Earth, Moon, and Sun

Dana Desonie, Ph.D.

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AUTHOR
Dana Desonie, Ph.D.

CONTRIBUTOR
Mary Lusk

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CHAPTER 1 Earth, Moon, and Sun

CHAPTER OUTLINE

A photograph of Earth taken by an astronaut orbiting the Moon on Christmas Eve, 1968. The three Apollo 8 astronauts were the first humans to ever leave Earth orbit.

In this image, light from the Sun partially illuminates Earth. Earth is partially darkened just as the Moon appears partially darkened to Earth observers during many of its phases.

Courtesy of the Apollo 8 crew and NASA. www.nasa.gov/multimedia/imagegallery/image_feature_102.html. Public Domain.

1.1 Planet Earth

Lesson Objectives

- Recognize that Earth is a modified sphere (oblate spheroid), and describe the evidence for this conclusion.
- Explain what causes Earth's magnetism and the effects that magnetism has on the Earth.
- Describe Earth's rotation on its axis.
- Describe Earth's revolution around the Sun.

Vocabulary

- axis
- ellipse
- hemisphere
- revolution
- rotation

Introduction

This book so far has been almost entirely about Earth. This chapter is concerned with Earth as a planetary body, a member of the Earth-Moon pair that orbit each other and the Sun.

Earth as a Planetary Body

Earth is an inner planet in the solar system and it is very much like the other inner planets, at least in its size, shape, and composition. But many features make Earth very different from the planets and any other planet that we know of so far.

Earth's Shape

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

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

Try to design an experiment involving a ship and the ocean to show Earth is round. If you are standing on the shore and a ship is going out to sea, the ship gets smaller as it moves further away from you but the ship's bottom also starts to disappear as the vessel goes around the arc of the planet (**Figure** 1.1). There are many other ways that early scientists and mariners knew that Earth was not flat.

FIGURE 1.1
Earth's curvature is noticeable when objects at a distance are below the arc.

Even the ancient Greeks knew that Earth was round by observing the arc shape of the shadow on the Moon during a lunar eclipse. NASA has an animation of a lunar eclipse here: http://science.nasa.gov/media/medialibrary/2003/10/29/04nov_lunareclipse2_resources/reddy1_big.gif .

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

Earth's Magnetism

Earth has a **magnetic field** (**Figure** 1.2) that behaves as if the planet had a gigantic bar magnet inside of it. Earth's magnetic field also has a north and south pole and a magnetic field that surrounds it. The magnetic field arises from the convection of molten iron and nickel metal in Earth's outer liquid iron core.

Earth's magnetic field extends several thousand kilometers into space. The magnetic field shields the planet from harmful radiation from the Sun (**Figure** 1.3).

Earth's Motions

Imagine a line passing through the center of Earth that goes through both the North Pole and the South Pole. This imaginary line is called an **axis**. Earth spins around its axis, just as a top spins around its spindle. This spinning movement is called Earth's **rotation**. At the same time that the Earth spins on its axis, it also orbits, or revolves around the Sun. This movement is called **revolution.**

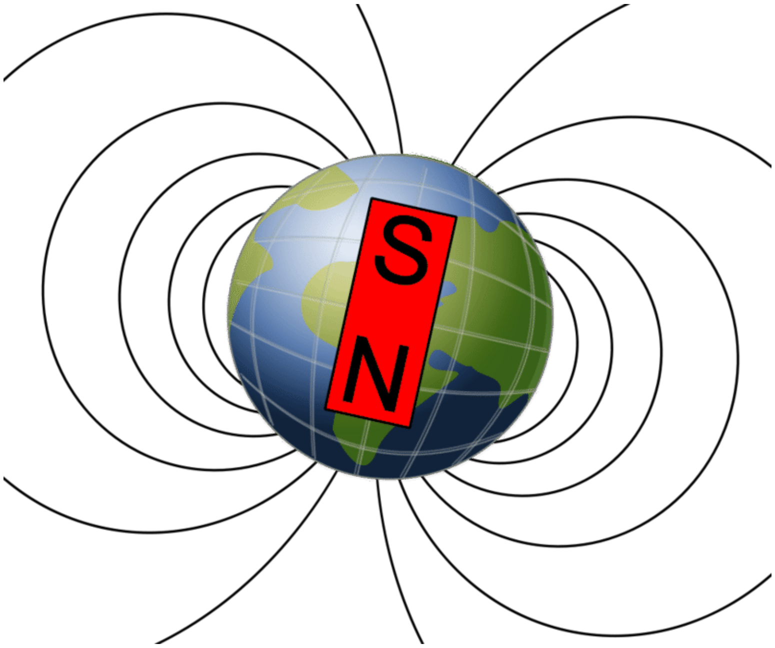

FIGURE 1.2
Earth's magnetic field.

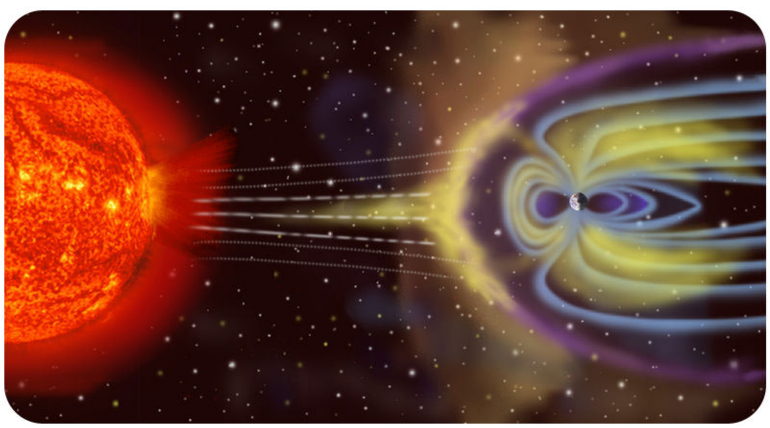

FIGURE 1.3
Earth, on the right, is tiny in comparison to the Sun, but its magnetic field extends far outward.

Earth's Rotation

In 1851, a French scientist named Léon Foucault took an iron sphere and swung it from a wire. He pulled the sphere to one side and then released it, letting it swing back and forth in a straight line (**Figure** 1.4). A ball swinging back and forth on a string is called a pendulum.

A pendulum set in motion will not change its motion, and so the direction of its swinging should not change. However, Foucault observed that his pendulum did seem to change direction. Since he knew that the pendulum could not change its motion, he concluded that the Earth, underneath the pendulum was moving. **Figure** 1.5 shows how this might look.

An observer in space will see that Earth requires 23 hours, 56 minutes, and 4 seconds to make one complete rotation on its axis. But because Earth moves around the Sun at the same time that it is rotating, the planet must turn just a little bit more to reach the same place relative to the Sun. Hence the length of a day on Earth is actually 24 hours. At the equator, the Earth rotates at a speed of about 1,700 km per hour, but at the poles the movement speed is nearly

FIGURE 1.4
Foucault's pendulum is now on display in the Pantheon in Paris.

FIGURE 1.5
Imagine a pendulum at the North Pole. The pendulum always swings in the same direction, but because of Earth's rotation, its direction appears to change to observers on Earth.

nothing.

A Turn of the Earth

In this video, MIT students demonstrate how a Foucault Pendulum is used to prove that the Earth is rotating. See the video at https://www.youtube.com/watch?v=_pECtfYa2Us .

