Earth as a Planet

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CHAPTER 1 Earth as a Planet

CHAPTER OUTLINE

Introduction

Is Earth a planet?

Yes! No one doubts that Earth is a planet, even though it's a lot different from the other planets in our solar system, like enormous Jupiter or scorching-hot Venus. The most different planet of all, though, was the planet that is no longer a planet, Pluto. Pluto is now categorized as a dwarf planet, more akin to Ceres and Makemake than Earth or Uranus. Changing Pluto's status forced scientists to confront the issue of what a planet is. We will look at some of the characteristics that make Earth a bona fide planet.

1.1 Earth's Shape

- Describe Earth's shape and explain how Earth's shape is related to its mass.

Before spacecraft, how did people know that Earth is spherical?

The ancient Greeks knew that Earth was round by observing the arc shape of the shadow on the Moon during a lunar eclipse. Was there other evidence of Earth's roundness available to people before spacecraft gave us a bird's eye view?

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. 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. 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. Here is a summary of some: http://www.physlink.com/education/askexperts/ae535.cfm .

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 spherical as well.

Summary

- Ancient Greeks knew that Earth was round because of the shadow the planet cast on the Moon during a lunar eclipse.
- A boat does not get smaller with distance but sinks below the horizon - more evidence for Earth's roundness.
- Earth is divided into hemispheres: northern, southern, eastern, and western.

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

Explore More

Use this resource to answer the questions that follow. https://www.youtube.com/watch?v=o_W280R_Jt8

1. What is the #10 reason that we know that Earth is spherical?
2. What is the #9 reason that we know that Earth is spherical?
3. What is the #8 reason that we know that Earth is spherical?
4. What is the #7 reason that we know that Earth is spherical?
5. What is the #6 reason that we know that Earth is spherical?
6. What is the #5 reason that we know that Earth is spherical?
7. What is the #4 reason that we know that Earth is spherical?
8. What is the #3 reason that we know that Earth is spherical?
9. What is the #2 reason that we know that Earth is spherical?
10. What is the #1 reason that we know that Earth is spherical?

Explore More Answers

1. Other planets and stars are round and Earth shouldn't be any different.
2. Day and night happen at different times at different places - time zones. It's always day somewhere!
3. Coriolis effect: freely moving things are deflected to right N of equator other way S of equator.
4. If you walk in 3 directions at three 90-degree angles to each other you will walk in a triangle, which is impossible on a flat surface.
5. The sun gets lower in sky as you travel away from equator.
6. Stars change from north to south.
7. Many people have circumnavigated the Earth, by going west and then ending in the same place as you started.
8. Ships disappear bottom first. If Earth were flat there wouldn't be a horizon.
9. Shadow of Earth on moon is curved.
10. Photographic evidence.

Review

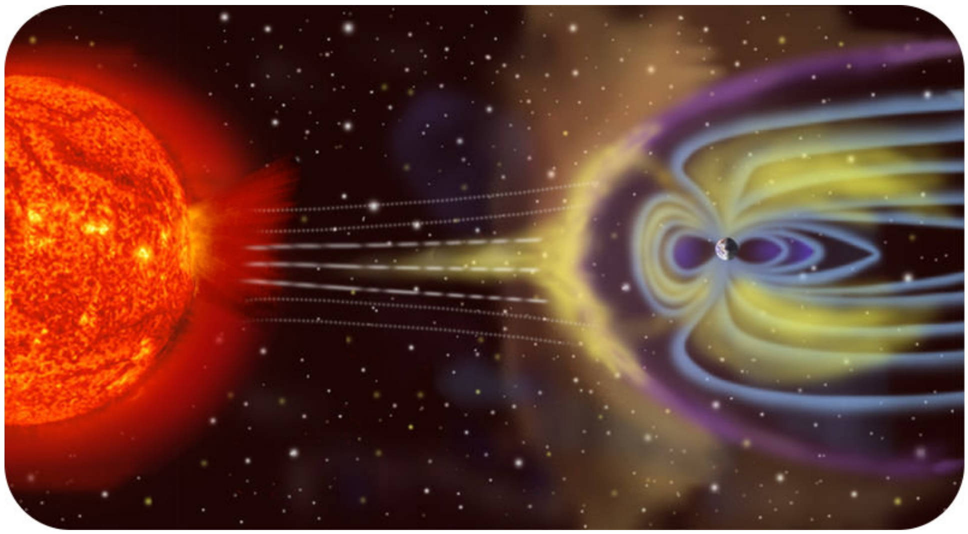
1. Describe where you live in terms of hemispheres.
2. If you met up with someone who claimed that Earth is flat, what evidence would you present to them that their assertion is not true?
3. What evidence do you have that our planet is flat? Which of these ideas do you believe and why?

Review Answers

1. If you live in North America you live in the Northern Hemisphere and the Western Hemisphere. That is also true if you live in the United Kingdom west of Greenwich England, but if you live east of Greenwich England you are in the Eastern hemisphere. English speaking people live in the Southern Hemisphere if they are in Australia or New Zealand.
2. There are many lines of evidence. One is that ships sink into the ocean rather than just getting smaller.
3. The planet appears flat because we can't see a curve from where we're standing. It's easy to test and see that it's round though.

1.2 Earth's Magnetic Field

- Describe Earth's magnetic field and explain its relationship to life on Earth.



What would happen if Earth suddenly lost its magnetic field?

The most obvious effect is that we would get lost, since our compasses wouldn't work. Less obvious is that without the magnetic field the solar wind would strip away ozone from Earth's atmosphere and leave us exposed to ultraviolet radiation. Would life on Earth look the way it does now? Most, if not all, lifeforms couldn't survive.

Earth's Magnetism

Earth is surrounded by 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. The magnetic field arises from the convection of molten iron and nickel metals in Earth's liquid outer core.

Magnetic Reversals

Many times during Earth history, even relatively recent Earth history, the planet's magnetic field has flipped. That is, the north pole becomes the south pole and the south pole becomes the north pole. Scientists are not sure why this happens. One hypothesis is that the convection that drives the magnetic field becomes chaotic and then reverses itself. Another hypothesis is that an external event, such as an asteroid impact, disrupts motions in the core and causes the reversal. The first hypothesis is supported by computer models, but the second does not seem to be supported by much data. There is little correlation between impact events and magnetic reversals.

Summary

- Earth's magnetic field is like a bar magnet through the planet, with the south magnetic pole nearly aligned with the north geographic pole and vice versa.
- The magnetic field is generated by convection in the liquid outer core.

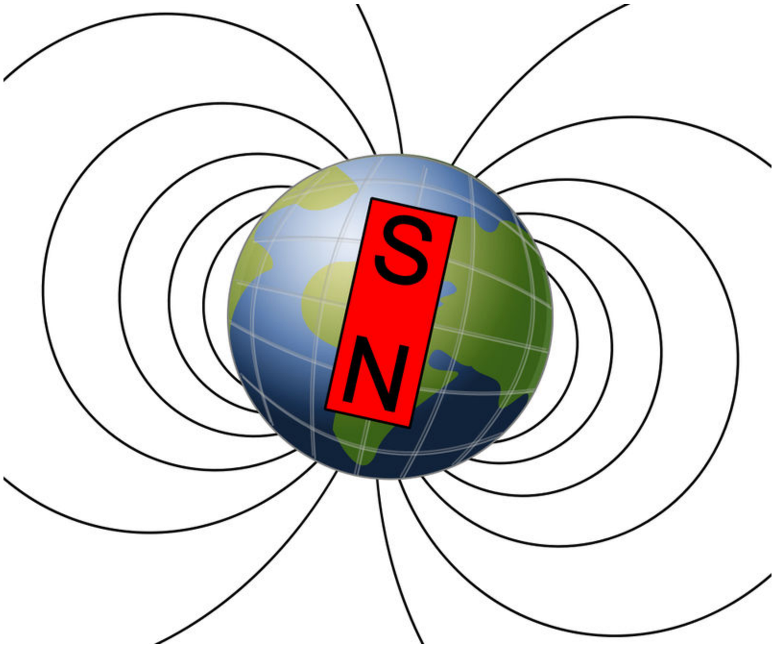


FIGURE 1.2
Earth's magnetic field is like a bar magnet resides in the center of the planet.

- Occasionally the magnetic field flips, with the north pole becoming the south pole and the south pole becoming the north pole.

Explore More

Use this resource to answer the questions that follow.

http://www.pbs.org/wgbh/nova/earth/when-our-magnetic-field-flips.html

1. How often has the magnetic field reversed?
2. What creates Earth's magnetic field?
3. How is the electric current generated in the outer core? What does this do to the magnetic field?
4. What is the energy source for the geomagnetic dynamo?
5. What role does Coriolis Effect play in the geomagnetic dynamo?

Review Answers

1. About every 250,000 years.
2. Liquid metal in the outer core.
3. The liquid metal passes through a magnetic field, causing the electric current. The electric current then creates a magnetic field, which is stronger than the original and so on.
4. The energy source is the release of heat from the surface of the inner core.
5. Coriolis causes the moving liquid metal to spiral, allowing separate magnetic fields to align rather than cancel each other out.

Review

1. What would Earth's magnetic field be like if the planet was solid and why?
2. What important role does the magnetic field play for our planet?

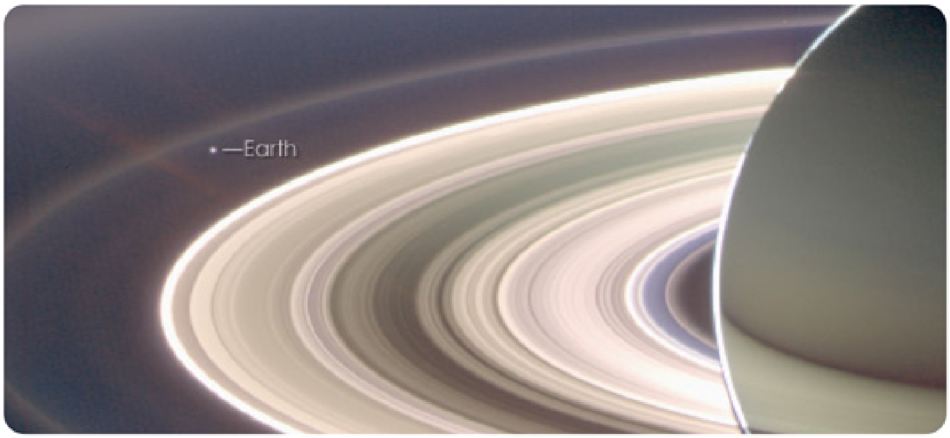
3. How does the magnetic field resemble a bar magnet?

Review Answers

1. Since the magnetic field is generated by convection in the liquid metal outer core there would be no magnetic field.
2. It protects us from the solar wind.
3. It behaves like the Earth has a bar magnet embedded in it with two poles and lines of magnetism running between them.

1.3 Revolutions of Earth

- Define the geocentric and heliocentric models of Earth's revolution.
- Describe Earth's revolution around the Sun.



How else can we identify a planet?

Saturn and Earth are both planets. Saturn is round, like Earth, but Saturn has fantastic rings, which Earth does not. A planet needs to be round but it doesn't need rings. Both of these bodies orbit a star, another thing planets need to do. That star is our Sun.

Earth Orbits a Star

Certainly no one today doubts that Earth orbits a star, the Sun. Photos taken from space, observations made by astronauts, and the fact that there has been so much successful space exploration that depends on understanding the structure of the solar system all confirm it. But in the early 17th century saying that Earth orbited the Sun rather than the reverse could get you tried for heresy, as it did Galileo. Let's explore the evolution of the idea that Earth orbits the Sun.

