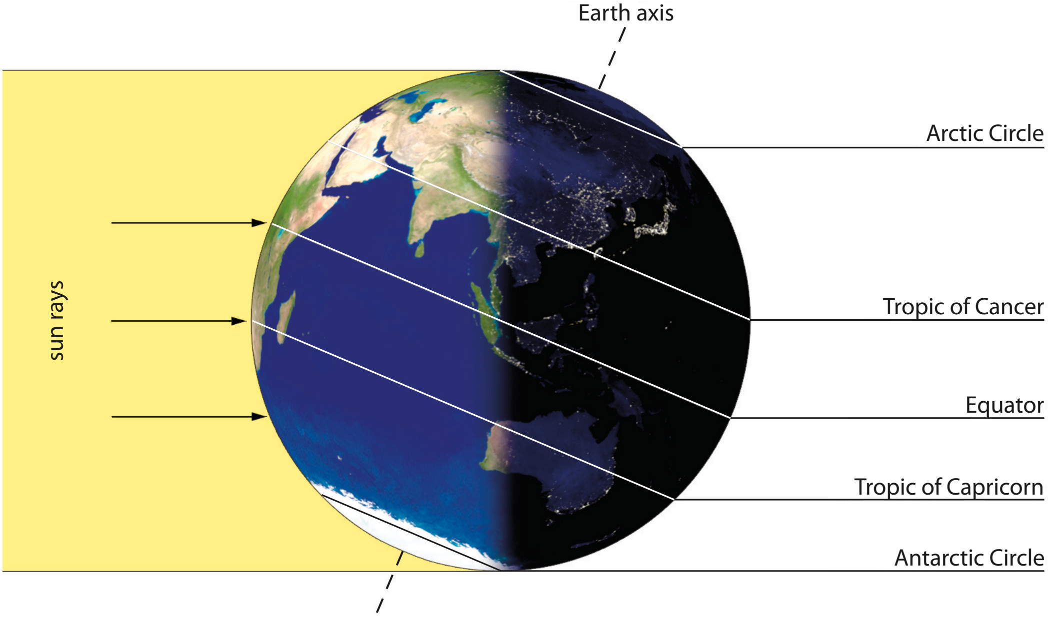


Figure 1.21. Earth at Northern Hemisphere winter solstice, showing the Tropic of Capricorn, Tropic of Cancer, Arctic Circle, and Antarctic Circle.

1 Latitude and longitude are discussed in Chapter 2.

Hawaii is in the tropics. In many tropical areas, the main difference in seasons is not between hot and cold, but between a wet season and a dry season.

The situation is quite different in polar regions. On the day of the Northern Hemisphere summer solstice, the sun does not set at any location farther north than the *Arctic Circle*, which is at about 66.5°N. These regions are sometimes referred to as "the land of the midnight sun." But the opposite situation occurs at the winter solstice, when the sun does not rise above the horizon north of the Arctic Circle. The Southern Hemisphere equivalent of the Arctic Circle is the *Antarctic Circle*, which is at approximately 66.5°S. Despite having up to 24 hours of sunlight, polar regions do not get hot in the summer because the sun is always low in the sky.

Learning Check 1.3

1. Calculate the approximate speed at which Earth moves in its orbit around the sun. You can simplify the problem by assuming that Earth's orbit around the sun is circular.
2. What effect does the elliptical orbit of the sun have on Earth's seasons?
3. Explain how the tilt of Earth's axis causes seasons.
4. Speculate as to what seasons would be like if Earth's axis were not tilted, and what seasons would be like if Earth's axis were tilted at 45° instead of 23.5°.

1.4 Phases of the Moon

There are nights when the moon shines bright in the sky, bright enough to walk outside without the need for artificial lighting. There are other nights when it is pitch black and there is no moon above, but thousands of stars shine in the dark sky. As the moon orbits Earth, its appearance, as well as the time it rises and sets, changes from day to day. The *phase* of the moon, or *lunar phase*, is the shape of the sunlit portion of the moon's face as seen from Earth. As the moon orbits Earth, the same hemisphere of the moon always faces us, but part of the near side of the moon is in sunlight, and part of it is in darkness. The phases of the 29.5-day lunar cycle are outlined in Table 1.1.

A helpful way of visualizing how lunar phases work is shown in Figure 1.22, which shows the moon revolving around Earth in a counter-clockwise direction. The phases of the moon are determined by the positions of the sun, Earth, and moon.

The moon emits no light of its own; we only see light that is reflected off it. Note that the side of the moon facing the sun is illuminated and the side facing away from the sun is dark. As the moon orbits Earth, varying amounts of light and dark are visible from Earth's surface.

When the moon is in the position represented by the right side of Figure 1.22, the side of the moon facing Earth is completely in darkness, while the side of the moon facing away from Earth is fully illuminated. This is called the *new moon*.

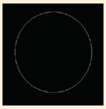
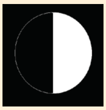
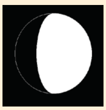
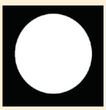
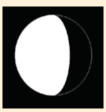
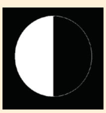
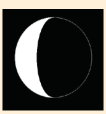
Phase		Moonrise	Moonset	Viewing
	New Moon	Sunrise	Sunset	Moon not visible
	Waxing Crescent	Just after sunrise	Just after sunset	Moon visible in the west just after sunset
	First Quarter	Noon	Midnight	Moon visible in afternoon and early evening
	Waxing Gibbous	Late afternoon	After midnight	Moon visible most of the night
	Full Moon	Sunset	Sunrise	Moon visible all night
	Waning Gibbous	Before midnight	Mid-morning	Moon visible late night until mid-morning
	Last Quarter	Midnight	Noon	Moon visible after midnight until noon
	Waning Crescent	Just before sunrise	Just before sunset	Moon visible in the east just before sunrise

Table 1.1. Phases of the moon, with moonrise and moonset times.

When the moon is new, its position in the sky is close to the position of the sun, so it rises in the morning, sets in the evening, and is invisible to us. A couple of days after the new moon, the moon has advanced in its orbit around Earth, and a thin sliver is visible in the western sky just after sunset. This is called the *waxing crescent*; the term waxing means increasing or growing. If you observe the moon from night to night, you see that the line that separates light from dark slowly moves across the moon's face from right to left. About a week after the new moon, the moon has completed a quarter of its orbit around Earth and it appears half illuminated. Rather than calling this a half moon, however, it is referred to as a quarter moon—in this case, the *first quarter* (top of Figure 1.22). After the first quarter, the near side becomes more fully illuminated, with more than half but less than all of the near side showing, a phase called the *waxing gibbous*. A full two weeks after the new moon, the moon

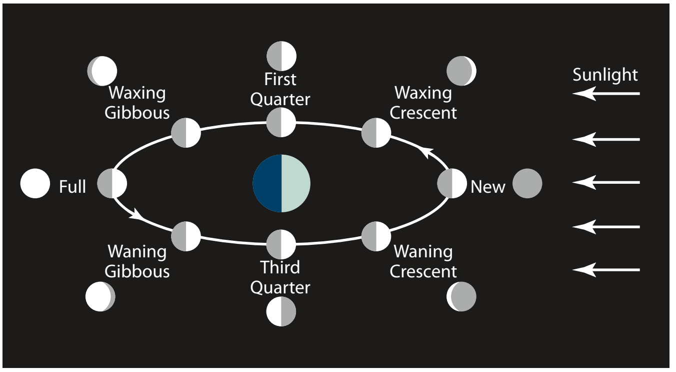


Figure 1.22. As the moon orbits Earth, varying amounts of the near side of the moon become illuminated by the sun, causing lunar phases.

is fully illuminated when viewed from Earth, and we see a *full moon* (far left of Figure 1.22).