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Earth's Revolution

For Earth to make one complete revolution around the Sun takes 365.24 days. This amount of time is the definition of one year. The gravitational pull of the Sun keeps Earth and the other planets in orbit around the star. Like the other planets, Earth's orbital path is an **ellipse** (**Figure** 1.6) so the planet is sometimes farther away from the Sun than at other times. The closest Earth gets to the Sun each year is at perihelion (147 million km) on about January 3rd and the furthest is at aphelion (152 million km) on July 4th. Earth's elliptical orbit has nothing to do with Earth's seasons.

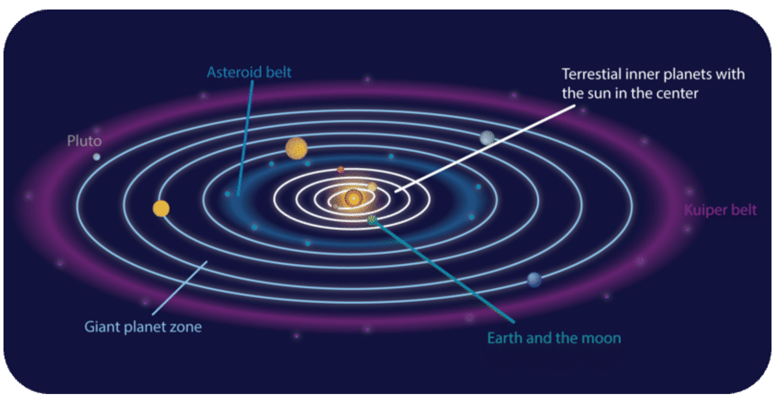


FIGURE 1.6

Earth and the other planets in the solar system orbit around the Sun. Although the orbits are slightly elliptical, in this image the ellipses are exaggerated.

During one revolution around the Sun, Earth travels at an average distance of about 150 million km. Earth revolves around the Sun at an average speed of about 27 km (17 mi) per second, but the speed is not constant. The planet moves slower when it is at aphelion and faster when it is at perihelion.

The reason the Earth (or any planet) has seasons is that Earth is tilted 23 $1/2^o$ on its axis. During the Northern Hemisphere summer the North Pole points toward the Sun, and in the Northern Hemisphere winter the North Pole is tilted away from the Sun (**Figure** 1.7).

Lesson Summary

- Earth rotates or spins on its axis approximately once each day and revolves around the Sun approximately once a year.

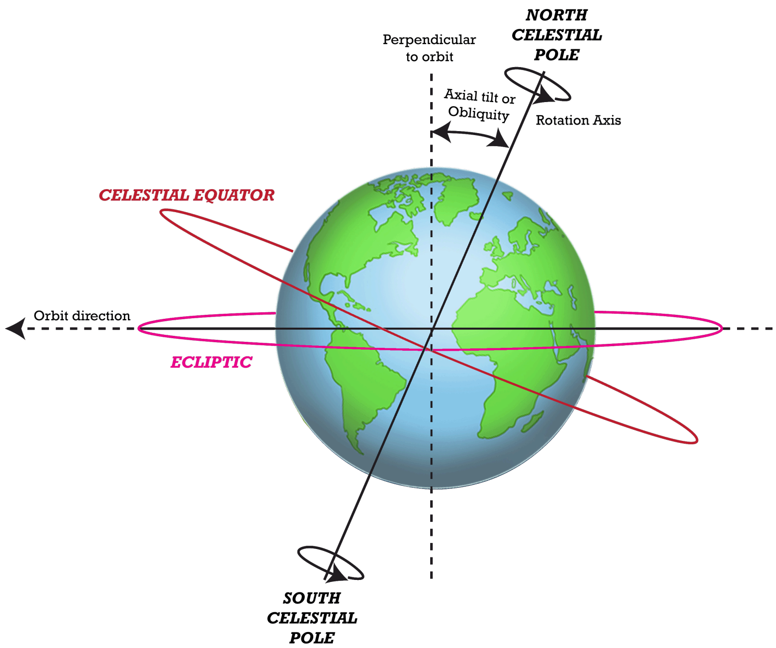


FIGURE 1.7
The Earth tilts on its axis.

- Earth's orbit around the Sun is elliptical; the planet is closer at perihelion and farther at aphelion.
- The tilt of Earth's axis produces seasons.
- The Earth and other planets in our solar system are rotating spheres.
- Earth has a magnetic field created by the convection of molten liquid in the outer core.
- The magnetic field shields Earth from harmful solar radiation.

Review Questions

1. When you watch a tall ship sail over the horizon of the Earth, you see the bottom part of it disappear faster than the top part. Why does this happen?

2. Why are we able to use magnets to determine north-south directions on Earth?

3. Describe the difference between Earth's rotation and its revolution.

4. What is the force that keeps the Earth and other planets in their orbital paths?

5. In its elliptical orbit around the Sun, the Earth is closest to the Sun in January. If Earth is closes to the Sun in January, why is January winter in the Northern Hemisphere?

6. Where on Earth would Foucault's pendulum appear to not be moving? Where would it appear to be moving the most?

7. The planet Jupiter is about 778,570,000 kilometers from the Sun; Earth is about 150,000,000 kilometers from the Sun. Does Jupiter take more or less time to make one revolution around the sun? Explain your answer.

Points to Consider

- What type of experiment could you create to prove that the Earth is rotating on its axis?

- If you lived at the equator, would you experience any effects because of Earth's tilted axis?
- If Earth suddenly increased in mass, what might happen to its orbit around the Sun?
- Would life on Earth be impacted if Earth lost its magnetic field?
- Why are the inner planets spherical?

1.2 Earth's Moon

Lesson Objectives

- Explain how scientists think the Moon formed.
- Describe the features of the Moon.

Vocabulary

- crater
- lunar
- maria
- terrae

Introduction

On July 20, 1969, hundreds of millions of people all over the world witnessed something incredible. Never before had a human being walked on a planetary body other than Earth. But on that day, Neil Armstrong and Buzz Aldrin walked on the Moon (**Figure** 1.8). More than 30 years later, the Moon remains the only place that humans have visited outside of our home planet.

Human explorations of the Moon, along with visits by rovers and satellites, have helped scientists learn a great deal about the geology of Earth's only natural satellite. Much of what we know about the Moon was learned by astronauts visiting the Moon and from data collected by the Apollo missions.

Lunar Characteristics

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

The Moon makes one complete orbit around the Earth every 27.3 days, relative to the fixed stars. This is the Moon's orbital period. The Moon also rotates on its axis once every 27.3 days. Do you know what this means? The same side of the Moon always faces Earth and so that side of the Moon is what we always see in the night sky (**Figure** 1.9). The Moon makes no light of its own, but instead only reflects light from the Sun.

FIGURE 1.8
Astronaut Buzz Aldrin walks on the Moon on July 20, 1969. The footprints are the first signs of life ever on the Moon.