The Geocentric Universe

To an observer, Earth appears to be the center of the universe. That is what the ancient Greeks believed. This view is called the **geocentric model**, or "Earth-centered" model, of the universe. In the geocentric model, the sky, or heavens, are a set of spheres layered on top of one another. Each object in the sky is attached to a sphere and moves around Earth as that sphere rotates. From Earth outward, these spheres contain the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. An outer sphere holds all the stars. Since the planets appear to move much faster than the stars, the Greeks placed them closer to Earth. The geocentric model explained why all the stars appear to rotate around Earth once per day. The model also explained why the planets move differently from the stars and from each other.

One problem with the geocentric model is that some planets seem to move backwards (in retrograde) instead of in their usual forward motion around Earth. A demonstration animation of retrograde motion of Mars as it appears to Earth can be found here: http://projects.astro.illinois.edu/data/Retrograde/index.html .

Around 150 A.D. the astronomer Ptolemy resolved this problem by using a system of circles to describe the motion of planets (**Figure** 1.3). In Ptolemy's system, a planet moves in a small circle, called an epicycle. This circle moves around Earth in a larger circle, called a deferent. Ptolemy's version of the geocentric model worked so well that it remained the accepted model of the universe for more than a thousand years.

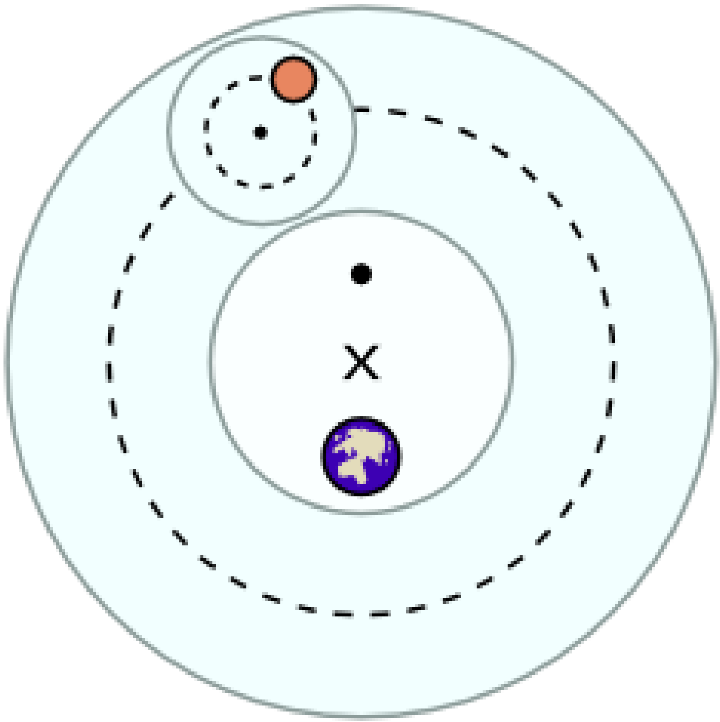


FIGURE 1.3

According to Ptolemy, a planet moves on a small circle (epicycle) that in turn moves on a larger circle (deferent) around Earth.

An animation of Ptolemy's system can be seen here: http://www.youtube.com/watch?v=FHSWVLwbbNw

The Heliocentric Universe

Ptolemy's geocentric model worked, but it was complicated and occasionally made errors in predicting the movement of planets. At the beginning of the 16th century A.D., Nicolaus Copernicus proposed that Earth and all the other planets orbit the Sun. With the Sun at the center, this model is called the **heliocentric model**, or "sun-centered" model.

Although Copernicus' model was simpler –it didn't need epicycles and deferents - it still did not perfectly describe the motion of the planets. Johannes Kepler solved the problem a short time later when he determined that the planets moved around the Sun in ellipses (ovals), not circles (**Figure** 1.4). Kepler's model matched observations perfectly.

Animation of Kepler's Laws of Planetary Motion: http://projects.astro.illinois.edu/data/KeplersLaws/index.html

The heliocentric model did not catch on right away. When Galileo Galilei first turned a telescope to the heavens in 1610, he made several striking discoveries. Galileo discovered that the planet Jupiter has **moons** orbiting around it. This provided the first evidence that objects could orbit something besides Earth.

An animation of three of Jupiter's moons orbiting the planet can be seen here: http://upload.wikimedia.org/wikipedia/commons/e/e7/Galilean_moon_Laplace_resonance_animation_de.gif .

Galileo also discovered that Venus has phases like the Moon (**Figure** 1.5), which provides direct evidence that Venus orbits the Sun.

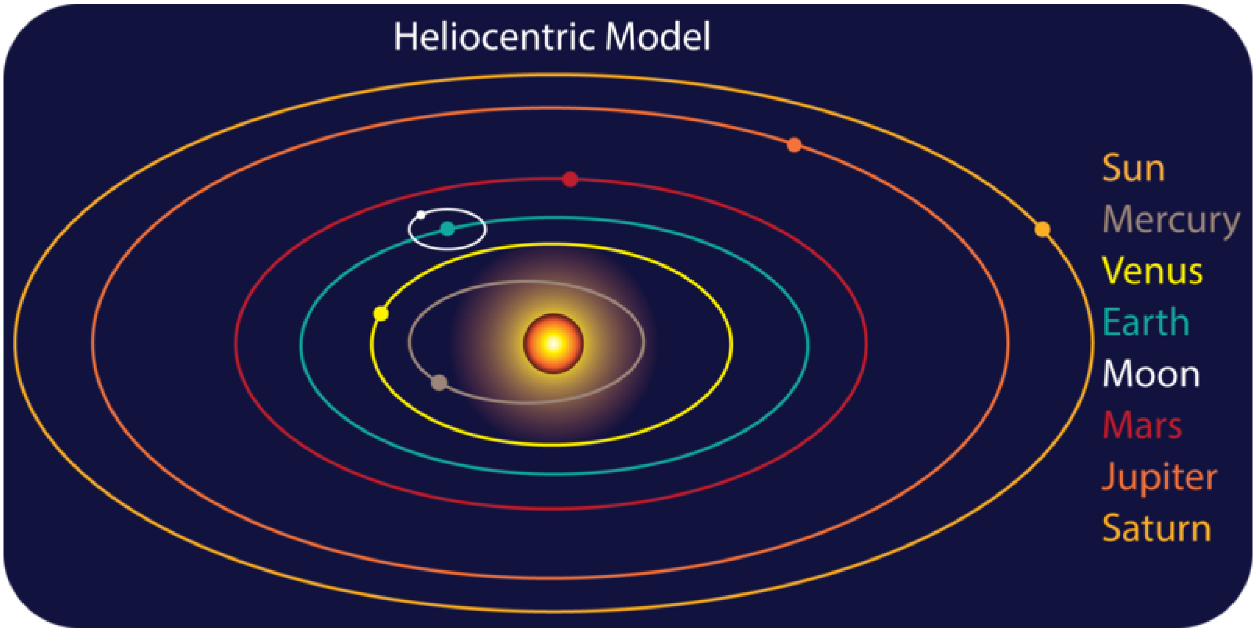


FIGURE 1.4
Kepler's model showed the planets moving around the Sun in ellipses.

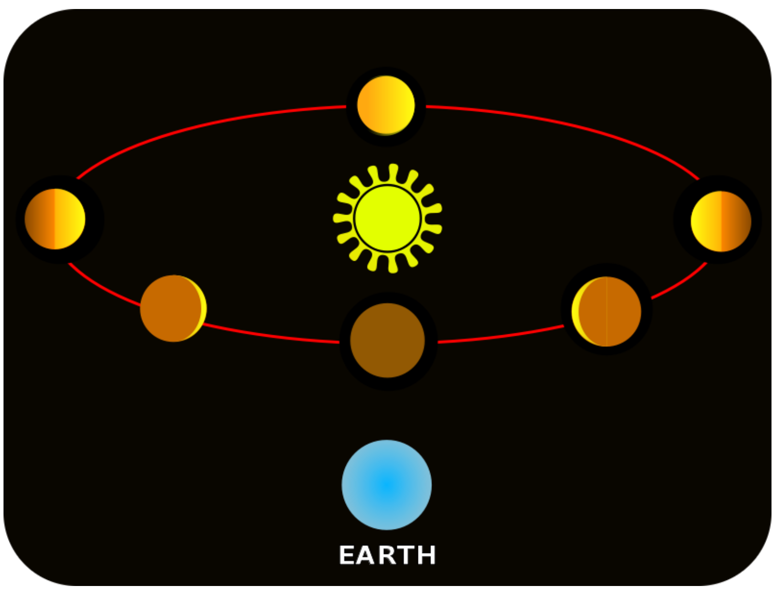


FIGURE 1.5
The phases of Venus.

Galileo's discoveries caused many more people to accept the heliocentric model of the universe, although Galileo himself was found guilty of heresy. The shift from an Earth-centered view to a Sun-centered view of the universe is referred to as the Copernican Revolution.

In their elliptical orbits, each planet is sometimes farther away from the Sun than at other times. This movement is called **revolution**. At the same time, Earth spins on its **axis**. Earth's axis is an imaginary line passing through the planet's center that goes through both the North Pole and the South Pole. This spinning movement is called Earth's **rotation**.

Earth's Revolution

Copernicus, Galileo, and Kepler were all right: Earth and the other planets travel in an elliptical orbit around the Sun. The gravitational pull of the Sun keeps the planets in orbit. This ellipse is barely elliptical; it's very close to being a circle. 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. The shape of Earth's orbit has nothing to do with Earth's seasons.

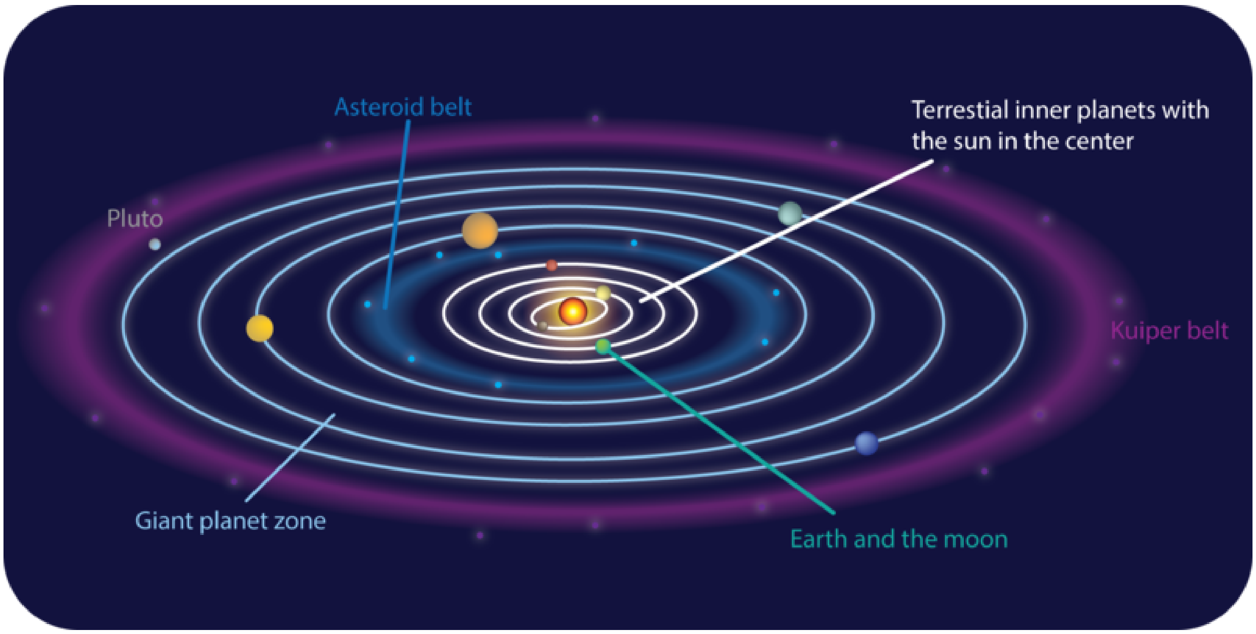


FIGURE 1.6
Earth and the other planets in the solar system make elliptical orbits around the Sun.