During the following two weeks, the process reverses (lower part of Figure 1.22). A few days after the full moon, darkness starts to slowly creep across the moon's face from right to left, leading to the *waning gibbous* phase. Waning means decreasing, the opposite of waxing. The *last quarter* occurs a week after the full moon, and a few days later, the *waning crescent* appears in the sky shortly before sunrise. After 29.5 days, the cycle repeats itself, starting with a new moon.

Something many people don't realize is that the moon is in the sky during the day time just as often it is in the sky during the night time. We don't notice the daytime moon as often for a couple reasons. First, the sky is bright during the day and it is easy to miss a pale crescent or quarter moon—or even a gibbous moon—against the bright blue sky. Second, even though the moon is in the sky when it is at or near the new moon phase, there is simply not enough of the sunlit side of the moon visible for us to see.

The time of day that the moon rises and sets goes hand in hand with the phases of the moon. For example, the full moon is on the opposite side of Earth from where the sun is, so the full moon rises roughly when the sun sets and sets roughly when the sun rises. Each day, the moon rises about 50 minutes later; thus three days after the full moon, the waning gibbous moon rises about 2.5 hours (150 minutes) later. Table 1.1 summarizes when the moon rises and sets for different phases.

Learning Check 1.4

1. Explain why the moon has phases.
2. Why does the full moon rise at roughly the same time that the sun sets?
3. If you were on the moon, how would the appearance of Earth change throughout the 29.5-day lunar cycle?

1.5 Eclipses

In addition to phases, the orbit of the moon around Earth causes another interesting phenomenon: *eclipses*. An eclipse occurs when one celestial body, such as

Earth or the moon, blocks the sun from another celestial body.

1.5.1 Solar Eclipses

A *solar eclipse* occurs when the moon passes in front of the sun, causing the moon's shadow to fall on Earth. In a *partial solar eclipse*, the moon only covers part of the sun's disk, as shown in Figure 1.23. In the case of a *total solar eclipse*, the moon completely covers the sun, as in Figure 1.24. During a total solar eclipse, the sky becomes dark, but the total part of the eclipse lasts for only a few minutes. Solar eclipses can only happen when the moon is between the Earth and the sun, when there is a new moon, illustrated in Figure 1.25.

Figure 1.23. Partial solar eclipse. (Caution: looking directly at a partial eclipse can damage your eyes!)

A shadow from a light source, such as the sun or a light bulb, has multiple parts to it. The darkest, inner part of the shadow is called the *umbra*. During a solar eclipse, the moon completely blocks the sun within the umbra. The *penumbra* is the part of the shadow that is not completely dark. Within the penumbra, the sun is not completely blocked, so a viewer sees a partial solar eclipse. The umbra and penumbra are easy to demonstrate, using a table lamp and a disk of some type, as shown in Figure 1.26.

Total solar eclipses are fairly rare events, and most people have never seen one. (I have seen a total solar eclipse once, in 1979). Looking back at Figure 1.22 (lunar phases), one might think that a solar eclipse should occur every month. But the moon orbits Earth in a plane that is about 5° tilted relative to the ecliptic, the plane in which Earth orbits the sun. This means that in most months, the new moon passes either above or below the sun in the sky rather than right in front of it. In some years, there are no total solar eclipses. In other years, there may be up to five solar eclipses, although this only

Figure 1.24. Total solar eclipse. This is the only time that the solar atmosphere is visible from Earth.

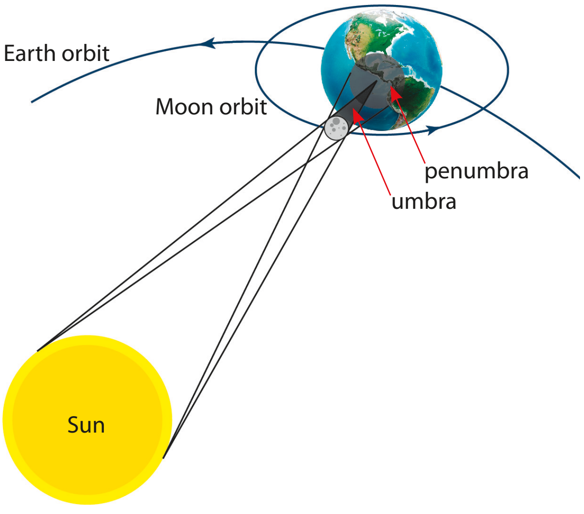


Figure 1.25. A solar eclipse occurs when the moon blocks the light of the sun. Viewers located in the umbra, which is very small on Earth, see a total solar eclipse; viewers located in the penumbra see a partial solar eclipse.

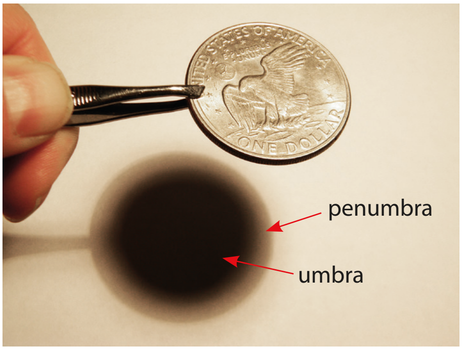


Figure 1.26. Umbra and penumbra. An ant within the umbra would not be able to see the light bulb, and an ant in the penumbra would be able to see part of the light bulb.

happens rarely. Because of the small size of the umbra on Earth, total solar eclipses are only visible in narrow bands on Earth's surface.

There is actually more to the sun than just the bright disk we normally see in the sky. When that disk is blocked, we can still see the solar atmosphere, appearing as a thin ring of pink light around the eclipse and a faint white glow that extends farther out (Figure 1.24). The solar atmosphere is made of hot glowing plasma, an ionized gas.

The sun is 400 times as large as the moon, but it is also 400 times farther away. The result is that the moon and the sun appear to be almost exactly the same size in the sky. It is truly amazing that we live on a planet that has total solar eclipses when the moon almost perfectly covers the sun. This requires a moon that is just the right size, at just the right distance from Earth. Being able to see solar eclipses is not just something that is cool, but something that has been critical in the development of science. For example, total solar eclipses helped us to understand the composition of the sun, and helped to confirm the validity of Albert Einstein's general theory of relativity. One could argue that there is nothing very

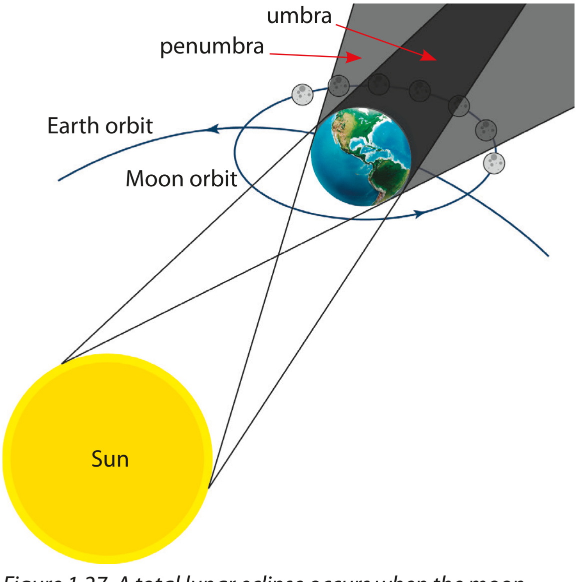


Figure 1.27. A total lunar eclipse occurs when the moon passes through Earth's umbra.

Chapter 1 Exercises

Answer each of the questions below as completely as you can. Write your responses in complete sentences unless instructed otherwise.