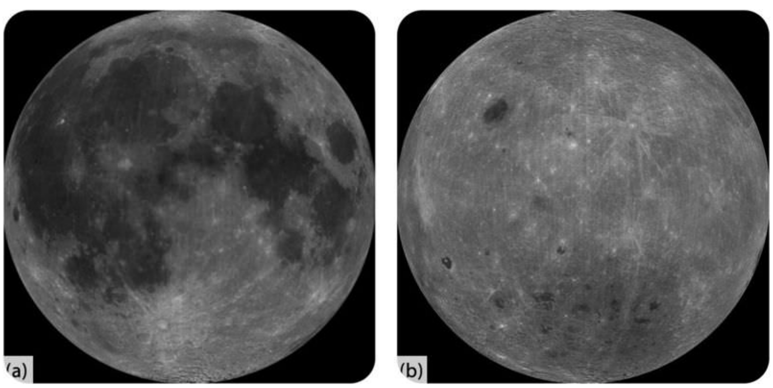


FIGURE 1.9
(a) The near side of the Moon faces Earth continually. It has a thinner crust with many more maria (flat areas of basaltic rock). (b) The far side of the Moon has only been seen by spacecraft. It has a thicker crust and far fewer maria (flat areas of basaltic rock).

The Lunar Surface

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

Earth's landscape is extremely varied with mountains, valleys, plains and hills. This landscape is always changing as plate tectonics builds new features and weathering and erosion destroys them.

The landscape of the Moon is very different. With no plate tectonics, features are not built. With no atmosphere, features are not destroyed. Still, the Moon has a unique surface. One major lunar surface feature is the bowl-shaped **craters** that are caused by meteorite impacts (**Figure** 1.10). If Earth did not have plate tectonics or erosion, its surface would also be covered with meteorite craters.

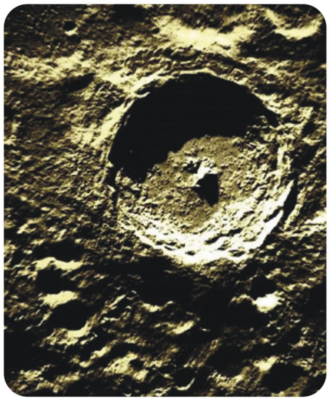


FIGURE 1.10
A crater on the surface of the Moon.

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

The lighter parts of the Moon are called **terrae** or highlands (**Figure** 1.11). The terrae are higher than the maria and include several high mountain ranges. The terrae are the light silicate minerals that precipitated out of the ancient magma ocean and formed the early lunar crust.

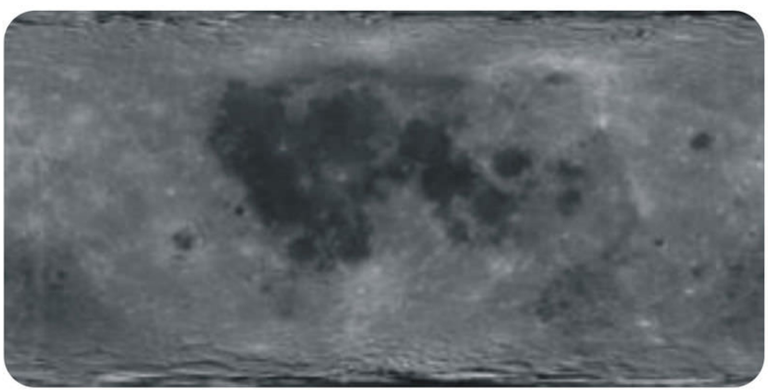


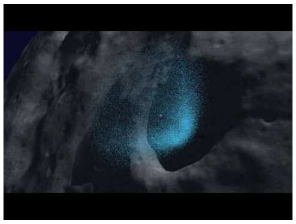
FIGURE 1.11
A close-up of the Moon, showing maria (the dark areas) and terrae (the light areas); maria covers around 16% of the Moon's surface, mostly on the side of the Moon we see.

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

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

KQED: NASA Ames Rocket to the Moon

LCROSS crashed into the Moon in May 2009. This QUEST video describes the mission. After watching, look up the mission to see what they found! Learn more at: http://science.kqed.org/quest/video/nasa-ames-rocket-to-the-moon/ .



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Interior of the Moon

Like Earth, the Moon has a distinct crust, mantle, and core. What is known about the Moon's interior was determined from the analysis of rock samples gathered by astronauts and from unpiloted spacecraft sent to the Moon (**Figure** 1.12).

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

FIGURE 1.12

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

- The mantle is composed of the minerals olivine and orthopyroxene. Analysis of Moon rocks indicates that there may also be high levels of iron and titanium in the lunar mantle.

- The crust is composed of igneous rock rich in the elements oxygen, silicon, magnesium, and aluminum. The crust is about 60 km thick on the near side of the Moon and about 100 km thick on the far side.

Lesson Summary

- The Moon makes one rotation on its axis in the time it takes for it to orbit the Earth.
- The Moon has dark areas, called maria, surrounded by lighter colored highland areas, called terrae.
- Because the Moon is geologically inactive and doesn't have an atmosphere, it has many thousands of craters on its surface.
- The Moon is made of many materials similar to Earth and has a crust, mantle, and core, just like the Earth.

Review Questions

1. Compare the composition of the Moon's surface with the composition of Earth's surface.

2. Why is there no weather on the Moon?

3. Rusting is a process that happens when oxygen reacts chemically with iron, in the presence of water. Can rusting occur on the Moon? Explain your answer.

4. What is the difference between maria and terrea?

5. How does the Moon's interior differ from Earth's?

6. How much do landscape features on the Moon change over time compared to landscape features on Earth? Explain your answer.

7. Why is the force of gravity on your body weaker on the Moon than on the Earth?

Points to Consider

- What things would be different on Earth if Earth did not have a moon?
- If the Moon rotated on its axis once every 14 days, would we see anything different than we do now?
- How do we know that the Moon has been geologically inactive for billions of years?

1.3 The Sun

Lesson Objectives

- Describe the layers of the Sun.
- Describe the surface features of the Sun.

Vocabulary

- chromosphere
- convection zone
- corona
- nuclear fusion
- photon
- photosphere
- plasma
- radiative zone
- solar flare
- solar prominence

Introduction

Consider Earth, the Moon, and all the other planets and satellites in the solar system. The mass of all of those objects together accounts for only 0.2% of the total mass of the solar system. The rest, 99.8% of all the mass in the solar system, is the Sun!

The Sun (**Figure** 1.13) is the center of the solar system and the largest object in the solar system. This nearby star provides light and heat and supports almost all life on Earth.

Layers of the Sun

The Sun is a sphere, composed almost entirely of the elements hydrogen and helium. The Sun is not solid or a typical gas. Most atoms in the Sun exist as **plasma**, a fourth state of matter made up of superheated gas with a positive electrical charge.

Internal Structure

Because the Sun is not solid, it does not have a defined outer boundary. It does, however, have a definite internal structure with identifiable layers (**Figure** 1.14). From inward to outward they are:

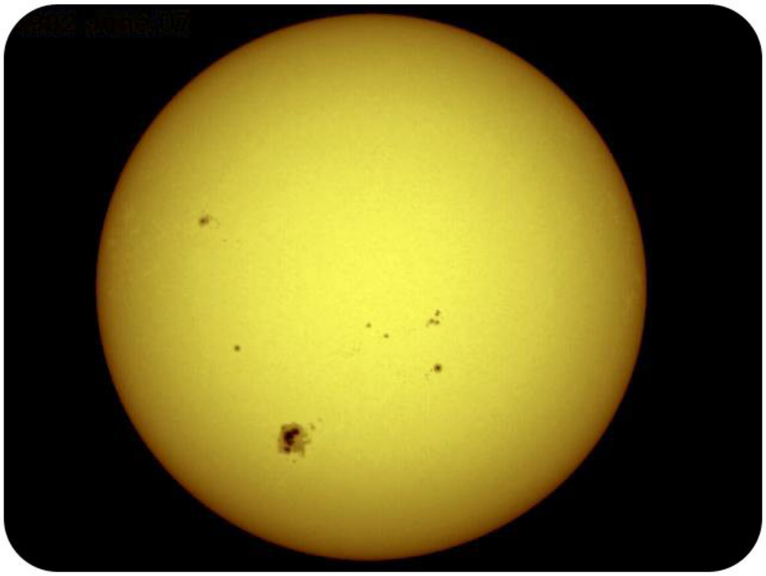


FIGURE 1.13
The Sun.