For Earth to make one complete revolution around the Sun takes 365.24 days. This amount of time is the definition of one year. Earth has one large moon, which orbits Earth once every 29.5 days, a period known as a month.

Summary

- In the geocentric model of the universe, Earth is at the center.
- In the heliocentric model of the universe, the Sun is at the center. The heliocentric model is the modern view of the solar system, but not the entire universe.
- Earth and the other planets of the solar system revolve around the Sun.

Explore More

Use this resource to answer the questions that follow.

http://www.universetoday.com/36487/difference-between-geocentric-and-heliocentric/

1. What does geocentric mean? What is the geocentric model?
2. What does heliocentric mean?
3. When did the heliocentric theory gain popularity and what prompted it?
4. Why was did geocentric theory remain popular for so long?
5. Why did the heliocentric theory eventually take precedence?

Explore More Answers

1. Earth-centered; Earth is at the center of the universe with the Sun, Moon, stars and planets circling it.
2. Sun-centered; the Sun is at the center of the solar system with Earth and the other planets orbiting it.
3. The 16th century when Copernicus published the theory in a book.
4. It seems sensible given our observations.
5. It fits the data.

Review

1. How does the heliocentric model differ from the geocentric model?
2. Why do you think people had a hard time switching from one worldview to the other?
3. Describe Earth's orbit around the Sun.

Review Answers

1. In a heliocentric model the sun is at the center and in a geocentric model Earth is at the center.
2. It seems sensible that Earth is at the center and the Sun and other bodies go around it. It also fits with a religious view that we are the most important creatures around.
3. Earth's orbit is elliptical. It travels closest to the Sun in January and furthest in July. It takes about one year, about 365.25 days, to complete a trip around the Sun.

1.4 Rotation of Earth

- Describe Earth's rotation on its axis.

What would you do if you were in Paris?

Take a view from the top of the Eiffel Tower? March up the stairs to eye the gargoyles at Notre Dame? Nibble on coffee and croissants in a sidewalk cafe? Visit Foucault's Pendulum in the Pantheon? Yes! When in Paris, don't forget to go to the Pantheon and visit this testament to Earth's rotation.

Foucault's Pendulum

In 1851, a French scientist named Léon Foucault took an iron sphere and hung it from a wire. He pulled the sphere to one side and then released it, as a pendulum. Although a pendulum set in motion should not change its motion, Foucault observed that his pendulum did seem to change direction relative to the circle below. Foucault concluded that Earth was moving underneath the pendulum. People at that time already knew that Earth rotated on its axis, but Foucault's experiment was nice confirmation.

FIGURE 1.7
Foucault's Pendulum is at the Pantheon in Paris, France.

Earth's Rotation

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**.

An observer in space will see that Earth requires 23 hours, 59 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 nothing.

Day-Night Cycle

Earth rotates once on its axis about every 24 hours. To an observer looking down at 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 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.

Summary

- Foucault's pendulum shows that Earth moves beneath a swinging pendulum.
- Earth rotates on its axis every 24 hours.
- Earth rotates so that the Sun, Moon, and stars appear to travel from east to west each day.

Explore More

Use these resources to answer the questions that follow.

https://www.youtube.com/watch?v=9n04SEzuvXo

1. What is the tilt of Earth's axis of rotation?
2. How often does Earth rotate on its axis?
3. Under what circumstances is it summer in the Northern Hemisphere?
4. As Earth revolves around the Sun over 6 months, how much does the tilt of the axis of rotation change?
5. Under what circumstances is it summer in the Southern Hemisphere? At this time, what is the season in the Northern Hemisphere?
6. What is the wobble effect? How long is one cycle of this effect?
7. What will happen to the seasons in 13,000 years and why?

Explore More Answers

1. 23.5-degrees
2. Once per day
3. When Earth's axis tilts toward the Sun.
4. not at all
5. The axis tilts away from the Sun so it is winter in the Northern Hemisphere and summer in the Southern Hemisphere.
6. A change in the direction of the axis of rotation, not a change in the angle. About 26,000 years.
7. They will be opposite due to the change in the tilt of the axis of rotation.

Review

1. How does Foucalt's pendulum show that Earth rotates on its axis?
2. Why do the Sun, Moon, and stars appear to rise in the east and set in the west each day?
3. Why does a point on the Equator travel at a speed of 1,700 km per hour and a point at the poles not travel at all?

Review Answers

1. The pendulum is moving back and forth on the same plane, but it appears to be moving back and forth in a circle. This is because the planet is moving beneath it.
2. Because Earth is rotating clockwise on its axis.
3. The point has a lot of distance to travel to make one rotation on Earth's axis, while the a point at the axis of rotation doesn't need to move anywhere but to spin on itself.

1.5 Coriolis Effect

- Explain the Coriolis effect and distinguish between an effect and a force.

Can you tell which hemisphere you're in?

People say that Coriolis effect determines the direction that water flushes down a toilet or sink. If that's true, then which hemisphere is this toilet in? It looks like it's in the Northern Hemisphere, because the spiral arms are going the same direction as a Northern Hemisphere hurricane. Unfortunately, there are too many other factors that determine the direction toilet water flushes, such as friction and the power of the flush. So we don't know where this toilet is.

Coriolis Effect

The **Coriolis effect** describes how Earth's rotation steers winds and surface ocean currents (**Figure** 1.8). Coriolis causes freely moving objects to appear to move to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The objects themselves are actually moving straight, but the Earth is rotating beneath them, so they seem to bend or curve. That's why it is incorrect to call Coriolis a force. It is not forcing anything to happen!

An example might make the Coriolis effect easier to visualize. If an airplane flies 500 miles due north, it will not arrive at the city that was due north of it when it began its journey. Over the time it takes for the airplane to fly 500 miles, that city moved, along with the Earth it sits on. The airplane will therefore arrive at a city to the west of the original city (in the Northern Hemisphere), unless the pilot has compensated for the change. So to reach his intended destination, the pilot must also veer right while flying north.

As wind or an ocean current moves, the Earth spins underneath it. As a result, an object moving north or south along the Earth will appear to move in a curve instead of in a straight line. Wind or water that travels toward the poles from the Equator is deflected to the east, while wind or water that travels toward the Equator from the poles gets bent to the west. The Coriolis effect bends the direction of surface currents to the right in the Northern Hemisphere and left in the Southern Hemisphere.

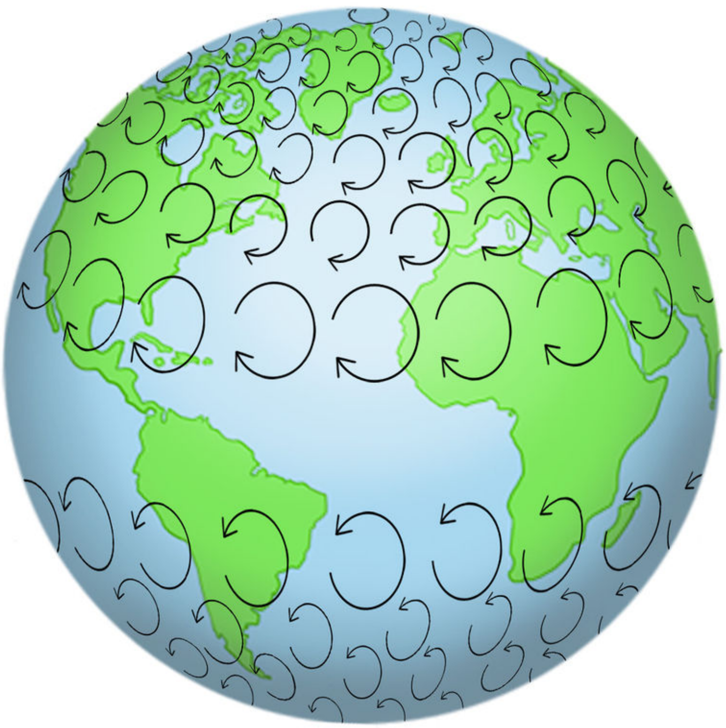


FIGURE 1.8
The Coriolis effect causes winds and currents to form circular patterns. The direction that they spin depends on the hemisphere that they are in.

Coriolis effect is demonstrated using a metal ball and a rotating plate in this video. The ball moves in a circular path just like a freely moving particle of gas or liquid moves on the rotating Earth **(5b)**: http://www.youtube.com/watch?v=Wda7azMvabE (2:04).

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1472

Summary

- Earth rotates beneath freely moving objects like water and air. Compared with a spot on the planet, the freely moving objects appear to be moving.
- Freely moving objects appear to move right in the Northern Hemisphere and left in the Southern Hemisphere.
- Coriolis is an effect rather than a force because it is not forcing a motion, it's just an appearance of a change of motion.

Explore More

Use these resources to answer the questions that follow.

https://www.youtube.com/watch?v=rdGtcZSFRLk

1. Why does some land on Earth move faster than other land? Where is the fastest and slowest land?
2. If you are at the equator and try to throw a ball to your friend at the north pole, what happens to the ball? What if your friend is at the south pole?
3. What would happen to the winds if Earth didn't rotate? What do they do instead?

http://www.montereyinstitute.org/noaa/lesson08/l8ex1.htm

1. What happens if pilots do not correct for the Coriolis effect?

Explore More Answers

1. Land at the equator has a much greater distance to go one rotation than land at the poles.
2. The ball appears to veer to the right. The ball appears to veer to the left.
3. They would flow north and south. They veer to the right in the Northern Hemisphere and left in the Southern Hemisphere.
4. The plane will end up in a different city from the one it is supposed to go to.

Review

1. If an airplane flies from east to west in the Northern Hemisphere without changing latitude at all, in which direction will it appear to curve?
2. If an airplane flies from south to north in the Southern Hemisphere, in which direction will it appear to curve?
3. If freely moving objects are only appearing to curve their paths, why is this important?

Review Answers

1. It will not appear to curve, but will just fly along its latitude line.
2. In the Southern Hemisphere it will appear to curve to the left.
3. Coriolis Effect helps to determine the directions of the wind and ocean currents.

1.6 Seasons

- Explain why seasons occur.

Do you like the seasons?

Do you live in a place with well-defined seasons? Do you appreciate the change of the seasons, from cold and dark to hot and bright, over the months? In other words, are you happy that Earth's axis is tilted?

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^o tilt of Earth's axis of rotation relative to its plane of orbit around the Sun (**Figure** 1.9). **Solstice** refers to the position of the Sun when it is closest to one of the poles. 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^o N).

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 Atmospheric Processes chapter.

Solar Radiation on Earth

Different parts of the Earth receive different amounts of solar radiation. Which part of the planet receives the most solar radiation? The Sun's rays strike the surface most directly at the Equator.

Different areas also receive different amounts of sunlight in different seasons. What causes the seasons? The seasons are caused by the direction Earth's axis is pointing relative to the Sun.