1. Give a definition for each of the four major Earth systems and describe how these systems interact with each other.
2. Draw a sketch of our solar system, showing the sun, planets, and habitable zone.
3. What are some ways in which Earth appears to be specially designed for living organisms to thrive?
4. Describe what is meant by the term "galactic habitable zone."
5. Describe Earth's orbit around the sun and explain why the shape of this orbit has little effect on Earth's seasons.
6. Draw a sketch like Figure 1.18 and use it to explain the cause of Earth's seasons.
7. Explain why, in general, summer days are hot and winter days are cold.
8. Predict what Earth's days and seasons would be like if Earth's axis were tilted at close to 90° rather than 23.5°.
9. Draw a sketch of Earth, showing the location of the Tropics of Cancer and Capricorn, and Arctic and Antarctic Circles.
10. Describe the path the sun would take across the sky viewed from the North Pole on the summer solstice, autumnal equinox, and winter solstice.
11. Draw sketches of the eight phases of the moon, in order, from the new moon through the waning crescent.
12. Draw a sketch like Figure 1.22 and use it to explain the cause of lunar phases.
13. When people on Earth see a quarter moon, what would Earth look like from the moon?
14. Draw a sketch of a total solar eclipse with labels for the sun, moon, Earth, umbra, and penumbra.
15. Explain why solar eclipses are only visible in limited geographic areas, but lunar eclipses are visible from the entire night side of Earth.
16. Describe the similarities between the Hebrew and Islamic calendars, and then explain what the biggest difference is between how they work.
17. Compare the Julian and Gregorian calendars and explain how the Gregorian calendar corrected a problem with the Julian calendar.

2.4.2 Topographic Maps

An important type of map in Earth sciences is the *topographic map*. A topographic map represents the surface of Earth, showing elevations by the use of contour lines or color tints (e.g., the color bands shown in Figure 2.27). Topographic maps also show other natural and man-made features such as streams, lakes, forests, roads, and buildings. They are used by geologists, foresters, wildlife biologists, engineers, planners, military personnel, campers, and backpackers. In the United States, detailed topographic maps have been made for the entire nation by government agencies such as the U.S. Geological Survey and the U.S. Forest Service. A section from a U.S. Geological Survey topographic map is shown in Figure 2.31. The topographic maps made by these agencies are referred to as quadrangles. Most other countries have similar topographic mapping programs.

Most topographic maps portray elevation using *contour lines*—curves that connect points of equal elevation. The brown curves in Figure 2.31 are contour lines. Each point along the 900-foot contour represents an elevation of 900 feet above sea

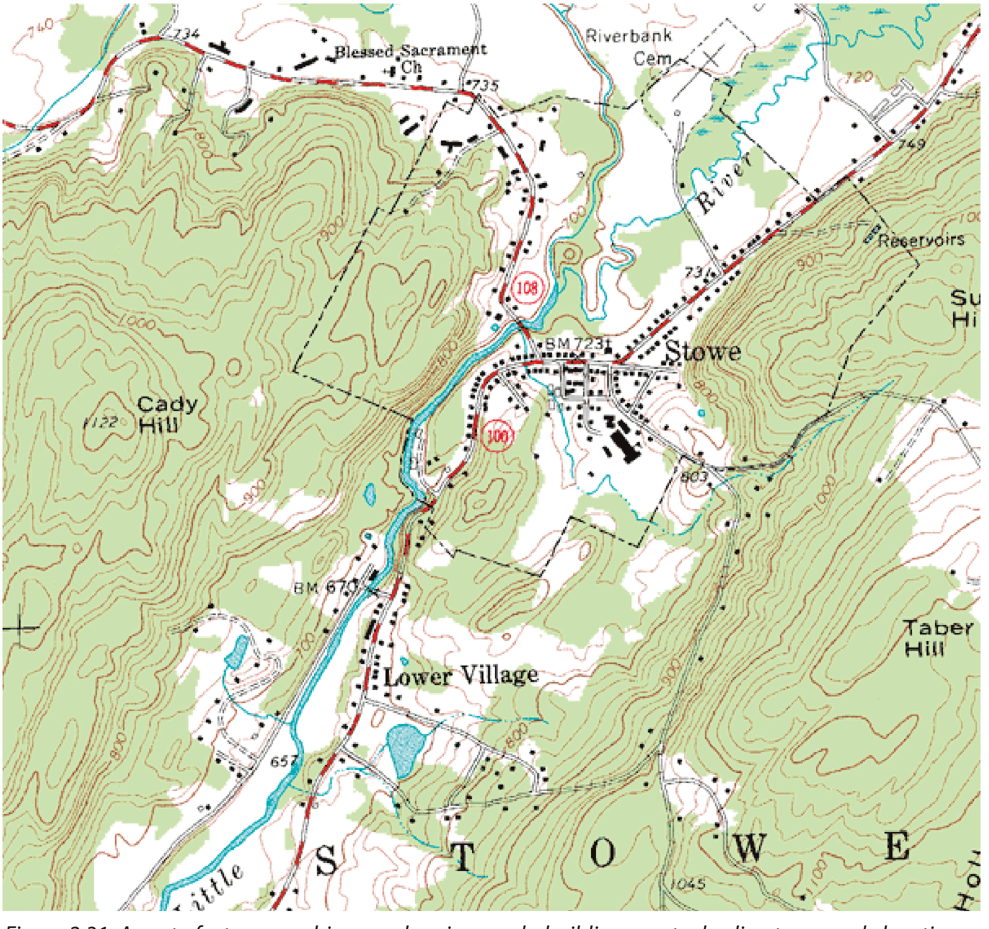


Figure 2.31. A part of a topographic map showing roads, buildings, water bodies, trees, and elevations.

level, and each point along the 1,100-foot contour represents an elevation of 1,100 feet above sea level. The shapes of the contour lines on the map reflect the shape of the land surface. The starting point for measuring elevation is sea level, which is assigned a value of zero. Most topographic maps in the United States show elevations in feet, but military topographic maps and topographic maps produced by other countries indicate elevations in meters.

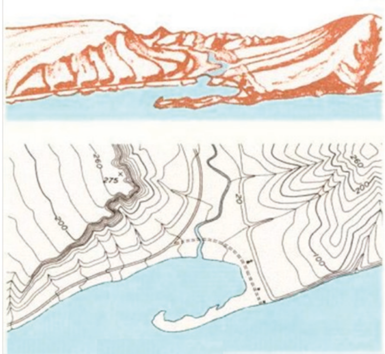


Figure 2.32. The relationship between landscape and contour lines.

Figure 2.32 illustrates the relationship between contour lines and landscape. In places where the land is relatively level, such as along the stream in the center of the diagram, the contour lines are far apart. Where the slope is steep, the contour lines are close to each other.

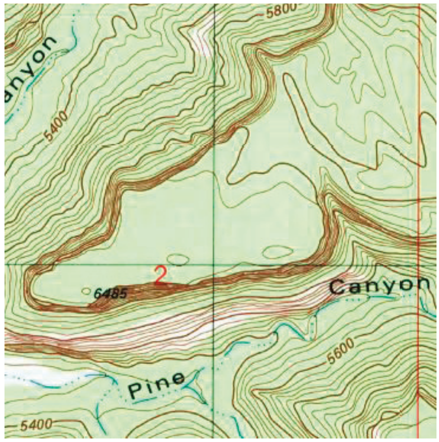


Figure 2.33. Principles 1 and 2—Contour lines are far apart in flat areas, and close to each other in steep areas, but contour lines never cross.

There are four basic principles associated with contour lines, illustrated in Figures 2.33, 2.34, and 2.35:

1. As just stated, where contour lines are far apart the slope is gentle; where they are close together the slope is steep.
2. Contour lines never cross each other. On some topographic maps, they can touch each other where there are cliffs, but they do not actually cross each other.
3. Where a contour line crosses a stream on a topographic map, the contour line is V-shaped, with the V pointing upstream toward areas with higher elevation.
4. Contour lines form closed loops around elevated areas (e.g., hills) and depressed areas (e.g., craters). For example, a hill on a topographic map looks like a series of concentric, irregular loops. Often, the contour lines extend beyond the edges of an individual map so you don't always see the complete closed loop.