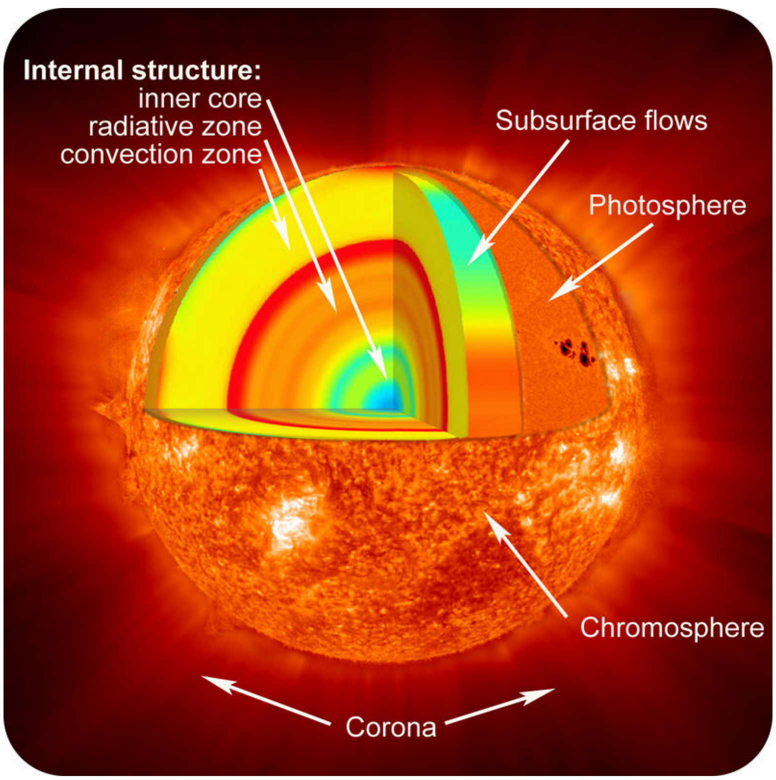


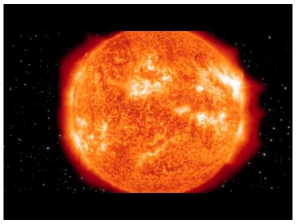
FIGURE 1.14
The layers of the Sun.

- The Sun's central core is plasma with a temperature of around 27 million^{o}C. At such high temperatures hydrogen combines to form helium by **nuclear fusion**, a process that releases vast amounts of energy. This energy moves outward, towards the outer layers of the Sun. Nuclear fusion in stars is discussed more in the *Stars, Galaxies, and the Universe* chapter.
- The **radiative zone**, just outside the core, has a temperature of about 7 million^{o}C. The energy released in the core travels extremely slowly through the radiative zone. A particle of light, called a **photon**, travels only a

few millimeters before it hits another particle. The photon is absorbed and then released again. A photon may take as long as 50 million years to travel all the way through the radiative zone.

- In the **convection zone**, hot material from near the radiative zone rises, cools at the Sun's surface, and then plunges back downward to the radiative zone. Convective movement helps to create solar flares and sunspots.

The first video describes the basics of our Sun, including how it is powered by nuclear reactions **(1e)**: http://www.youtube.com/watch?v=JHf3dG0Bx7I (8:34).



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The second video discusses what powers the sun and what is its influence on Earth and the rest of the solar system **(1e)**: http://www.youtube.com/watch?v=S6VRKKh6gyA (8:25).

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The Outer Layers

The next three layers make up the Sun's atmosphere. Since there are no solid layers to any part of the Sun, these boundaries are fuzzy and indistinct.

- The **photosphere** is the visible surface of the Sun, the region that emits sunlight. The photosphere is relatively cool – only about 6,700°C. The photosphere has several different colors; oranges, yellow and reds, giving it a grainy appearance.
- The **chromosphere** is a thin zone, about 2,000 km thick, that glows red as it is heated by energy from the photosphere (**Figure** 1.15). Temperatures in the chromosphere range from about 4,000°C to about 10,000°C. Jets of gas fire up through the chromosphere at speeds up to 72,000 km per hour, reaching heights as high as 10,000 km.

- The **corona** is the outermost plasma layer – It is the Sun's halo or 'crown.' The corona's temperature of 2 to 5 million°C is much hotter than the photosphere (**Figure** 1.16).

The movie *Seeing a Star in a New Light* can be seen here: http://sdo.gsfc.nasa.gov/gallery/youtube.php .

Surface Features

The Sun's surface features are quite visible, but only with special equipment. For example, sunspots are only visible with special light-filtering lenses.

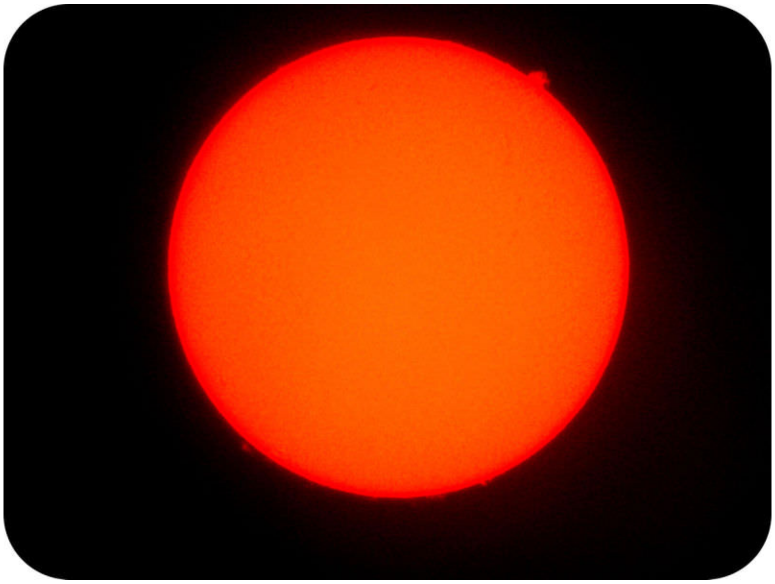


FIGURE 1.15
The chromosphere as seen through a filter.

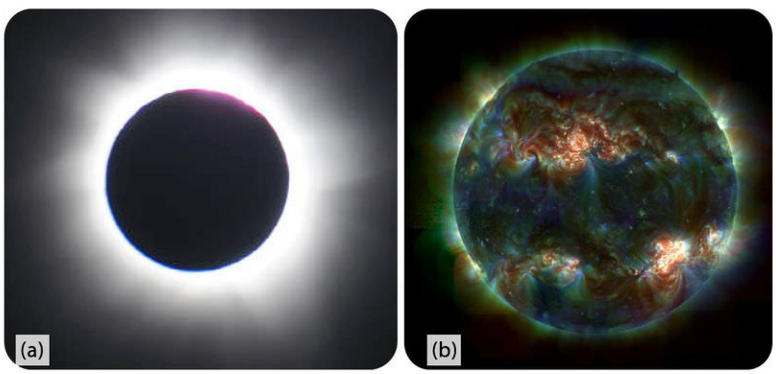


FIGURE 1.16
(a) During a solar eclipse, the Sun's corona is visible extending millions of kilometers into space. (b) The corona and coronal loops in the lower solar atmosphere taken by the TRACE space telescope.