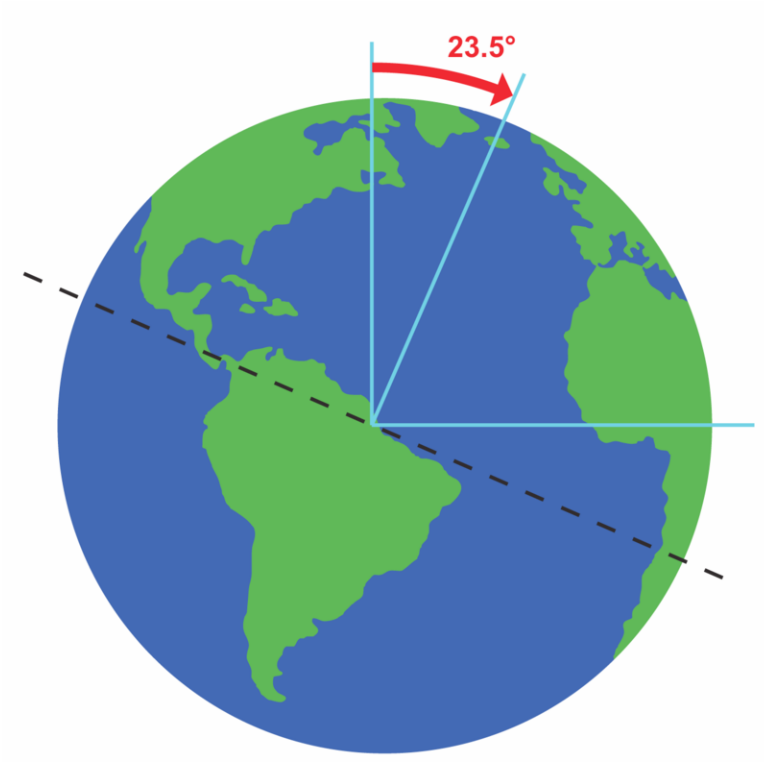


FIGURE 1.9

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

The Earth revolves around the Sun once each year and spins on its axis of rotation once each day. This axis of rotation is tilted 23.5^o relative to its plane of orbit around the Sun. The axis of rotation is pointed toward Polaris, the North Star. As the Earth orbits the Sun, the tilt of Earth's axis stays lined up with the North Star.

Northern Hemisphere Summer

The North Pole is tilted towards the Sun and the Sun's rays strike the Northern Hemisphere more directly in summer (**Figure** 1.10). At the summer solstice, June 21 or 22, the Sun's rays hit the Earth most directly along the Tropic of Cancer (23.5^oN); that is, the angle of incidence of the Sun's rays there is zero (the angle of incidence is the deviation in the angle of an incoming ray from straight on). When it is summer solstice in the Northern Hemisphere, it is winter solstice in the Southern Hemisphere.

Northern Hemisphere Winter

Winter solstice for the Northern Hemisphere happens on December 21 or 22. The tilt of Earth's axis points away from the Sun (**Figure** 1.11). Light from the Sun is spread out over a larger area, so that area isn't heated as much. With fewer daylight hours in winter, there is also less time for the Sun to warm the area. When it is winter in the Northern Hemisphere, it is summer in the Southern Hemisphere.

An animation of the seasons from the University of Illinois is seen here: http://projects.astro.illinois.edu/data/Seasons/seasons.html . Notice the area of solar radiation, or insolation, in the lower right of the screen.

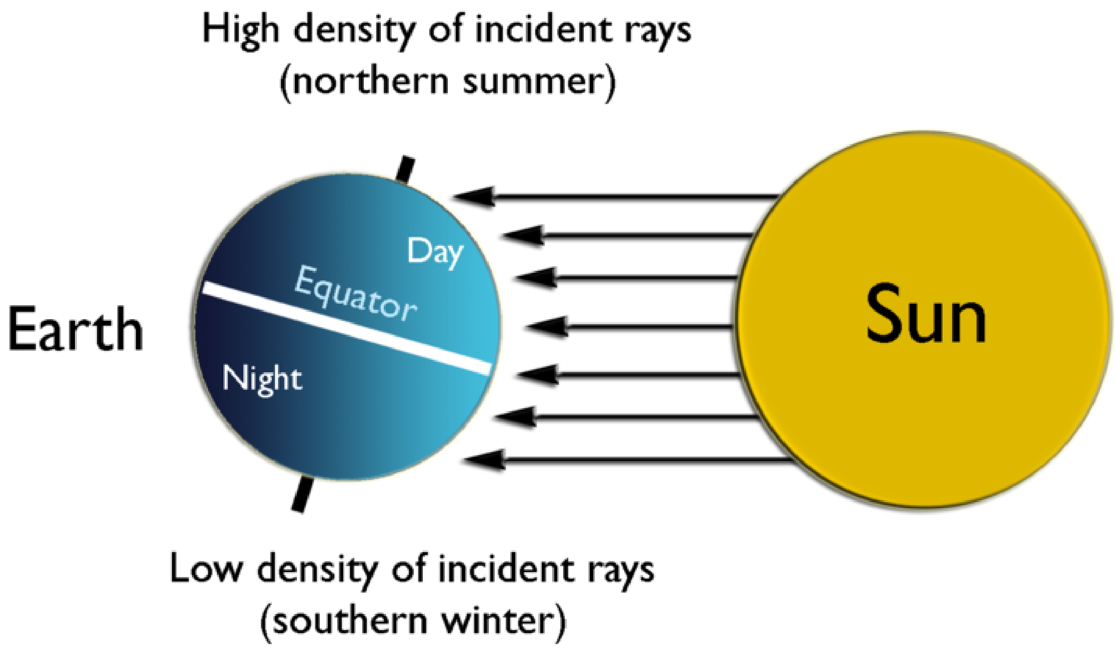


FIGURE 1.10
Summer solstice in the Northern Hemisphere.

Equinox

Halfway between the two solstices, the Sun's rays shine most directly at the Equator, called an **equinox** (**Figure** 1.12). The daylight and nighttime hours are exactly equal on an equinox. The autumnal equinox happens on September 22 or 23 and the vernal, or spring, equinox happens March 21 or 22 in the Northern Hemisphere.

Summary

- In the Northern Hemisphere, at summer solstice the Sun is closest to the north pole (around June 22) and at winter solstice, the Sun is closest to the south pole (around December 22). In the Southern Hemisphere, the names are changed.
- Over the course of a year, the amount of solar energy received by the Equator is greater than the amount received elsewhere.
- At equinox the Sun is directly over the Equator; autumnal equinox is around September 22 and spring equinox is around March 22 in the Northern Hemisphere.

Explore More

Use these resources to answer the questions that follow.

https://www.youtube.com/watch?v=wwdB22opre0

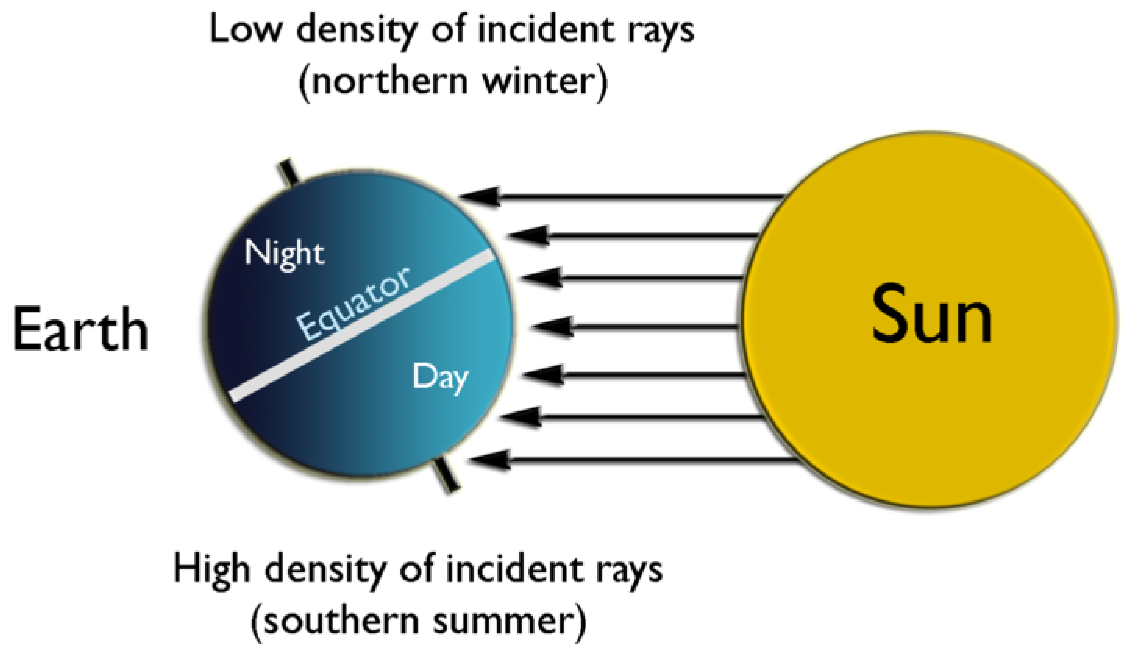


FIGURE 1.11
In Southern Hemisphere summer, the Sun's rays directly strike the Tropic of Capricorn (23.5^{o}S). Sunlight is spread across a large area near the South Pole. No sunlight reaches the North Pole.

1. What is the tilt of Earth's axis? How often does Earth go around the Sun?
2. What effect does the axial tilt have on solar radiation on Earth?
3. When the Northern Hemisphere points toward the sun, what season is it in the Southern Hemisphere?
4. Within a hemisphere, what causes the seasons?
5. What location on Earth receives roughly the same amount of solar radiation year-round? What location has the most variability in solar radiation?

http://www.learner.org/jnorth/tm/mclass/eclipticsimulator.swf

6. Place the observer on the Tropic of Capricorn and run the animation. When does the observer get the most direct sunlight (90 degree angle)?

7. Place the observer in the Arctic Circle and run the simulation. Explain what occurs for the observer over the year.

8. Place the observer close to your present latitude and run the simulation. Explain what the observer experiences over a year.

Explore More Answers

1. 23.5-degrees; 365.25 days
2. The tilt changes the amount of solar radiation that different parts of the Earth experience at any given time.
3. It is winter.
4. The angle of the incoming sun's rays.

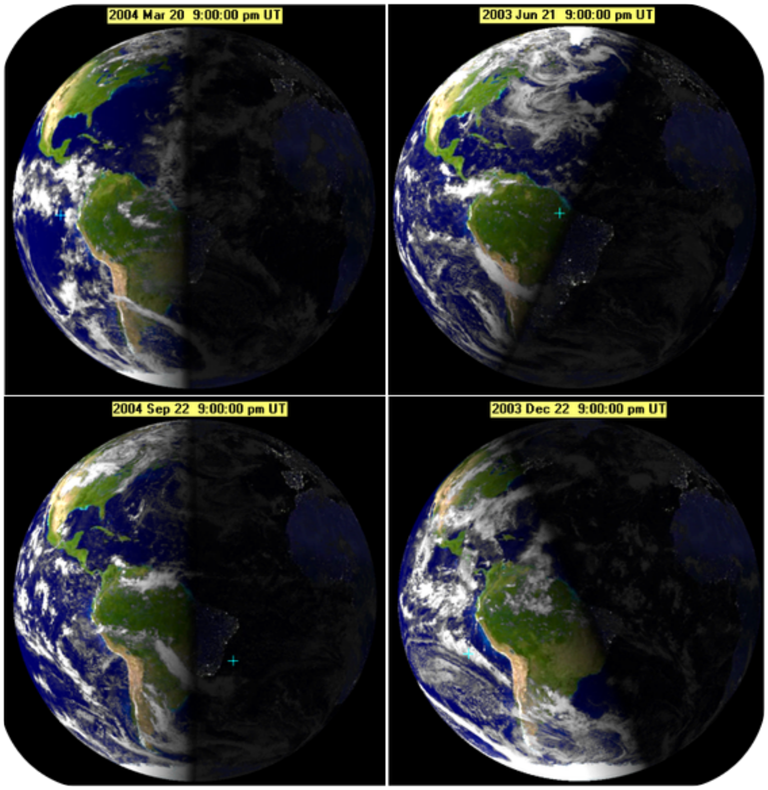


FIGURE 1.12
Where sunlight reaches on spring equinox, summer solstice, vernal equinox, and winter solstice. The time is 9:00 p.m. Universal Time, at Greenwich, England.