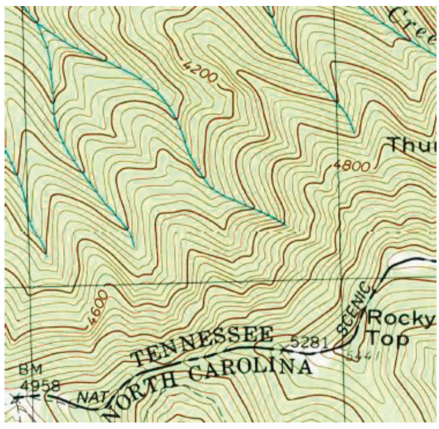


Figure 2.34. Principle 3—Contour lines make a V where they cross streams, with the V pointing upstream.

The *contour interval* of a topographic map is the difference in elevation between adjacent contour lines. If the contour interval is 20 feet, then contour lines are shown for every multiple of 20 feet, such as at 100, 120, 140, and 160 feet.

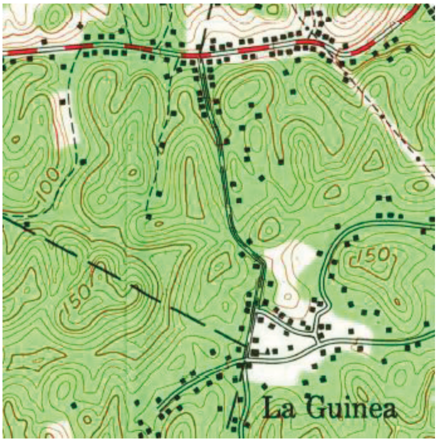


Figure 2.35. Principle 4—Contour lines form closed loops around hills.

In flat areas, there is not a great elevation difference from one part of a map to another, so a topographic map of an area of plains might have a contour interval of only 10 feet. Most hilly areas can be sufficiently portrayed with a 20-foot contour interval; mountainous areas typically have contour intervals of 40 feet. If a mountainous area were portrayed with a 10-foot contour interval, the contours would be so close to each other that they would blend together.

In order to make a map easier to read, every fourth or fifth contour line, known as an *index contour line*, is drawn with a heavier line weight and usually labeled to indicate its elevation. If the contour interval on a map is 20 feet, then every fifth contour line has a value that is a multiple of 100 feet and designated as an index contour line. Contour interval and index contours are depicted in Figure 2.36.

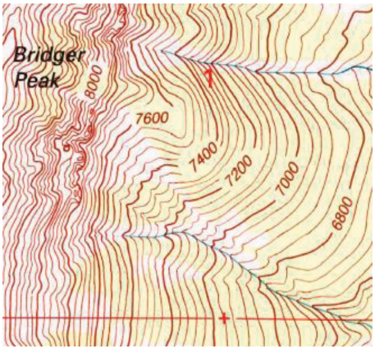


Figure 2.36. This map has a contour interval of 40 feet, with index contours every 200 feet.

2.4.3 Map Margin Information

Some of the most important features of a topographic map (or other types of maps) are found not in the main part of the map but in the margins around the map's edge. The margin gives information about the location of the map, publisher, date, and accuracy of the map. One important element of the map margin is the *map scale*. The map scale is the ratio between a length on a map and the corresponding horizontal distance on the ground. For example, a map scale of 1:100,000, means that features shown on the map are one-100,000th their true size. It also means that one unit of measurement on the map represents 100,000 of those same units on Earth. In this case, 1 cm on the map represents 100,000 cm on the ground. This is a convenient scale, because it means that 1 cm on the map also represents 1 km on the ground. (There are 100,000 cm in 1 km.) Another way of expressing map scale is with a *scale bar*. A scale bar graphically represents the scale of the map and consists of a line with marks like a ruler. The map scale and scale bar for a U.S. Geological Survey topographic map are shown in Figure 2.37.

Another important part of the map margin is the *legend*, an example of which is shown in Figure 2.38. A map legend is a key that indicates what each symbol on the map represents. Many symbols on a map are designed to look like the features they symbolize. For example, trees are shown with a green tint and water bodies are depicted with blue. However, many other symbols are not the same color as the features they represent. Man-made features such as buildings are usually black, regardless of what color they really are.

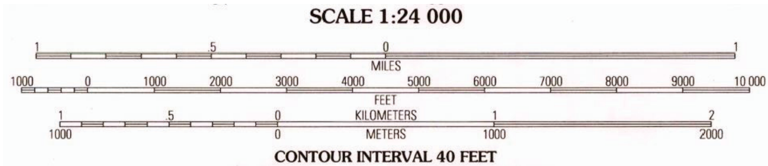


Figure 2.37. Scale bar and map scale from a topographic map.

2.4.4 Gradient and Percent Slope

We can describe the slope of a geographic feature such as a hillside, stream, or road as gentle or steep, or we can actually measure a slope to determine its *gradient*. Gradient is a mathematical measurement of the rate of change of the elevation of Earth's surface over a given horizontal distance. In algebra, the slope of a line is the ratio of "rise" over "run." The gradient of Earth's surface is measured in a similar way.

One way to express gradient is as the rise or drop in elevation per horizontal distance. For instance, if a stream drops in elevation 50 ft in 2.0 mi, its gradient is calculated as

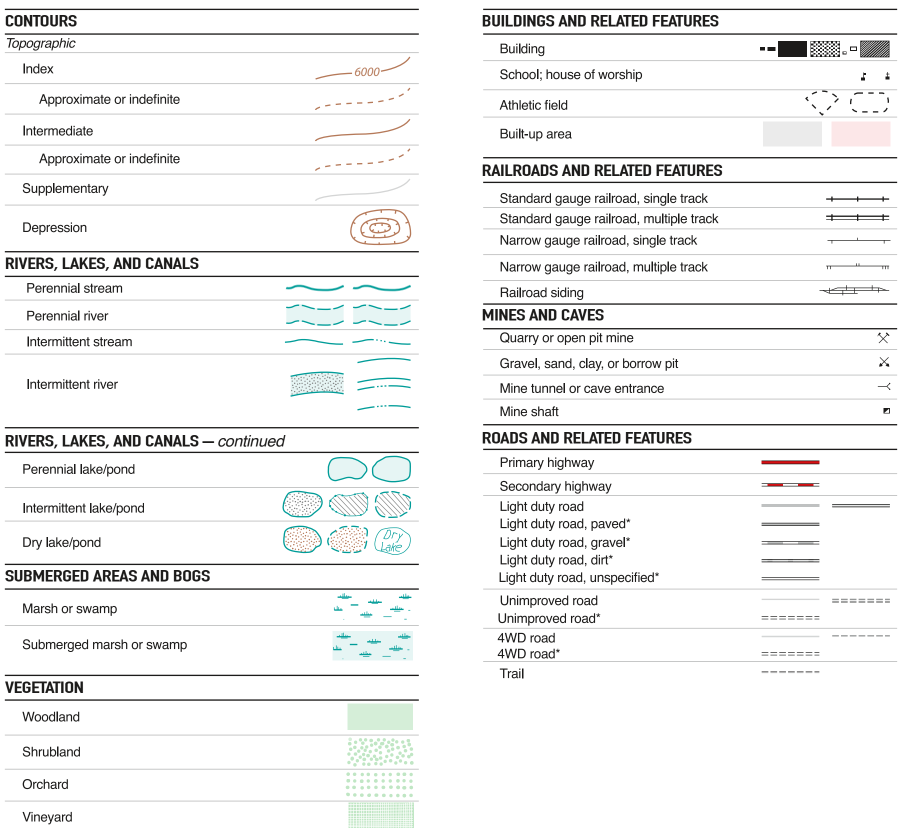


Figure 2.38. Simplified legend for U.S. Geological Survey topographic maps.

$$\text{gradient} = \frac{\text{rise (or drop)}}{\text{run}} = \frac{50\text{ ft}}{2\text{ mi}} = 25\text{ ft/mi}$$

When expressed this way, the units of gradient are always distance of rise or drop per distance of run, such as feet per mile (ft/mi) or meters per kilometer (m/km).