Sunspots

The most noticeable surface feature of the Sun are cooler, darker areas known as sunspots (**Figure** 1.17). Sunspots are located where loops of the Sun's magnetic field break through the surface and disrupt the smooth transfer of heat from lower layers of the Sun, making them cooler and darker and marked by intense magnetic activity. Sunspots usually occur in pairs. When a loop of the Sun's magnetic field breaks through the surface, a sunspot is created where the loop comes out and where it goes back in again.

Solar Flares

There are other types of interruptions of the Sun's magnetic energy. If a loop of the sun's magnetic field snaps and breaks, it creates **solar flares**, which are violent explosions that release huge amounts of energy (**Figure** 1.18).

A movie of the flare is seen here: http://www.youtube.com/watch?v=MDacxUQWeRw .

A strong solar flare can turn into a coronal mass ejection (**Figure** 1.19).

A solar flare or coronal mass ejection releases streams of highly energetic particles that make up the solar wind. The solar wind can be dangerous to spacecraft and astronauts because it sends out large amounts of radiation that can

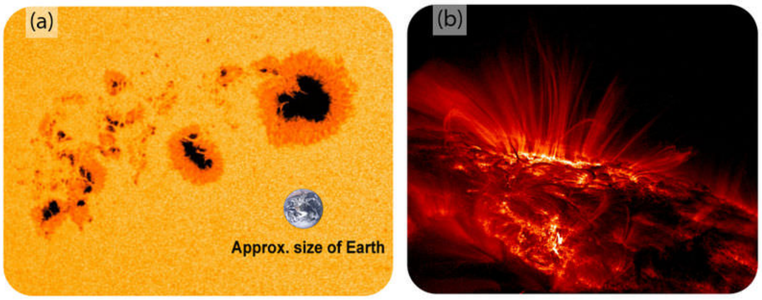


FIGURE 1.17
(a) Sunspots usually occur in 11-year cycles, increasing from a minimum number to a maximum number and then gradually decreasing to a minimum number again. (b) A close-up of a sunspot taken in ultraviolet light.

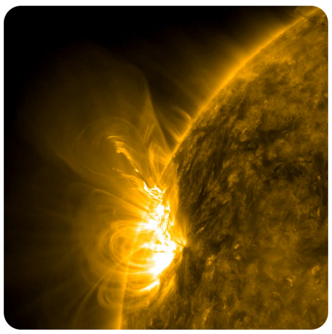


FIGURE 1.18
Magnetic activity leads up to a small solar flare.

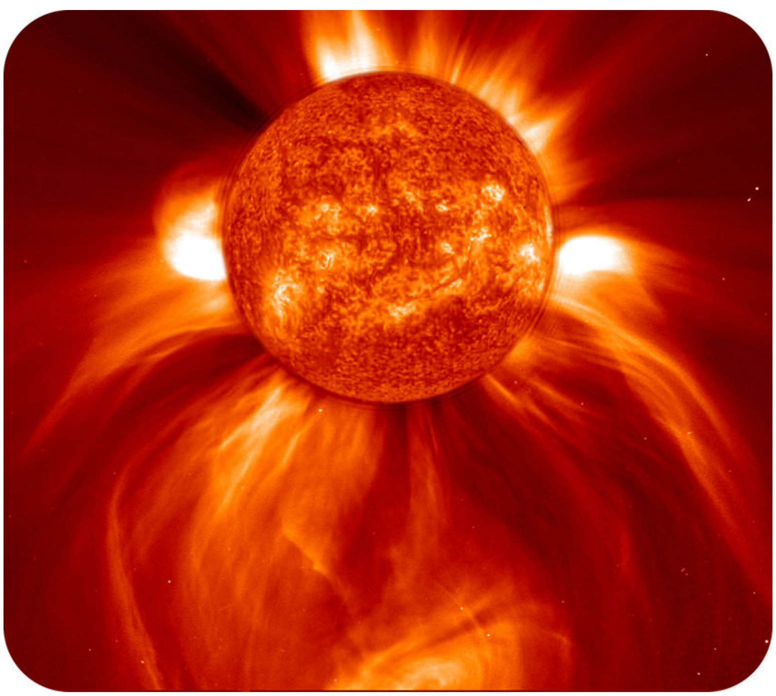
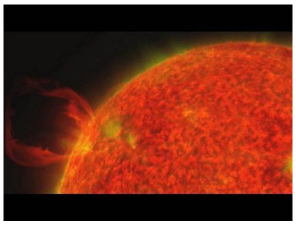


FIGURE 1.19
A coronal mass ejection is a large ejection of plasma from the star seen in this image.

harm the human body. Solar flares have knocked out entire power grids and disturbed radio, satellite, and cell phone communications.

KQED: Journey Into the Sun

The Solar Dynamics Observatory is a NASA spacecraft launched in early 2010 is obtaining IMAX-like images of the sun every second of the day, generating more data than any NASA mission in history. The data will allow researchers to learn about solar storms and other phenomena that can cause blackouts and harm astronauts. Learn more at: http://science.kqed.org/quest/video/quest-quiz-the-sun/ .



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Solar Prominences

Another highly visible feature on the Sun is **solar prominences**. If plasma flows along a loop of the Sun's magnetic field from sunspot to sunspot, it forms a glowing arch that reaches thousands of kilometers into the Sun's atmosphere. Prominences can last for a day to several months. Prominences are also visible during a total solar eclipse.

Solar prominences are displayed in this video from NASA's Solar Dynamics Observatory (SDO): http://www.youtube.com/watch?v=QrmUUcr4HXg .

Most of the imagery comes from SDO's AIA instrument; different colors represent different temperatures, a common technique for observing solar features. SDO sees the entire disk of the Sun in extremely high spatial and temporal resolution, allowing scientists to zoom in on notable events such as flares, waves, and sunspots.

Solar Dynamics Observatory

The video above was taken from the SDO, the most advanced spacecraft ever designed to study the Sun. During its five-year mission, SDO will examine the Sun's magnetic field and also provide a better understanding of the role the Sun plays in Earth's atmospheric chemistry and climate. Since just after its launch on February 11, 2010, SDO is providing images with clarity 10 times better than high-definition television and will return more comprehensive science data faster than any other solar observing spacecraft.

Lesson Summary

- The mass of the Sun is 99.8% of the mass of our solar system.
- The Sun is mostly made of hydrogen with smaller amounts of helium in the form of plasma.
- The main part of the Sun has three layers: the core, radiative zone, and convection zone.
- The Sun's atmosphere also has three layers: the photosphere, the chromosphere, and the corona.
- Nuclear fusion of hydrogen in the core of the Sun produces tremendous amounts of energy that radiate out from the Sun.
- Some features of the Sun's surface include sunspots, solar flares, and prominences.