5. The equator, the poles

Review

1. At summer solstice in the Northern Hemisphere, what is the date and where is the Sun? What is happening at the South Pole at that time?
2. Since the Sun is up for months during the summer at the north pole, why is it that the Equator actually gets the most solar radiation over the course of a year?
3. What are equinoxes and when do they come?

Review Answers

1. Summer solstice is around June 22. The Sun is directly above the Tropic of Cancer. In the Southern Hemisphere, it is winter solstice and the South Pole is in complete darkness.
2. The Sun isn't up at all for about 6 months of the year and when it is up it's at a very low angle so its energy is spread over a large area.
3. The equinoxes are when the day and night are of equal length everywhere. They come around March 22 and September 22, midway between the summer and winter solstices.

1.7 Eclipses

- Describe the types of eclipses and explain why eclipses occur.

If science weren't around to tell you what it is, would an eclipse scare you?

Ancient people could not predict eclipses and didn't know when one would end or even that it would end. Rituals to persuade the Sun or Moon to return to its normal state were developed. And they worked! The heavens always return to normal after an eclipse.

Solar Eclipses

A **solar eclipse** occurs when the new Moon passes directly between the Earth and the Sun (**Figure** 1.13). 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** 1.14). 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** 1.15).

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

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.

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.

See more at http://www.kqed.org/quest/television/eclipse-chasers .

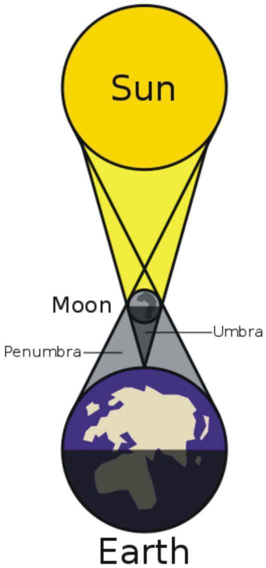


FIGURE 1.13
A solar eclipse, not to scale.

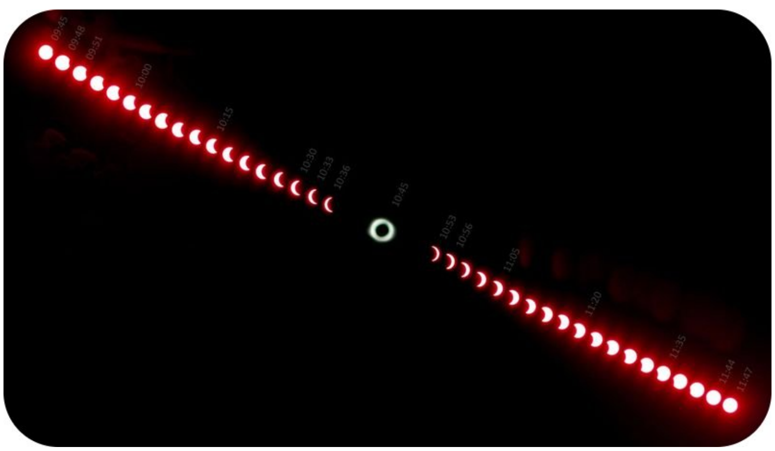
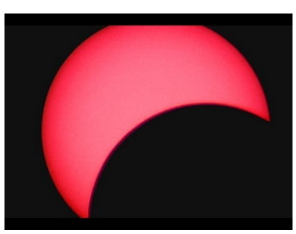


FIGURE 1.14
A solar eclipse shown as a series of photos.



MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/114948

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** 1.16). 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.

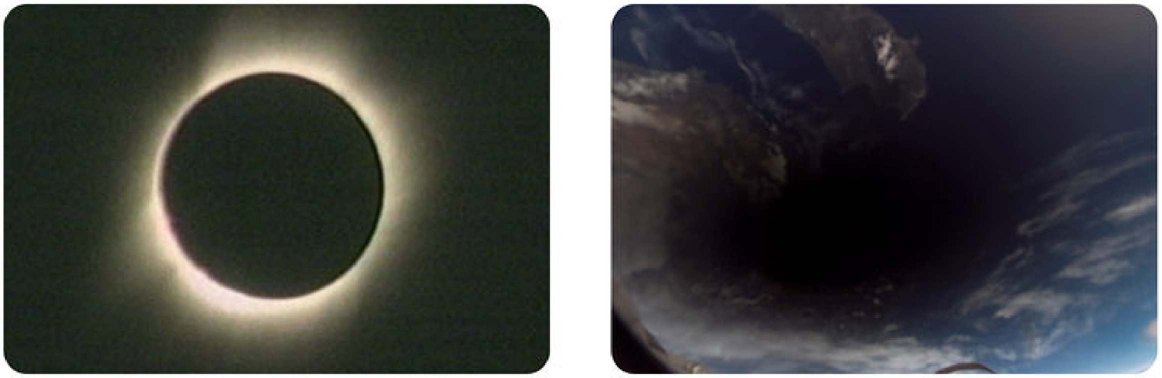


FIGURE 1.15
The Moon's shadow in a solar eclipse covers a very small area.

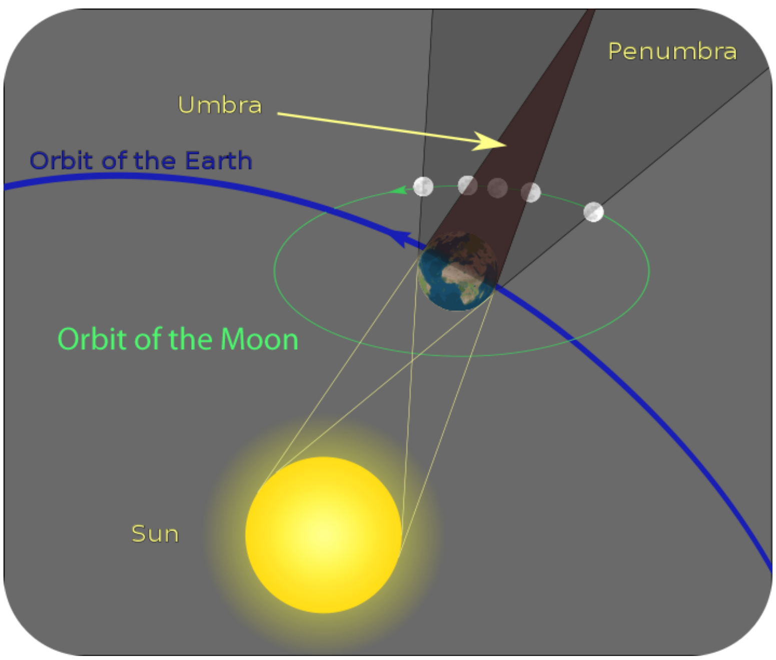


FIGURE 1.16
A lunar eclipse.

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** 1.17). A lunar eclipse does not occur every month because Moon's orbit is inclined 5-degrees to Earth's orbit, so the two bodies are not in the same plane every month.

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 .

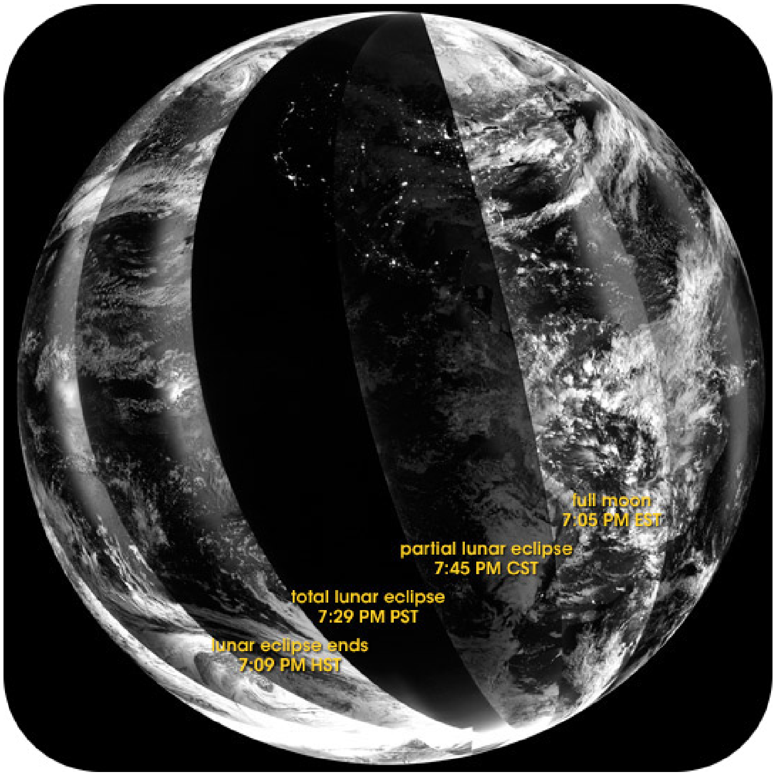


FIGURE 1.17
Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common.

Summary

- During a solar eclipse, the new Moon passes between Earth and Sun.
- During a lunar eclipse, the full Moon moves through Earth's shadow.
- The umbra is the part of the shadow in which light is completely blocked and the penumbra is the part of the shadow that is partially lit.

Explore More

Use these resources to answer the questions that follow.

NASA: Understanding Lunar Eclipses https://www.youtube.com/watch?v=lNi5UFpales

1. About how often does a lunar eclipse take place?
2. When does a lunar eclipse occur? When does a solar eclipse occur?
3. Why don't eclipses happen at every new and full moon?
4. What circumstances must be in place for there to be a lunar eclipse?
5. What is the name of the central part of Earth's shadow? What happens to the Moon when it is there and why?

Explore More Answers

1. About twice a year.
2. When the Moon passes through Earth's shadow. When part of the Earth passes through the Moon's shadow.
3. The Moon's orbit is tilted relative to Earth's orbit.
4. The Moon's orbital tilt changes with respect to the Sun. About twice a year the Moon travels through Earth's shadow.

5. While the Moon is in the umbra, it darkens and then appears a dim red because sunlight is scattered through Earth's atmosphere.