Gradient is often presented as a *percent slope*. Percent slope is the rise over run of Earth's surface multiplied by 100%, as illustrated in Figure 2.39. When calculating percent slope, the units for the rise and run must be the same, so the calculation uses an equation such as

$$\text{percent slope} = \frac{\text{rise feet}}{\text{run feet}} \times 100\%$$

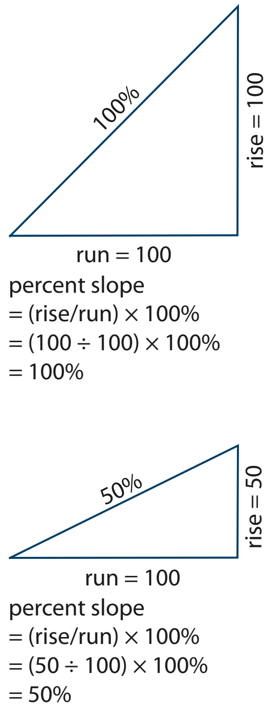


Figure 2.39. Calculating percent slope.

Let's calculate the percent slope for the same stream. The stream drops 50 feet in 2.0 miles, but we must first convert the miles to feet. There are 5,280 feet in a mile, so the conversion is as follows:

$$2\text{ mi} \cdot \frac{5280\text{ ft}}{1\text{ mi}} = 10{,}560\text{ ft}$$

The stream's percent slope is calculated as follows:

$$\text{percent slope} = \frac{\text{rise feet}}{\text{run feet}} \times 100\% = \frac{50}{10{,}560} \times 100\% = 0.47\%$$

Note that because there are units of feet in both the numerator and denominator of this ratio, the length units cancel out and the result has units of percent; the answer is 0.47%, not 0.47 feet per foot.

Gradient can be determined by interpretation of contour lines on topographic maps. To calculate the gradient of a hillside, for example, one determines the rise by calculating the difference between the elevation for the highest contour line and the lowest contour line. The run is determined by using the map scale to measure the horizontal distance between those points. A sample calculation based on a topographic map is shown in Figure 2.40.

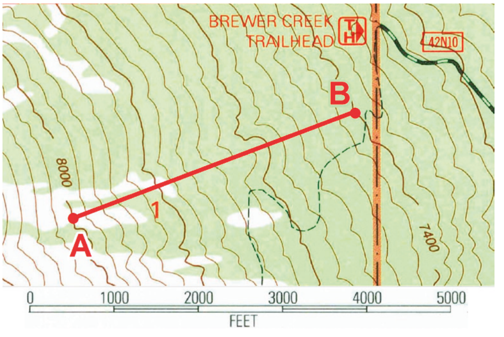


Figure 2.40. Point A has an elevation of 8000 feet, and point B has an elevation of 7400 feet, a rise of 600 feet. The horizontal distance between A and B is 3600 feet. The percent slope is (rise/run) × 100% = (600 ft/3600 ft) × 100 % = 16.7%.

Learning Check 2.4

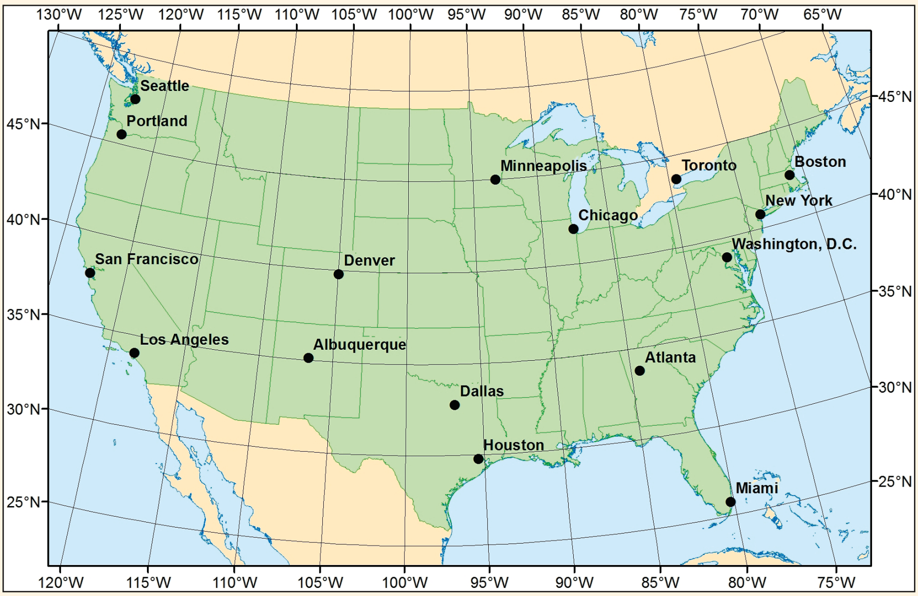
1. Explain what a Geographic Information System is.
2. Explain how contours are used to portray Earth's landscape on a topographic map.
3. What are the four basic principles of contour lines?
4. Explain what is meant by the term *map scale*.

Chapter 2 Exercises

Answer each of the questions below as completely as you can. Write your responses in complete sentences unless instructed otherwise.

1. Use the map of the United States below to determine the name of the cities with the following coordinates:

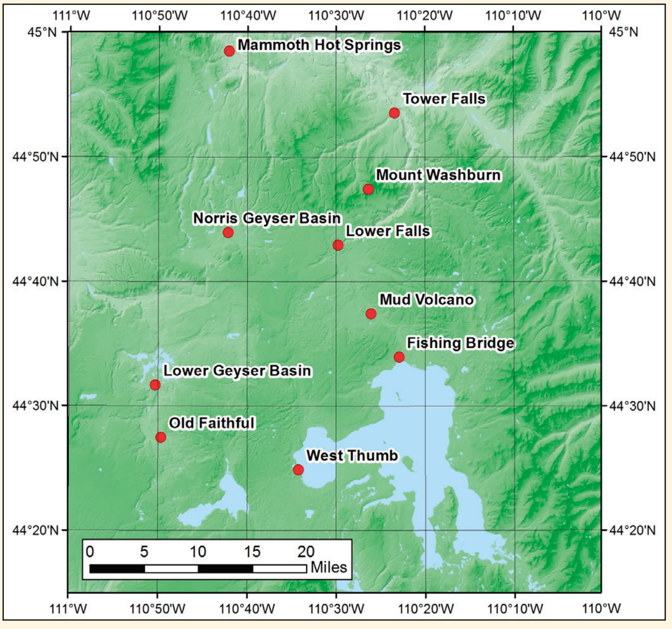
a. 40°N, 105°W	b. 42°N, 88°W	c. 26°N, 80°W	d. 46°N, 123°W
e. 41°N, 74°W	f. 34°N, 118°W	g. 42°N, 71°W	h. 30°N, 95°W



2. Use the map of the United States above to determine the latitude and longitude, to the nearest degree, of the following cities:

a. Albuquerque, New Mexico	b. Atlanta, Georgia
c. Dallas, Texas	d. Minneapolis, Minnesota
e. San Francisco, California	f. Seattle, Washington
g. Toronto, Ontario, Canada	h. Washington, D.C.