Review Questions

1. In what way does the Sun support all life on Earth?
2. Which two elements make up the Sun almost in entirety?
3. Which process is the source of heat in the Sun and where does it take place?
4. Why would human astronauts on a trip to Mars need to be concerned about solar wind? What is solar wind?
5. Describe how movements in the convection zone contribute to solar flares.
6. Do you think fusion reactions in the Sun's core will continue forever and go on with no end? Explain your answer.

Further Reading / Supplemental Links

- To find these videos for download, check out: http://www.nasa.gov/mission_pages/sdo/news/briefing-materials-20100421.html and http://svs.gsfc.nasa.gov/Gallery/SDOFirstLight.html .
- Subscribe to NASA's Goddard Shorts HD podcast: http://svs.gsfc.nasa.gov/vis/iTunes/f0004_index.html .
- To learn more about the SDO mission, visit: http://sdo.gsfc.nasa.gov/ .
- To learn about an older solar mission, SOHO, see: http://sohowww.nascom.nasa.gov/ .

Points to Consider

- If something were to suddenly cause nuclear fusion to stop in the Sun, how would we know? When would we know?
- Are there any types of dangerous energy from the Sun? What might be affected by them?
- If the Sun is made of gases such as hydrogen and helium, how can it have layers?

Going Further - Applying Math

Have would you measure something that you cannot reach? The answer is that you can use simple geometry. We can measure the diameter of the Sun, even though we cannot go to the Sun and even though the Sun is far too large for a human being to measure. To measure the Sun we use the rules of similar triangles. The sides of similar triangles are proportional to each other. By setting up one very small triangle that is proportional to another very large triangle, we can find an unknown distance or measurement as long as we know three out of four of the parts of the equation. If you make a pinhole in an index card and project an image of the Sun onto a clipboard held 1 meter from the index card, the diameter of our projected image of the Sun will be proportional to the true diameter of the Sun. Here's the equation: $s / d = S / D$, where s = diameter of the projected image of the Sun, S = true diameter of the Sun. The calculation also requires you to know the true distance between the Earth and the Sun, $D = 1.496 \times 10^8$ km and the distance ($d = 1$ meter) between the clipboard and the index card. Before you can correctly solve this equation, you will need to be sure all of your measurements are in the same units - in this case, change all your measurements to km. Try this out and see how accurately you can measure the true diameter of the Sun.

1.4 The Sun and the Earth-Moon System

Lesson Objectives

- Describe how Earth's movements affect seasons and cause day and night.
- Explain solar and lunar eclipses.
- Describe the phases of the Moon and explain why they occur.
- Explain how movements of the Earth and Moon affect Earth's tides.

Vocabulary

- crescent
- gibbous
- lunar eclipse
- penumbra
- shadow
- solar eclipse
- umbra

Introduction

The motions of bodies in the solar system are, for the most part, regular and understandable. From Earth, the Sun rises in the eastern sky in the morning and sets in the western sky in the evening. If the Moon is full on Day 1, it will be full again on Day 28, and new on Day 14. The motions of Earth relative to the Sun, and the motions of the Moon and Sun relative to Earth affect different phenomena on Earth, including day and night, the seasons, tides, and phases of the Moon.

Day-Night Cycle

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

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

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

Earth's Seasons

A common misconception is that the Sun is closer to Earth in the summer and farther away from it during the winter. Instead, the seasons are caused by the 23.5° tilt of Earth's axis of rotation relative to its plane of orbit around the Sun (**Figure** 1.20). At summer solstice, June 21 or 22, Earth's axis points toward the Sun and so the Sun is directly overhead at its furthest north point of the year, the Tropic of Cancer (23.5° N).

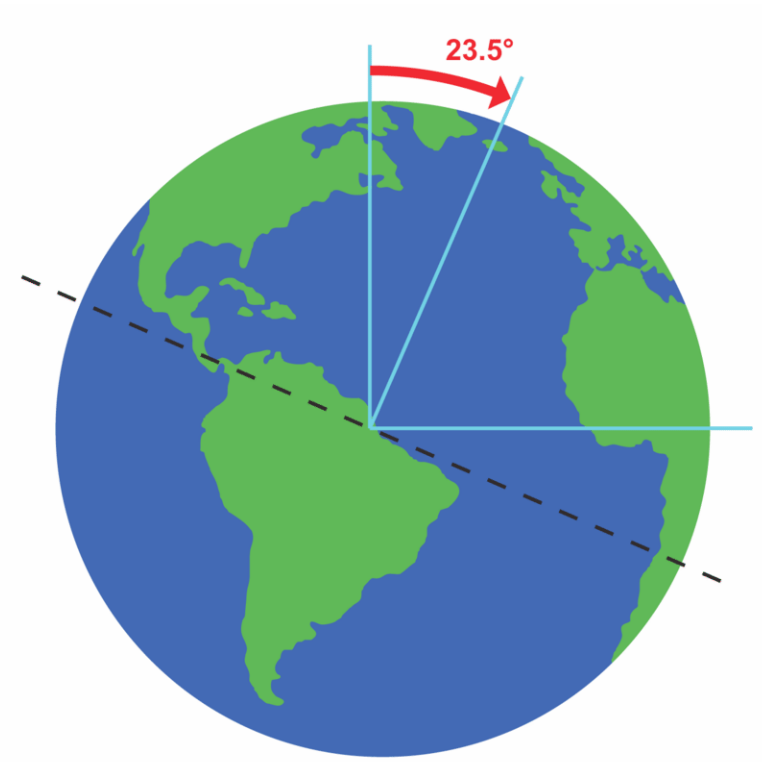


FIGURE 1.20
The Earth's tilt on its axis leads to one hemisphere facing the Sun more than the other hemisphere and gives rise to seasons.

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

Check out this video on why earth has seasons to learn more: http://www.youtube.com/watch?v=DuiQvPLWziQ .

Solar Eclipses

A **solar eclipse** occurs when the new moon passes directly between the Earth and the Sun (**Figure** 1.21). This casts a shadow on the Earth and blocks Earth's view of the Sun.

A total solar eclipse occurs when the Moon's shadow completely blocks the Sun (**Figure** 1.22). When only a portion of the Sun is out of view, it is called a partial solar eclipse.

Solar eclipses are rare and usually only last a few minutes because the Moon casts only a small shadow (**Figure** 1.23).

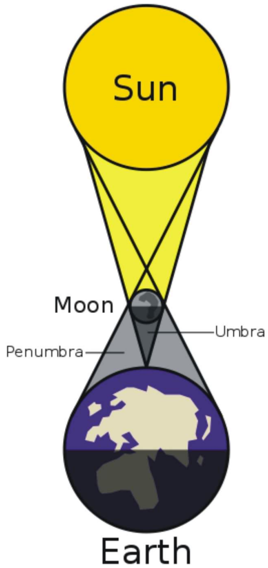


FIGURE 1.21
A solar eclipse, not to scale.