Review

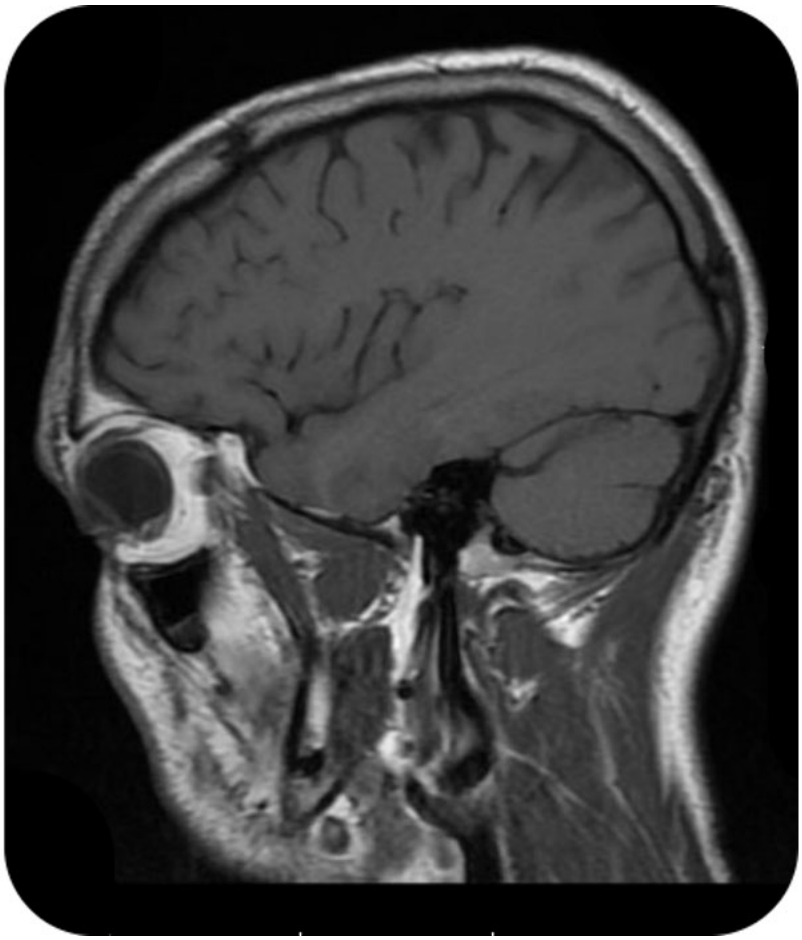
1. What happens during a solar eclipse?
2. What happens during a lunar eclipse?
3. Why do we not see lunar eclipses every month?

Review Answers

1. The Moon passes between the Earth and Sun so that part or all of the Sun is blocked from our view.
2. Earth passes between the Sun and Moon so that our view of the Moon is blocked by Earth's shadow.
3. The Moons orbit is not on the same plane as Earth's orbit of the Sun so eclipses only happen when the orbits intersect.

1.8 Seismic Waves

- Identify and define the components of a wave.
- Identify and define the types of seismic waves.
- Explain how scientists use seismic waves to study Earth's interior.



How is a seismologist like a medical doctor?

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

Waves

Energy is transmitted in waves. Every wave has a high point called a **crest** and a low point called a **trough**. The height of a wave from the center line to its crest is its **amplitude**. The distance between waves from crest to crest (or trough to trough) is its **wavelength**. The parts of a wave are illustrated in **Figure** 1.18.

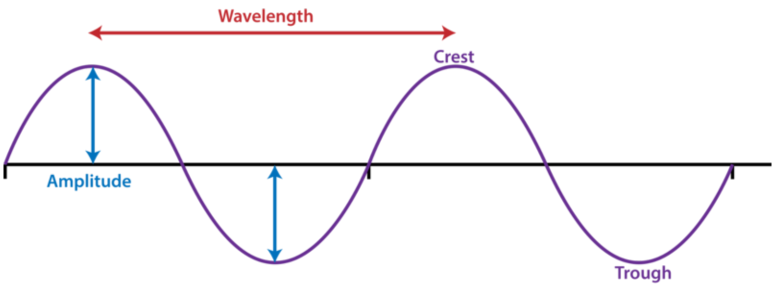


FIGURE 1.18
The crest, trough, and amplitude are illustrated in this diagram.

Earthquake Waves

The energy from earthquakes travels in waves. The study of seismic waves is known as **seismology**. Seismologists use seismic waves to learn about earthquakes and also to learn about the Earth's interior.

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

Body Waves

P-waves and S-waves are known as **body waves** because they move through the solid body of the Earth. P-waves travel through solids, liquids, and gases. S-waves only move through solids (**Figure** 1.19). Surface waves only travel along Earth's surface. In an earthquake, body waves produce sharp jolts. They do not do as much damage as surface waves.

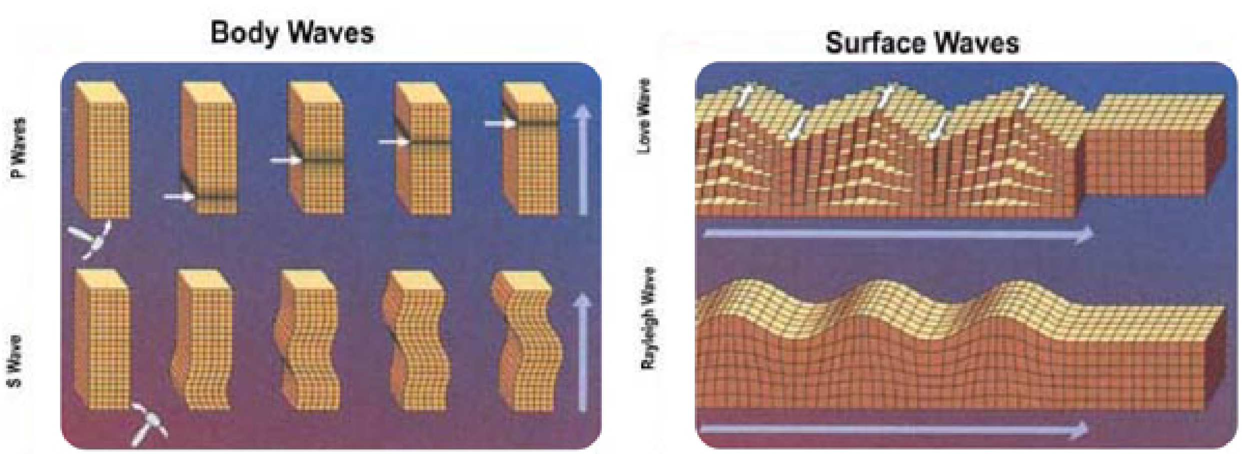


FIGURE 1.19

- **P-waves** (primary waves) are fastest, traveling at about 6 to 7 kilometers (about 4 miles) per second, so they arrive first at the seismometer. P-waves move in a compression/expansion type motion, squeezing and unsqueezing Earth materials as they travel. This produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. Seismic waves move faster through denser or more rigid material. As P-waves encounter the liquid outer core, which is less rigid than the mantle, they slow down. This makes the P-waves arrive later and further away than would be expected. The result is a P-wave shadow zone. No P-waves are picked up at seismographs 104^o to 140^o from the earthquakes focus.

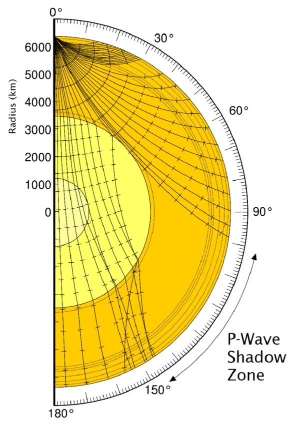


FIGURE 1.20
How P-waves travel through Earth's interior.

- **S-waves** (secondary waves) are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second, and arrive second at seismographs. S-waves move in an up and down motion perpendicular to the direction of wave travel. This produces a change in shape for the Earth materials they move through. Only solids resist a change in shape, so S-waves are only able to propagate through solids. S-waves cannot travel through liquid.

Earth's Interior

By tracking seismic waves, scientists have learned what makes up the planet's interior (**Figure** 1.21).

- P-waves slow down at the mantle core boundary, so we know the outer core is less rigid than the mantle.
- S-waves disappear at the mantle core boundary, so we know the outer core is liquid.

Surface Waves

Surface waves travel along the ground, outward from an earthquake's epicenter. Surface waves are the slowest of all seismic waves, traveling at 2.5 km (1.5 miles) per second. There are two types of surface waves. The rolling motions of surface waves do most of the damage in an earthquake.

Interesting earthquake videos are seen at National Geographic Videos, Environment Video, Natural Disasters, Earthquakes: http://video.nationalgeographic.com/video/player/environment/ . Titles include:

- "Earthquake 101."
- "Inside Earthquakes" looks at this sudden natural disaster.

This animation shows a seismic wave shadow zone: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Shadow+Zone&flash_file=shadowzone&flash_width=220&flash_height=320 .

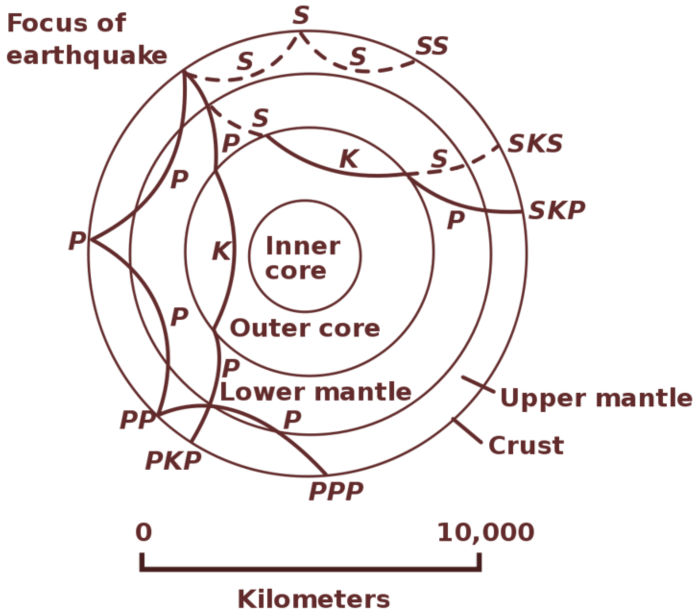


FIGURE 1.21
Letters describe the path of an individual P-wave or S-wave. Waves traveling through the core take on the letter K.

Summary

- P-waves arrive first to a seismograph because they are faster. They travel through solids, liquids, and gases.
- S-waves arrive second to a seismograph, and they only travel through solids.
- The behavior of P- and S-waves indicates that the outer core is liquid.

Explore More

Use this resource to answer the questions that follow.

https://www.khanacademy.org/science/cosmology-and-astronomy/earth-history-topic/seismic-waves-tutorial/v/seismic-waves

1. What are seismic waves?
2. Describe surface waves and in which direction they move (note that the two types of surface waves are Love and Rayleigh).
3. What is important about body waves?
4. What is the fastest type of body wave? How does this type of wave move? What materials can these waves move through?
5. What are the 2nd fastest waves? How do they move? What materials can these waves move through?

Explore More Answers

1. Ordinarily earthquakes but a large explosion, anything that sends energy through earth.
2. Surface waves travel over the surface of the ground. The movement of surface waves is perpendicular to the direction of motion.
3. They are the fastest moving and they are used to figure out the structure of Earth.
4. P-waves or primary waves are the fastest. They move by compression so molecules move closer and further apart; a changing density move in the direction of the wave. These waves can move through solids,liquids and

gases.
5. S-waves are 2nd fastest, They move back and forth through the material. The material moves perpendicular to the direction the wave is moving. S-waves can only travel through solids.

Review

1. What are the properties of P-waves?
2. What are the properties of S-waves?
3. How do scientists use seismic waves to learn about Earth's interior?

Review Answers

1. P-waves travel the fastest and in a compression/expansion type motion, which produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. P-waves move perpendicular to the direction of travel and they only move through solids.
2. S-waves travel more than half as fast as P-waves perpendicular to the direction of motion and cause a change in the shape of the material. S-waves only move through solids so they can't travel through all of the layers of Earth.
3. They can figure out the composition of the material by the speed of the wave and by the time of waves that travel through it. They can look at the bending of waves from one layer to another.

1.9 Earth's Interior Material

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

In *A Journey to the Center of the Earth* , what did they find?