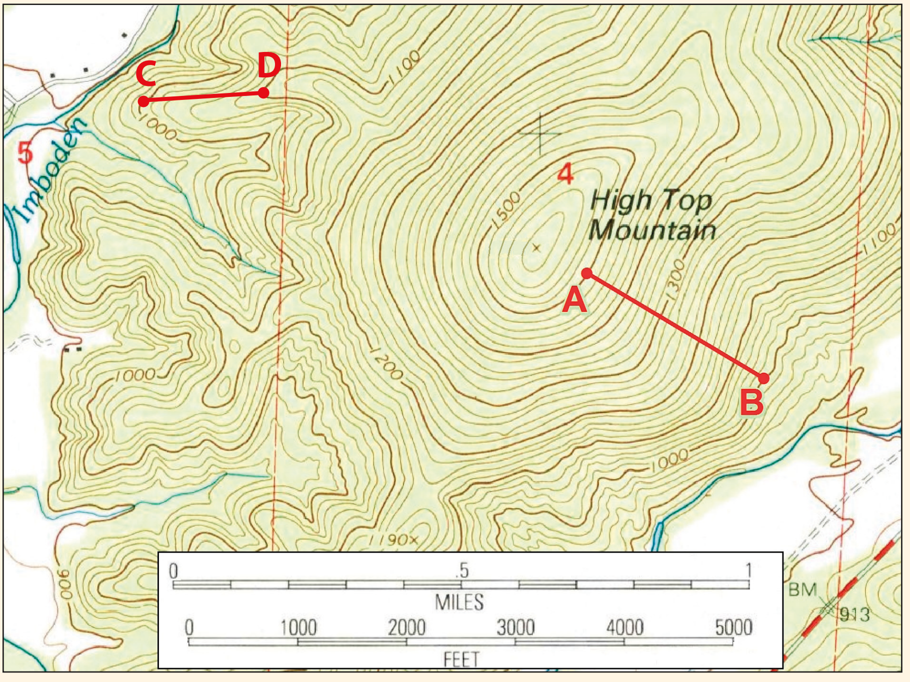
3. Use the map of a portion of Yellowstone National Park below to determine the names of the features with the following coordinates:
   a. 44°59′N, 110°42′W
   b. 44°48′N, 110°27′W
   c. 44°38′N, 110°27′W
   d. 44°32′N, 110°50′W
   e. 44°25′N, 110°34′W



4. Use the map of a portion of Yellowstone National Park above to determine the latitude and longitude, to the nearest minute, of the following features:
   a. Fishing Bridge
   b. Lower Falls
   c. Norris Geyser Basin
   d. Old Faithful
   e. Tower Falls
5. Illustrate how features on a globe can be projected onto a cylinder, cone, and plane.
6. Describe the shape of Earth and explain why it is not spherical.
7. Describe an example of remote sensing using one of the non-visible parts of the electromagnetic spectrum.
8. What are some advantages of using satellites to observe Earth's weather?
9. Explain why contour lines are far apart in flat areas and close together

in steep areas.

10. Use the topographic map of High Top Mountain below to answer the following questions (elevation values are in feet).
    a. What is the contour interval of this map?
    b. What is the interval between index contours?
    c. Estimate an elevation value for the × at the top of High Top Mountain.
    d. What are the gradients between A—B and C—D, measured in feet per mile?
    e. What are the percent slopes between A—B and C—D?



Answers

1. a. Denver b. Chicago c. Miami d. Portland e. New York f. Los Angeles g. Boston h. Houston
2. a. 35°N, 107°W b. 34°N, 84°W c. 33°N, 97°W d. 45°N, 93°W e. 38°N, 122°W f. 48°N, 122°W g. 44°N, 79°W h. 39°N, 77°W
3. Mammoth Hot Springs b. Mount Washburn c. Mud Volcano d. Lower Geyser Basin e. West Thumb
4. a. 44°34′N, 110°23′W b. 44°43′N, 110°30′W c. 44°44′N, 110°42′W d. 44°28′N, 110°50′W e. 44°54′N, 110°23′W

10. a. 20 ft b. 100 ft c. between 1580 and 1600 ft, e.g., 1590 ft d. 1400 ft/mi, 480 ft/mi e. 26%, 9%

Experimental Investigation 1: Interpreting Topographic Maps

Overview

Mount Shasta is a volcano in northern California, and is the second tallest volcano in the Cascade Range of western North America. Mt. Shasta last erupted somewhere between 200 and 300 years ago, and is considered to be a serious volcanic hazard. A good way to study and visualize a mountain like Mount Shasta is by interpreting a topographic map. In this investigation, you will examine various features of a U.S. Geological Survey topographic map of the Mt. Shasta area. You will also learn how to construct topographic profiles, which are graphs showing cross sections along Earth's surface.

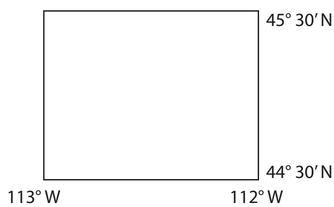
Mount Shasta. A newer volcanic cone called Shastina is forming on its west side (right side in this image).

Basic Materials List

- U.S. Geological Survey 1:24,000 topographic map of Mount Shasta, California, preferably 1998 edition.
- Ruler
- Graph paper (5 squares to an inch preferred)

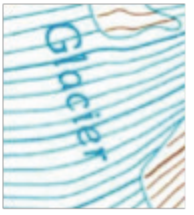
Part 1—Topographic Map Interpretation

In your Lab Journal, record the latitude and longitude of each corner of the map, and draw a sketch of the map with labels as illustrated to the right. Then address the following questions:



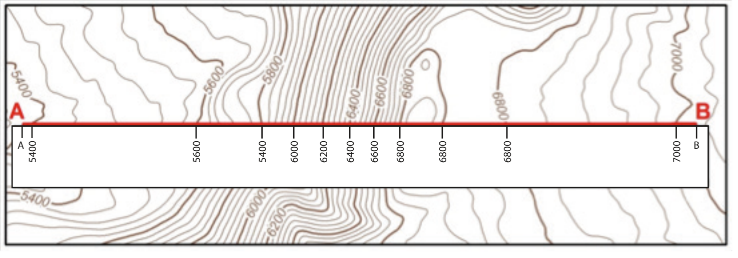
1. What is the scale of this map? What does that mean?
2. What is the distance, in a straight line, between the summit of Mt. Shasta and Clarence King Lake? Give your answer in miles and meters.
3. What is the contour interval of this map? What does that mean? What is the interval between index contours?
4. What is the elevation of the summit of Mt. Shasta? How do you know? What is this value in meters?

5. What is the elevation of Sisson Lake? How do you know? What is this value in meters?
6. What is the elevation difference between the top of Bolam Glacier and the bottom of Bolam Glacier? What is the overall gradient of Bolam Glacier in feet per mile? What is the overall percent slope of Bolam Glacier?
7. What is the gradient along Road 43N21 in the northwest corner of the map? How does this compare to the gradient of Bolam Glacier? Describe how the contour lines relate to the gradients at these two locations.
8. The trail heading south from the Bolam trailhead (at the end of road 43N21 in Question 7) does not follow a straight line. Why not?
9. Where is the lowest elevation on the map and what is the elevation at this location?
10. Compare the size of the glaciers (blue contour lines) on the north side of Mt. Shasta with the size of the glaciers on the south side of Mt. Shasta. Form a hypothesis as to why there is a difference in the areas of these glaciers.



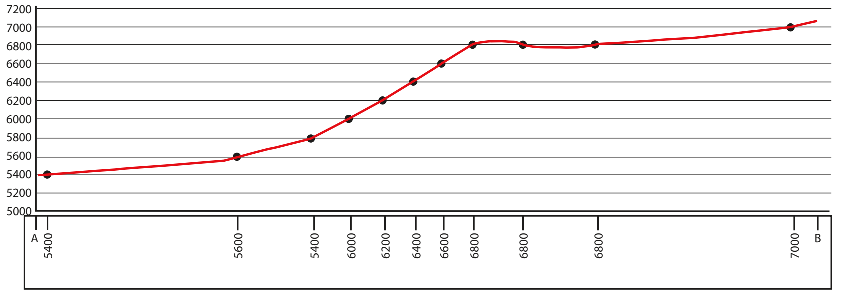
Part 2—Constructing a Topographic Profile

A *topographic profile* is a cross section through Earth's surface along a line. One can think of a topographic profile as a graph of what Earth's surface would look like if one were to take a slice out of Earth's crust and view it from the side. The first step in constructing a topographic profile is to lay a strip of paper along the profile line, and transfer contour values to the paper, as shown below.