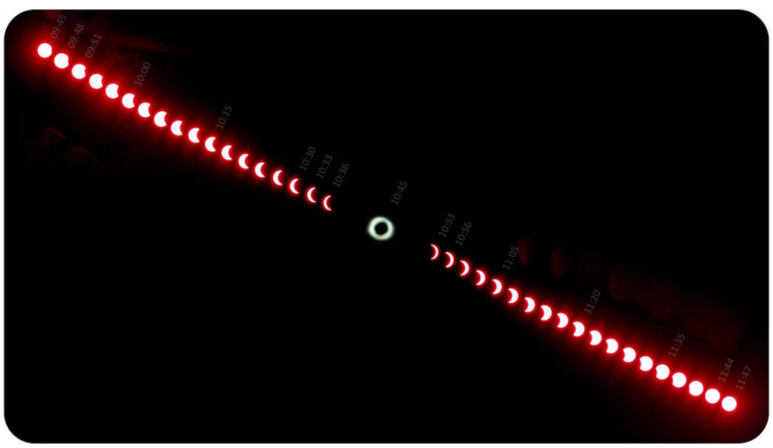


FIGURE 1.22
A solar eclipse shown as a series of photos.

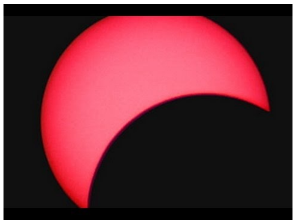
A BBC video of a solar eclipse is seen here: http://www.youtube.com/watch?v=eOvWioz4PoQ .

FIGURE 1.23
The Moon's shadow in a solar eclipse covers a very small area.

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

KQED: Eclipse Chasers

A solar eclipse occurs when the Moon passes between Earth and the Sun in such a way that the Sun is either partially or totally hidden from view. Some people, including some scientists, chase eclipses all over the world to learn or just observe this amazing phenomenon. Learn more at: http://www.kqed.org/quest/television/eclipse-chasers .



MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/114948

A Lunar Eclipse

A **lunar eclipse** occurs when the full moon moves through Earth's shadow, which only happens when Earth is between the Moon and the Sun and all three are lined up in the same plane, called the ecliptic (**Figure** 1.24). In an eclipse, Earth's shadow has two distinct parts: the **umbra** and the **penumbra**. The umbra is the inner, cone-shaped part of the shadow, in which all of the light has been blocked. The penumbra is the outer part of Earth's shadow where only part of the light is blocked. In the penumbra, the light is dimmed but not totally absent.

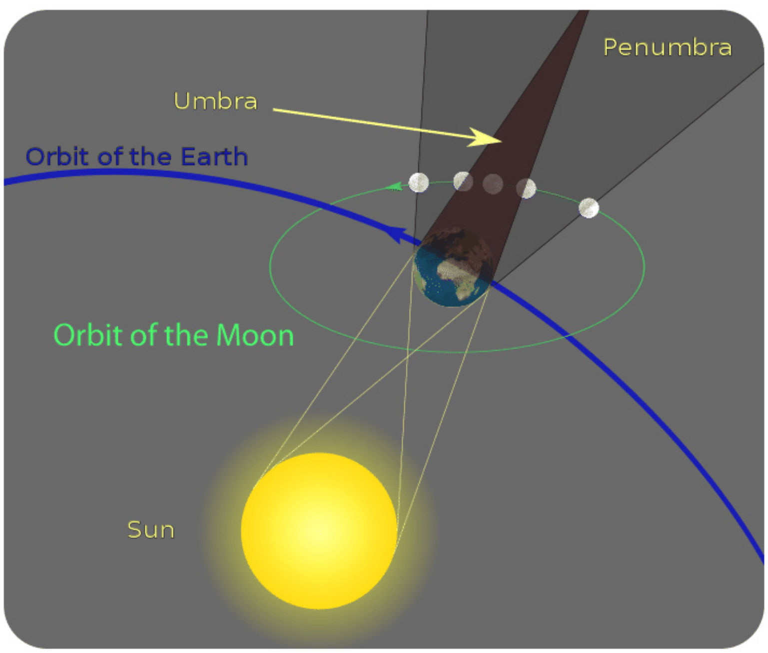


FIGURE 1.24
A lunar eclipse.

A total lunar eclipse occurs when the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. Earth's shadow is large enough that a lunar eclipse lasts for hours and can be seen by any part of Earth with a view of the Moon at the time of the eclipse (**Figure** 1.25).

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

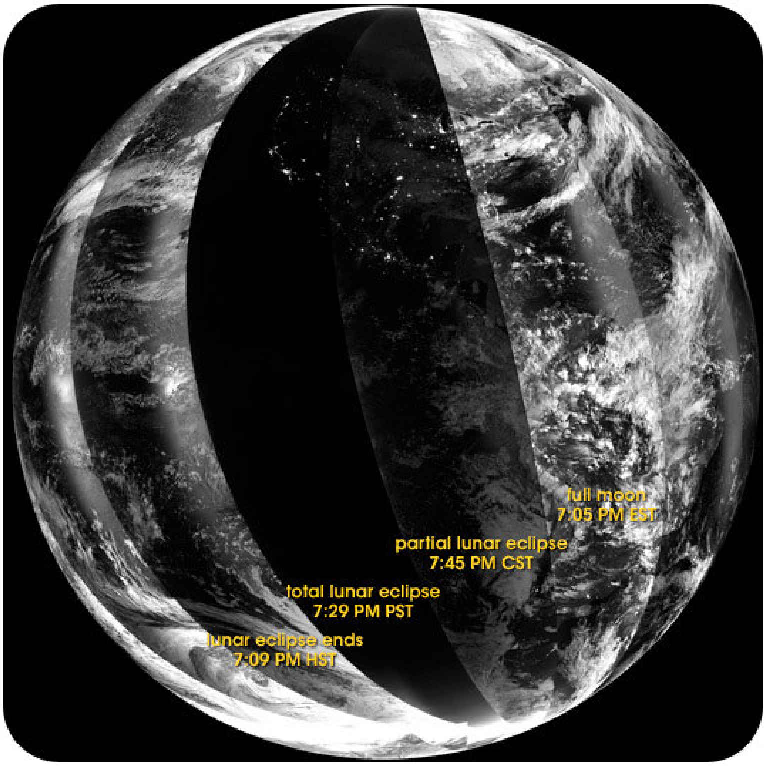


FIGURE 1.25
Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common.

The Phases of the Moon

Like everything in the solar system except the Sun, the Moon does not produce any light of its own —it only reflects sunlight. As the Moon moves around Earth, different portions of the satellite are illuminated. This causes the phases of the Moon, so that our view of the Moon goes from fully lit to completely dark and back again.

- The Moon is full when Earth is between the Moon and the Sun and the Moon's nearside is entirely lit.
- The Moon is at first quarter phase about one week later, when the Moon appears as a half-circle. Only half of the Moon's lit surface is visible from Earth.
- The Moon is in a new moon phase when the Moon moves between Earth and the Sun and the side of the Moon facing Earth is completely dark. Earth observers may be able to just barely see the outline of the new moon because some sunlight reflects off the Earth and hits the moon.
- Before and after the quarter-moon phases are the gibbous and crescent phases. During the **gibbous** moon phase, the moon is more than half lit but not full. During the **crescent** moon phase, the moon is less than half lit and is seen as only a sliver or crescent shape.

It takes about 29.5 days for the Moon to make one cycle relative to the Sun and go through all the phases (**Figure** 1.26). The time between two new Moon phases or two full Moon phases is 29.5 days. Remember that the Moon's orbital period is 27.3 days. The difference of 29.5 and 27.3 is that while the Moon is orbiting the Earth, the Earth is moving along in its orbit so it takes longer for the Moon to reach the same position relative to the Sun.

An animation of lunar phases from the University of Illinois: http://projects.astro.illinois.edu/data/MoonPhases/index.html .