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

Other Clues about Earth's Interior

1. Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal.
2. Since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic.

3. **Meteorites** are the remains of the material that formed the early solar system and are thought to be similar to material in Earth's interior (**Figure** 1.22).

FIGURE 1.22
This meteorite contains silica minerals and iron-nickel. The material is like the boundary between Earth's core and mantle. The meteorite is 4.2 billion years old.

Summary

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

Explore More

Use this resource to answer the questions that follow.

https://www.khanacademy.org/science/cosmology-and-astronomy/earth-history-topic/plate-techtonics/v/how-we-know-about-the-earth-s-core

1. What can P-waves travel through? How about S-waves?
2. What can you measure in the S-wave shadow zone? How many degrees from the quake is that boundary?
3. What is the meaning of the S-wave shadow zone?
4. How do we know that there's an inner core?

Explore More Answers

1. Anything; solids only.
2. Only P-waves; 105-degrees.

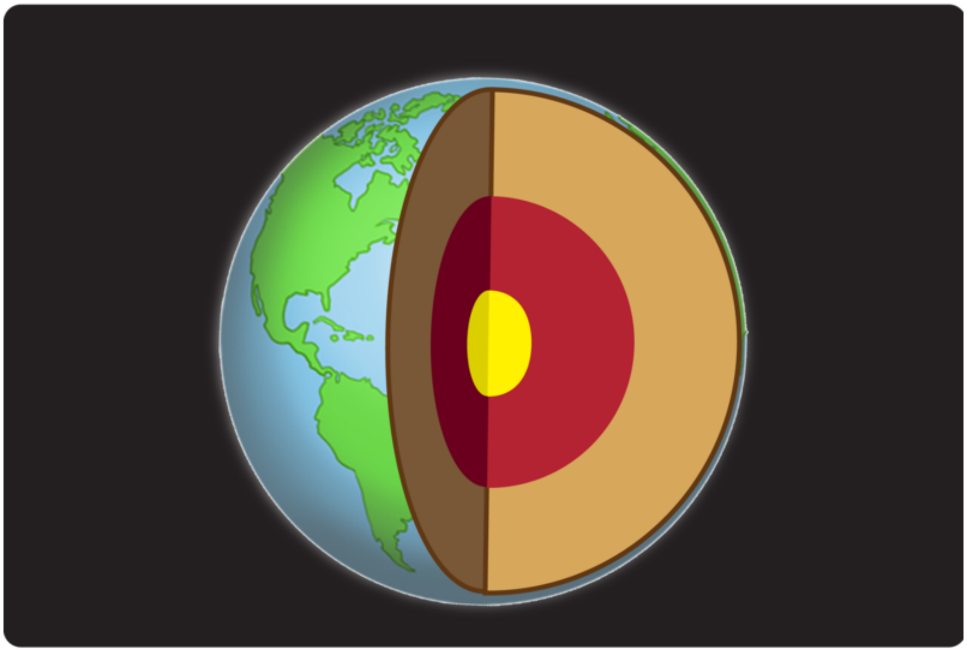
3. At least the outer part of the core is liquid.
4. As material gets denser, P-waves move faster; P-waves move slower in liquids. The seismic patterns indicate P-waves going through a slower medium and then a faster medium. It is the refraction pattern of the P-waves.

Review

1. Scientists know that Earth's interior contains metal, but how do they know it's in the core?
2. How does the meteorite in the **Figure** 1.22 give clues as to what is found in Earth's interior?
3. If a planet in our solar system has a magnetic field, what do we know about it?

1.10 Earth's Layers

- Identify Earth's layers and describe their characteristics.



What's below our feet? What's way below?

If we could cut Earth open, we'd see the inner core at the center, then the outer core, the mantle in the middle and the crust on the outside. If you are talking about plates, though, there's the brittle lithosphere riding on the plastic asthenosphere. Whew!

Layers by Composition

The layers scientists recognize are pictured below (**Figure** 1.23).

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

1. The **crust** is less than 1% of Earth by mass. The two types are oceanic crust and continental crust.Continental crust is felsic and oceanic crust is mafic.
2. The **mantle** is hot, ultramafic rock. It represents about 68% of Earth's mass.
3. The **core** is mostly iron metal. The core makes up about 31% of the Earth.

Layers by Mechanical Properties

Lithosphere and asthenosphere are divisions based on mechanical properties:

1. The **lithosphere** is composed of both the crust and the portion of the upper mantle and behaves as a brittle, rigid solid.
2. The **asthenosphere** is partially molten upper mantle material and behaves plastically and can flow.

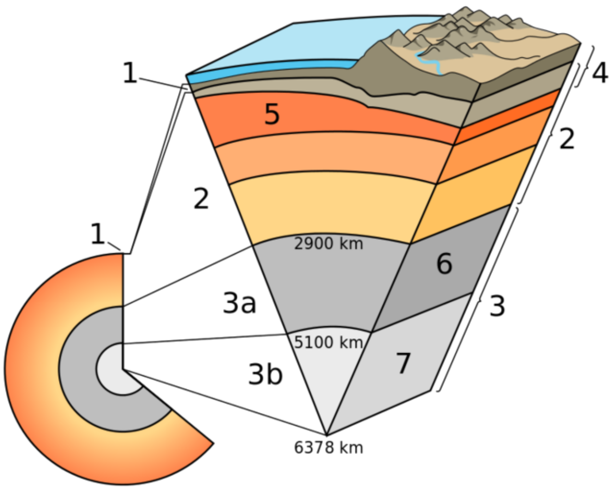


FIGURE 1.23
A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

This animation shows the layers by composition and by mechanical properties: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html .

Summary

- By composition, Earth is divided into core, mantle, and crust.
- By mechanical properties, the crust and upper mantle are divided into lithosphere and asthenosphere.
- Continental crust is felsic, oceanic crust is mafic, the mantle is ultramafic, and the core is metallic.

Explore More

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/structure.html

1. What substances make up the inner core?
2. What is the structure of the inner core?
3. What is the structure of the outer core?
4. Explain the composition of the mantle.
5. What is the role of the asthenosphere?

Explore More Answers

1. iron and nickel metal
2. The inner core is a solid and is at the center of the planet.
3. The outer core is also iron and nickel metal but it is liquid.
4. The mantle is hot semi-solid rock.
5. The asthenosphere is hot and malleable and the lithosphere rides along on it.

Review

1. What are the the layers of Earth based on composition and where are they located?
2. What is the composition of the different layers?
3. How do the lithosphere and asthenosphere differ from each other?

Review Answers

1. The layers based on composition are the core, mantle and crust, from inside to outside. The inner core is solid and the outer core is liquid.
2. The inner core is solid iron and nickel metal and the outer core is liquid iron and nickel metal. Themantle is ultramafic rock. The oceanic crust is mafic rock and the continental crust is felsic rock.
3. The lithosphere is brittle and will break and the asthenosphere is plastic and can flow.

1.11 Earth's Crust

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

How does a loaf of bread resemble Earth?

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

Crust

Earth's outer surface is its crust, a cold, thin, brittle outer shell made of rock. The crust is very thin relative to the radius of the planet. There are two very different types of crust, each with its own distinctive physical and chemical properties, which are summarized in **Table** 1.1.

TABLE 1.1: **Oceanic and Continental Crust**

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

Oceanic Crust

Oceanic crust is composed of mafic magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro (**Figure** 1.24).

FIGURE 1.24
Gabbro from ocean crust. The gabbro is deformed because of intense faulting at the eruption site.

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

The oceanic crust is relatively thin and lies above the mantle. The cross section of oceanic crust in the **Figure** 1.25 shows the layers that grade from sediments at the top to extrusive basalt lava, to the sheeted dikes that feed lava to the surface, to deeper intrusive gabbro, and finally to the mantle.

Continental Crust

Continental crust is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic rocks of the oceanic crust (**Figure** 1.26). Because it is thick and has relatively low density, continental crust rises higher on the mantle than oceanic crust, which sinks into the mantle to form basins. When filled with water, these basins form the planet's oceans.

Summary

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

Interactive Practice

Use these resources to answer the questions that follow.

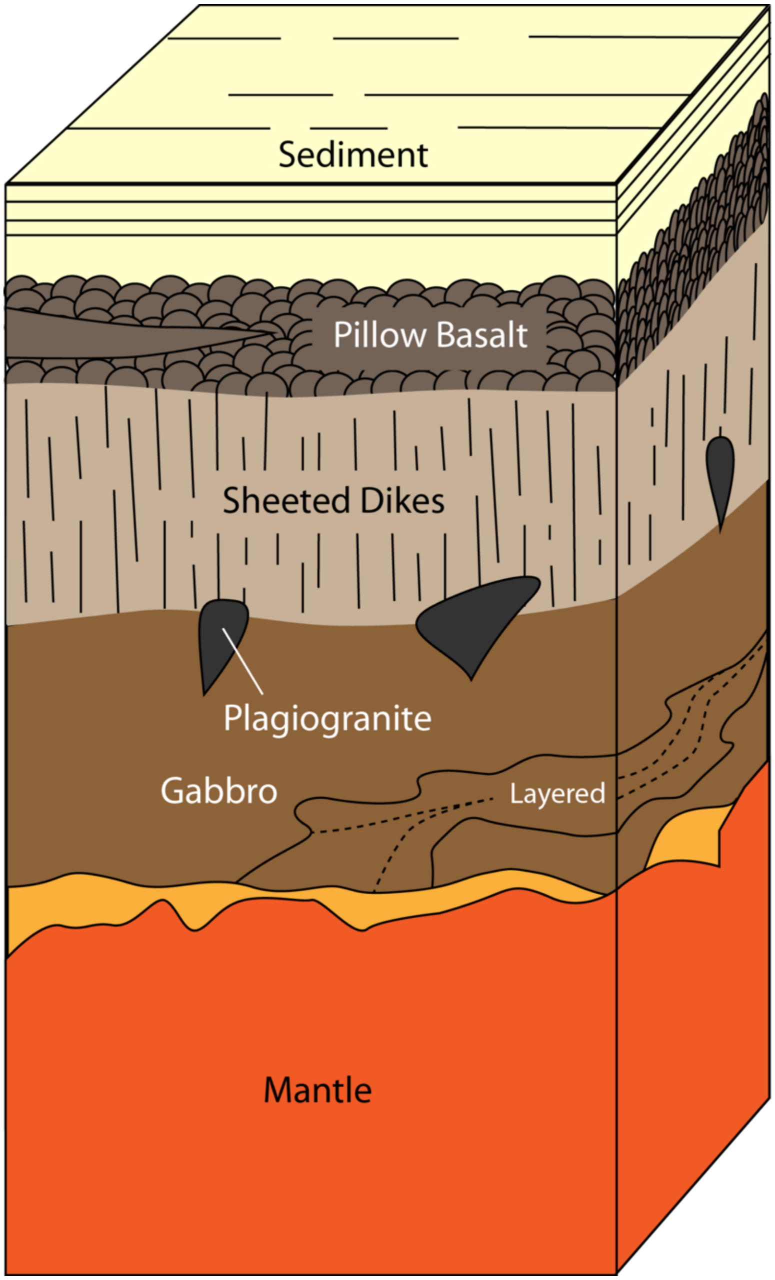


FIGURE 1.25
A cross-section of oceanic crust.

http://www.learner.org/interactives/dynamicearth/structure.html

Click on the crust to answer the questions below:

1. Describe the crust.
2. Where is the crust the thickest?

http://www.scec.org/education/k12/learn/plate1.htm

1. How thick is continental crust?
2. How thick is oceanic crust?
3. Compare the thickness of the crust in comparison with the rest of the layers of the earth.