The second step is to take the strip of paper and transfer the values to a graph on graph paper, as shown by the black dots below. For the vertical scale on your graph, use the same scale as shown on the map.

On a 1:24,000 topographic map, one inch represents 24,000 in (2,000 ft) on Earth's surface. In the topographic profile above, the horizontal and vertical scales are both 1:24,000, so 1 inch in either the horizontal or vertical directions represents 2,000 ft. Since the scales on the horizontal and vertical axes of the graph are the same, the graph visually represents the true slope of Earth's surface.

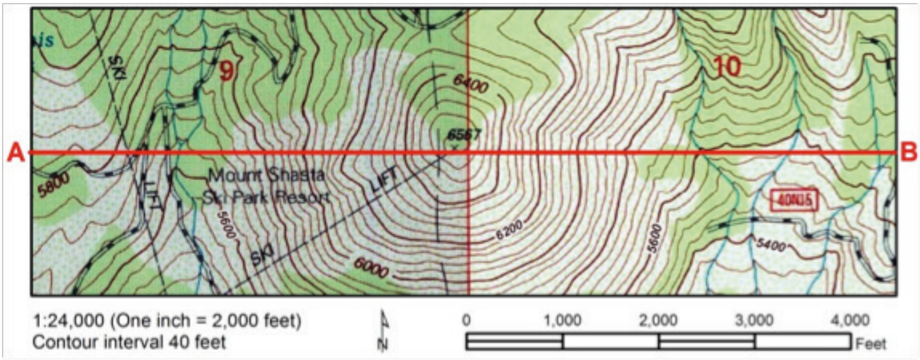


In some cases, such as in flat areas, it is preferable to have the vertical scale larger than the horizontal scale in order to emphasize subtle variations in the topography. This is called *vertical exaggeration*.

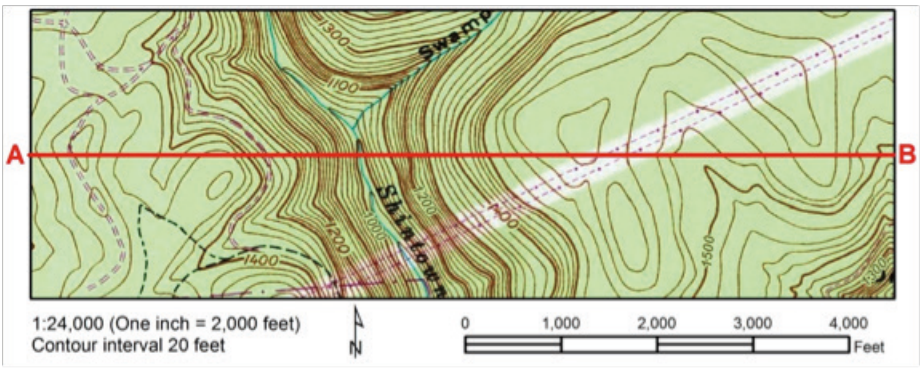
Finally, draw a smooth curve to represent Earth's surface along the profile line. Note that on the topographic profile, the curve is steeper where contour lines are closer together; the slope is more gentle where contour lines are farther apart.

Construct topographic profiles from A to B for the three topographic maps shown on the next page.

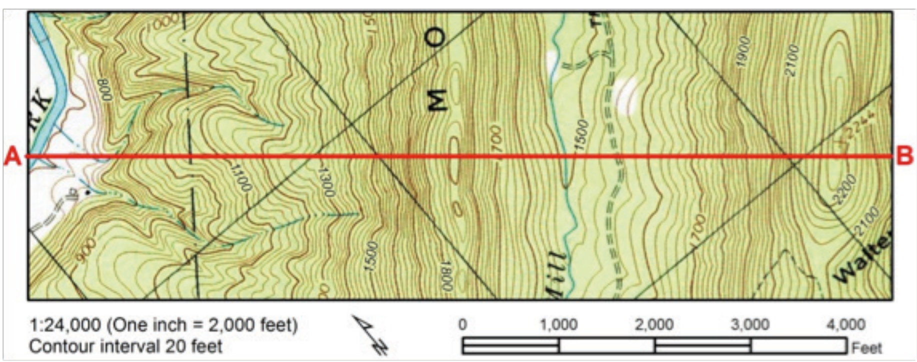
Map 1: McCloud, California



Map 2: Rileyville, Virginia



Map 3: Renova West, Pennsylvania



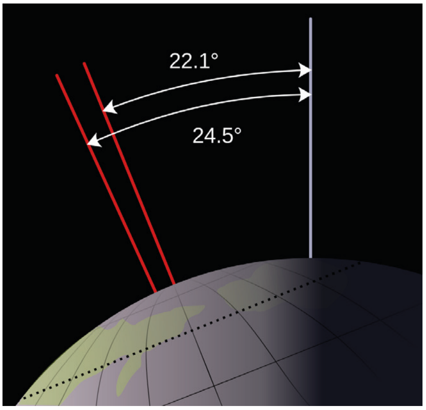


Figure 15.26. The angle at which Earth's axis is tilted changes over a period of 41,000 years.

in Figure 15.26. Earth's axis presently tilts at an angle of 23.5° relative to the ecliptic, but varies between 22° and 24.5° over a 41,000-year cycle. This variation affects the difference in temperatures between summer and winter.

Earth's climate is very complex, and the causes of natural climate changes are not completely understood. There is no single theory that explains all the ups and downs of climate variations in the past, and so there are uncertainties in predicting how climate will change in the future. However, there are reasons to believe that human activities are changing global climate in ways that are more significant than changes that occur naturally.

15.3.2 Human-Caused Climate Change

The topic of climate change is often in the news, and the issue is very controversial, both among Christians and in the world as a whole. Almost all climate scientists—those meteorologists who specialize in climate—believe that Earth's surface and troposphere are rapidly warming and that this warming is due to human activities.

One of the main factors that controls the temperature of Earth's surface is the *greenhouse effect*, discussed in Chapter 3. To review, the greenhouse effect is the heating of a planet's atmosphere by gases that trap heat in the atmosphere. As shown in Figures 3.3 and 13.17, most incoming sunlight travels through Earth's atmosphere without being absorbed by gases; if sunlight were absorbed by gases, the sky would be dark rather than bright. Earth's surface, on the other hand, absorbs sunlight and becomes warm. This warm surface radiates invisible infrared radiation back toward space. Some of this radiation is absorbed by atmospheric *greenhouse gases*, resulting in the heating of the atmosphere. Greenhouse gases are gases that have the ability to trap heat in the atmosphere. They include water vapor, carbon dioxide (CO_2), methane (CH_4), and ozone (O_3). None of the most abundant gases in the atmosphere—nitrogen, oxygen, and argon—are greenhouse gases.

The natural greenhouse effect is actually a very good thing. Climate scientists estimate that Earth's surface temperature would average about 33°C (59°F) colder than it is at present if the greenhouse effect did not occur. Even during the summer, high temperatures in most places on Earth would be below freezing without the greenhouse effect. The ocean surface would be frozen in most places and ice sheets would cover most of the land. Most of the planet would be uninhabitable.