FIGURE 1.26
The phases of the moon as if the Sun is above the top of this picture with its rays directed downward.

The Tides

Tides are the regular rising and falling of Earth's surface water in response to the gravitational attraction of the Moon and Sun. The Moon's gravity pulls upwards on Earth's water, causing it to bulge out in the direction of the Moon. On the other side of the Earth, a high tide is produced where the Moon's pull is weakest. As the Earth rotates on its axis, the areas directly in line with the Moon experience high tides. The places directly in between the high tides are low tides. There are two high tides and two low tides each tidal day. Since the Earth is rotating on its axis, the high-low-tide cycle moves around the globe in a 24-hour period.

The gravity of the Sun also pulls Earth's water towards it and causes its own tides. Because the sun is so far away, its pull is smaller than the Moon's. When the Sun and Moon are in line, during the new moon and the full moon, their high tides add up and create a spring tide. During a spring tide, high tides are really high, which means that low tides are really low (**Figure** 1.27).

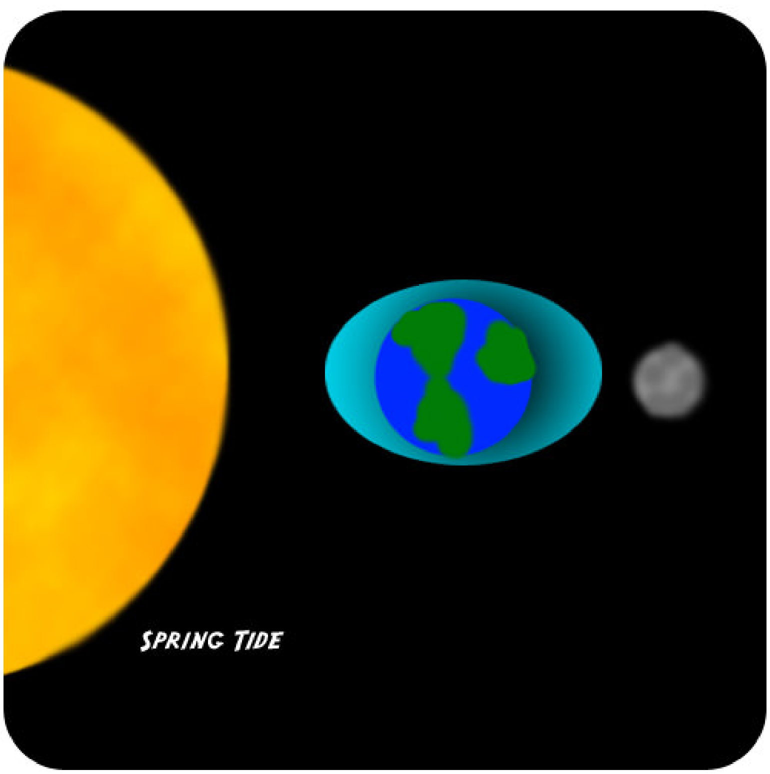


FIGURE 1.27
A spring tide is the added highs produced by the Moon and Sun and the added lows, creating a large tidal range.

When the Earth and Sun are in line but the Moon is perpendicular to the Earth a neap tide occurs. This happens when the moon is at first or last quarter-moon phase. In a neap tide the difference between high and low tides is not very large since the pull of gravity from the Sun partially cancels out the pull of gravity from the Moon. Neap tides produce less extreme tides than the normal tides (**Figure** 1.28).

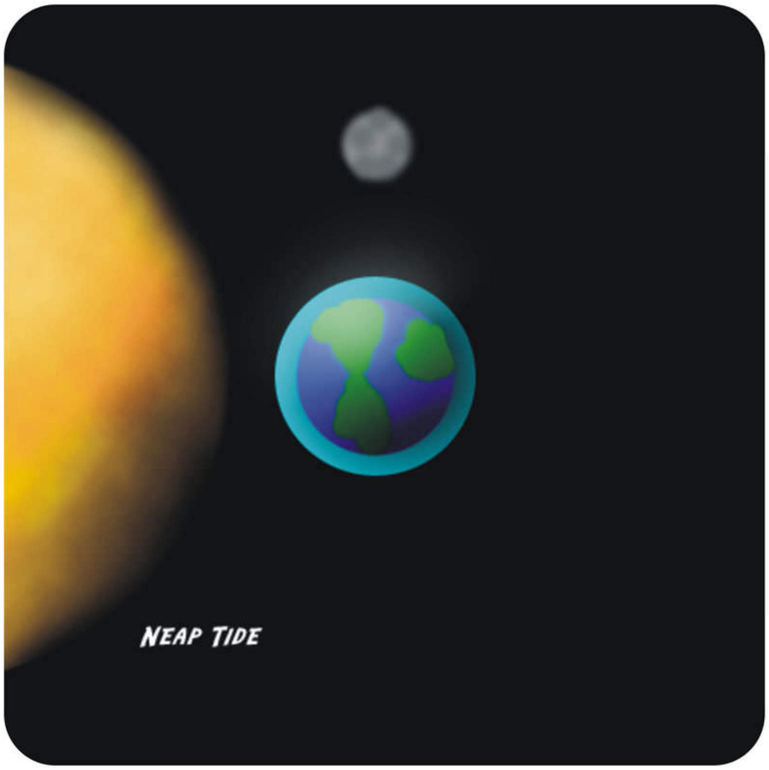


FIGURE 1.28
A neap tide occurs when the high tide of the Sun adds to the low tide of the Moon and vice versa so the tidal range is relatively small.

More about tides is found in the chapter *Earth's Ocean*.

Lesson Summary

- As the Earth rotates on its axis and revolves around the Sun, day and night and seasons result.
- When the new moon comes between the Earth and the Sun along the ecliptic, a solar eclipse is produced.
- When the Earth comes between the full moon and the Sun along the ecliptic, a lunar eclipse occurs.
- Observing the Moon from Earth, there is a sequence of phases as the side facing us goes from completely darkened to completely illuminated and back again every 29.5 days.
- As the Moon orbits Earth, tides align with its gravitational pull.
- The Sun produces a smaller tide. When the solar and lunar tides align, at new and full moons, higher than normal tidal ranges called spring tides occur.
- At first and last quarter moons, the solar tide and lunar tide interfere with each other, producing lower than normal tidal ranges called neap tides.

Review Questions

1. The globe is divided into time zones, so that any given hour of the day in one time zone occurs at a different time in other time zones. For example, New York City is in one time zone and Los Angeles is in another time zone. When it is 8:00 a.m. in New York City, it is only 5:00 a.m. in Los Angeles. Explain how Earth's motions cause this difference in times.

2. Explain how Earth's tilt on its axis accounts for seasons on Earth.

3. Explain how the positions of the Earth, Moon, and Sun vary during a solar eclipse and a lunar eclipse.

4. Draw a picture that shows how the Earth, Moon, and Sun are lined up during the new moon phase.

5. Why are neap tides less extreme than spring tides?

Further Reading / Supplemental Links

- Watch this video to understand the difference between solar and lunar eclipses: http://www.youtube.com/watch?v=tIE1MTGz4eI .

Points to Consider

- Why don't eclipses occur every single month at the full and new moons?
- The planet Mars has a tilt that is very similar to Earth's. What does this produce on Mars?
- Venus comes between the Earth and the Sun. Why don't we see an eclipse when this happens?

1.5 References

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