Human activities are causing the amounts of greenhouse gases in Earth's atmosphere to increase, especially the level of carbon dioxide. Carbon dioxide is released into the air when fossil fuels—petroleum, natural gas, and coal—are burned. The variation in the concentration of carbon dioxide in Earth's atmosphere over time is graphed in Figure 15.27, and was probably about 280 ppm at the beginning of the Industrial Revolution in the mid-1700s when factories began burning large amounts of coal. The amount of carbon dioxide has been steadily rising since then, especially in the past several decades because of a world-

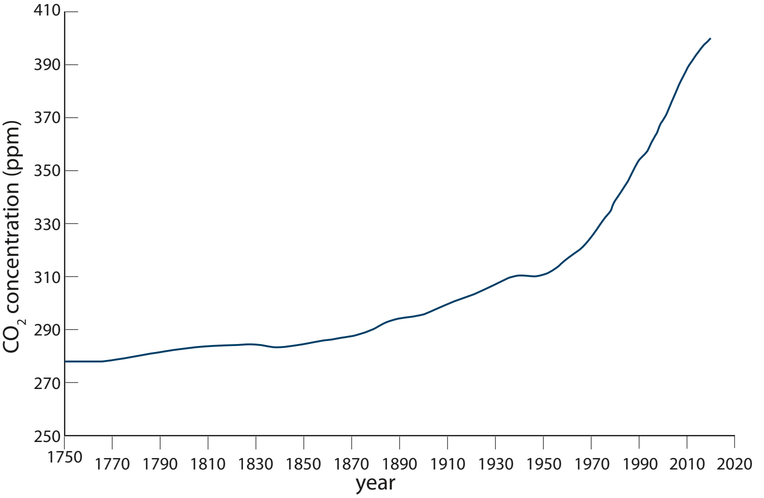


Figure 15.27. The concentration of carbon dioxide in Earth's atmosphere has been increasing since at least the 1700s primarily due to burning of fossil fuels.

wide increase in the number of automobiles (which burn gasoline derived from petroleum) and fossil fuel-burning power plants (which burn either coal or natural gas). The concentration of carbon dioxide in the atmosphere reached 400 ppm in 2015. Taking our present rates of fossil-fuel combustion and projecting these rates into the future, scientists predict atmospheric CO_2 to increase to somewhere between 500 and 800 ppm by the year 2100.

Figure 15.22 shows how temperature has changed over the past 11,000 years. Note that at the far right side of the graph, temperatures have risen considerably in a short period of time, reversing what had been an overall downward trend. Most climate scientists are convinced that this rapid increase in global temperatures is human-caused, and that it will continue into the future due to elevated levels of carbon dioxide. Based on computer models of how the greenhouse effect works, many believe Earth's temperature will increase by 1° to 3.5°C (2° to 6°F) by the year 2100.

Earth's atmosphere is complex, and one cannot simply say, "The amount of carbon dioxide is increasing, so the atmosphere will definitely get warmer." For example, if Earth's atmosphere warms up a bit because the amount of carbon dioxide has increased, then there will be more evaporation of water from the surface. This evaporation could lead to more cloud cover in many places. Greater cloud cover could lead to either greater trapping of heat within the atmosphere (resulting in even greater heating) or greater reflection of sunlight back into space (producing a cooling effect). The outcome that actually occurs depends on the types of clouds that form. There are a number of other complications that affect our models of increasing greenhouse-gas concentrations in the atmosphere. Some of these complications cause the models to predict an increase in temperature, others result in predictions of a decrease.

Even when these complications are taken into consideration, almost all climate scientists agree that Earth is warming and that the increase in global temperatures is human-caused (*anthropogenic*). A global temperature increase of 3°C (6°F) may not sound like much, but this increase would make the world a very different place than what it has been throughout human history. Here are just a few of the potential consequences that would probably occur if the average global temperature of Earth were to increase by up to 3°C:

- Weather would exhibit more extremes. In fact, many scientists believe that a trend in this direction has already begun. Each year brings new reports of extreme drought, flooding, and storms. The year 2015 was recently determined to be the warmest year on record. Extreme cold-weather events can also be part of this scenario because climate models indicate that an increase in global average temperature does not result in an even temperature increase across the globe. Some areas will get warmer and others will not, but all areas will contend with more extreme fluctuations in weather.
- Sea level around the planet would rise. There are two reasons for this. The first is that seawater, like most substances, expands when it is heated, as mentioned in Section 12.6.3 in the chapter on oceanography. The surface of the ocean has only one way to go if the ocean volume expands—upward. The second reason is that a warmer world would likely cause an increase in melting of a portion of the ice sheets that cover Antarctica and Greenland. Almost all the water from this melted ice would end up in the oceans. Sea level has risen by 10–25 cm (4–10 in) in the past century, and it is expected to continue to rise as global temperatures increase. A sea level rise of only 50 cm (20 in), which is likely if Earth warms up by 3°C, would cause serious problems for low-lying cities such as New Orleans and New York, for large parts of low-elevation nations such as The Netherlands, Bangladesh, and for many coral atoll nations in the Indian and Pacific Oceans.
- More of the precipitation that falls on mountainous areas in the winter would fall as rain rather than as snow. Many of the world's great rivers, ranging from the Missouri and Colorado in North America to the Indus, Ganges, and Yangtze in Asia, depend on snowmelt for much of their summer discharge. If precipitation falls as snow in the winter, it feeds streams during the summer when the snow melts. If precipitation falls as rain in the winter, much of it will immediately enter streams and return to the sea, resulting in far less water available in the hottest part of the year for agriculture, industry, communities, and wildlife.
- Some areas would actually benefit in various ways from warmer temperatures. For example, large agricultural areas of Canada would have a longer growing season for crops due to a shorter winter season. Other regions would become less productive for growing crops because of increased evaporation due to higher temperatures. The result for these regions would be extensive drought leading to famines and other severe problems.

So long as humans continue to burn large quantities of fossil fuels, the amount of carbon dioxide in Earth's atmosphere will continue to rise. Even if we stopped burning coal, petroleum, and natural gas today, it is likely that Earth's temperature would continue to rise for decades or longer because of the excess greenhouse gases we have already pumped into the atmosphere. Most scientists agree that it is crucial for us to develop alternatives to fossil fuels as quickly as possible in order to reduce the negative consequences of a warming global climate. Alternative energy sources include electricity generated from wind, water, sunlight, nuclear power plants (perhaps), and liquid fuels created from plants or algae.

There are many (particularly in the U.S.) who believe humans are not the cause of the present warming of Earth; most of these people are not climate scientists. It is clear that we do not yet fully understand natural changes to Earth's climate, but that does not mean we cannot predict some of the consequences of continuing to add large amounts of carbon dioxide to the atmosphere, which will almost certainly lead to further warming. We do not need to have a complete understanding of how climate works in order to recognize that a warming climate brings significant risks to human well-being and causes problems for the rest of the living world as well.

Many books have been written about climate change. There are many other factors involved, and our treatment here is quite brief. For example, oceans and forests absorb CO_2, helping to maintain atmospheric balance. However, oceanic absorption increases ocean acidity, a problem that is already having a devastating effect on coral reefs. And though forests help, increasing temperature and CO_2 levels indicate that they cannot absorb the large amounts of CO_2 we are producing.

The response to human-caused climate change involves not only scientists, but lawmakers, businesses, and many other people. This response has already begun: world leaders have already met several times to discuss and plan actions to reduce CO_2 emissions, most recently at the climate summit in Paris, France, in December 2015. It is virtually certain that dealing with climate change will be a major political, social, and scientific concern in your lifetime and for generations to come.

Learning Check 15.3

1. Describe the changes that occur to surface waters in the Pacific Ocean when an El Niño is occurring.
2. Describe how large volcanic eruptions affect climate.
3. Give examples of a factor that affects climate for a short amount of time (for a few months or years) and a factor that affects climate for a longer period of time.
4. Describe the three aspects of Earth's orbit that are part of the Milankovitch theory.
5. Explain why most climate scientists believe increasing levels of carbon dioxide in the atmosphere are leading to a warmer global climate.
6. Describe the potential consequences of a warming climate.