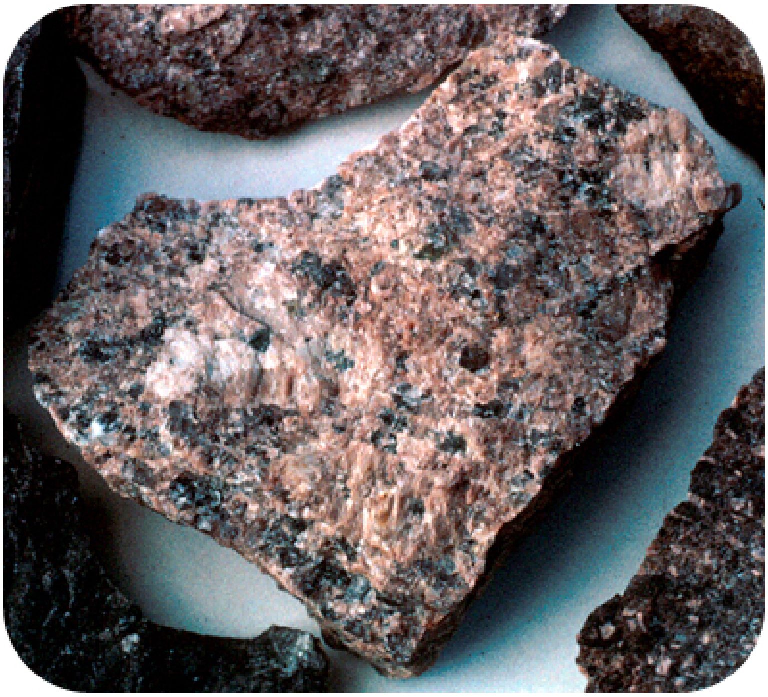


FIGURE 1.26
This granite from Missouri is more than 1 billion years old.

Explore More Answers

1. The crust is the outermost layer. It is brittle. Oceanic crust is much thinner than continental crust.
2. Crust is the thickest where large mountains grow tall. There is a root to those mountains that means the crust is really thick there.
3. Between 35 and 70 km thick.
4. Between 5 to 10 km thick.
5. The crust is extremely thin compared to the thickness of the other layers.

Review

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

Review Answers

1. The oceanic crust is mafic volcanic rock, extrusive at the top and intrusive deeper down. It is covered with sediments, including parts of organisms. Oceanic crust is much thinner than continental crust.
2. The continental crust is made of all three rock types, with the average composition of granite. It is much thicker than oceanic crust.
3. Mafic igneous rock for oceanic crust and all three rock types for continental crust.

1.12 Earth's Mantle

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

What is a diamond delivery system?

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

Mantle

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

Solid Rock

Scientists know that the mantle is made of rock based on evidence from seismic waves, heat flow, and meteorites. The properties fit the ultramafic rock **peridotite**, which is made of the iron- and magnesium-rich silicate minerals (**Figure** 1.27). Peridotite is rarely found at Earth's surface.

Heat Flow

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

Heat flows in two different ways within the Earth:

FIGURE 1.27
Peridotite is formed of crystals of olivine (green) and pyroxene (black).

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

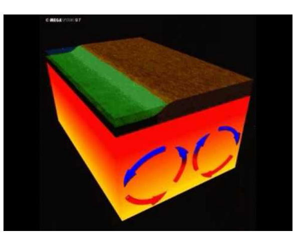
Convection in the mantle is the same as convection in a pot of water on a stove. Convection currents within Earth's mantle form as material near the core heats up. As the core heats the bottom layer of mantle material, particles move more rapidly, decreasing its density and causing it to rise. The rising material begins the convection current. When the warm material reaches the surface, it spreads horizontally. The material cools because it is no longer near the core. It eventually becomes cool and dense enough to sink back down into the mantle. At the bottom of the mantle, the material travels horizontally and is heated by the core. It reaches the location where warm mantle material rises, and the mantle **convection cell** is complete (**Figure** 1.28).

Summary

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

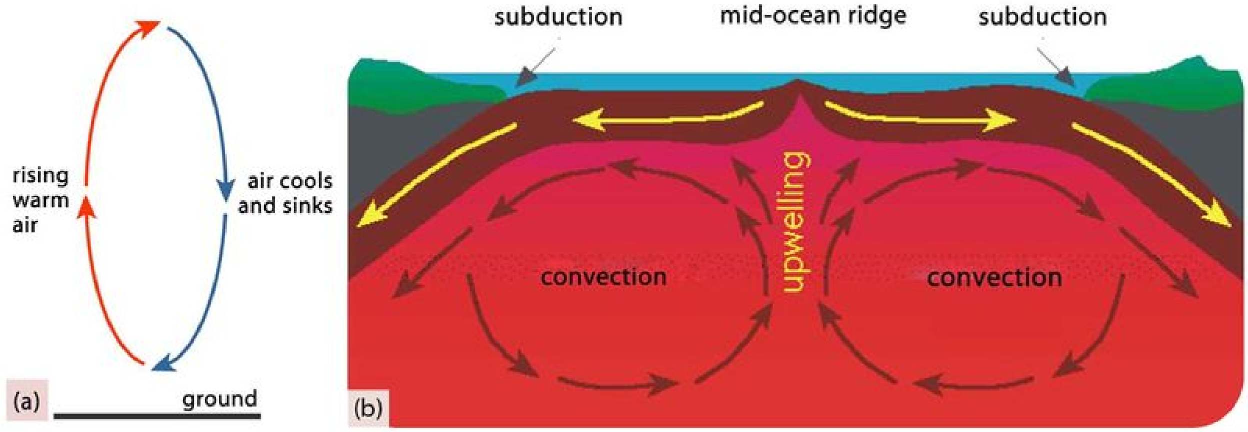
Explore More

Use these resources to answer the questions that follow.



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

1. What incorrect statement does this video make about the asthenosphere? What is correct?



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

Diagram of convection within Earth's mantle.

FIGURE 1.28
Convection.

2. What causes plate movement?
3. What is convection?

http://www.youtube.com/watch?v=yt_K_bfKxTc

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

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

Explore More Answers

1. It says that the asthenosphere is liquid and that for a material to flow it must be liquid, but the asthenosphere is a solid that can flow.
2. Convection in the asthenosphere causes plate motion.
3. When material is heated from below it rises and then cools and sinks, making a convection cell.
4. convection currents form because of differences in density between materials.
5. Denser material sinks and less dense material rises.
6. Convection currents are found in any material that can flow: air, fluid, solids that can flow plastically.

Review

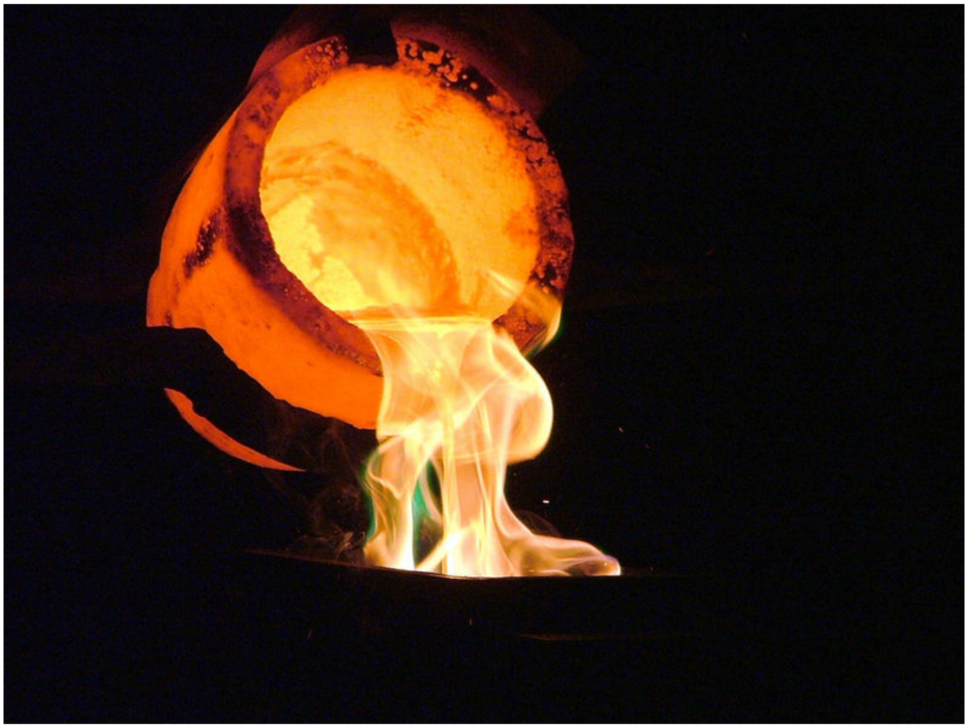
1. What is the composition of the mantle and how do scientists know this?
2. What is conduction?
3. How does convection work in the mantle?

Review Answers

1. Scientists know that the mantle is mostly made of the ultramafic mineral peridotite due to seismic waves, heat flow and the composition of meteorites.
2. Conduction is how heat is passed from warmer to cooler areas. Molecules are more active when they are warmer and this activity is passed to the next group of molecules.
3. The lower mantle is hotter due to heat coming from the core. This is buoyant and rises. As it rises it cools and eventually becomes dense and sinks back into the mantle.

1.13 Earth's Core

- Describe the characteristics of Earth's inner core and outer core.



Do you want to take a journey to the center of the earth?

Jules Verne's imagined core was fiery. But we know that the outer core is molten metal, as seen above. As hot as a journey to Verne's center of the earth might have been, a visit to the real location would be worse.

Core

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

1. The density of Earth's surface layers is much less than the overall density of the planet, as calculated from the planet's rotation. If the surface layers are less dense than average, then the interior must be denser than average. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%.
2. Metallic meteorites are thought to be representative of the core. The 85% iron/15% nickel calculation above is also seen in metallic meteorites (**Figure** 1.29).

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

Scientists know that the outer core is liquid and the inner core is solid because:

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

FIGURE 1.29
An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

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

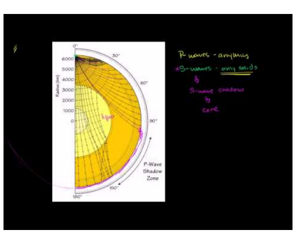
The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core.

Summary

- Earth's core is dense metal.
- The inner core is solid and the outer core is liquid, as indicated by seismic waves.
- Metallic meteorites, density calculations, and the magnetic field are all clues that about the composition of Earth's inner and outer core.

Explore More

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1474

1. What materials can P-waves travel through?
2. What materials can S-waves travel through?
3. How do we know the outer core is liquid?
4. What happens to P-waves when they go through a liquid?
5. What do P-waves tell about the inner core?

Practice Results

1. P-waves can travel through solids, liquids and gases.
2. S-waves can only travel through solids.
3. We know that the outer core is liquid because there is an S-wave shadow zone. S-waves stop when they reach the outer core.
4. P-waves refract when they move from one medium to another. They travel at different speeds.
5. It is the change of behavior in P-waves that lets us know that the inner core is solid.

Review

1. Why is there convection in the outer core and what is the result of this?
2. If scientists discovered a major mistake in their calculations and Earth's crust turned out to be much denser than they'd thought, what would this say about the material that makes up the core?
3. Why is the outer core so hot?

Review Answers

1. The outer core is liquid. It is hotter at the bottom where the inner core is giving off heat so it is more buoyant and rises. It cools as it moves toward the lower mantle and eventually will become dense and sink back.
2. Since we know the total density of the planet, if the crust turned out to be much denser than we think then the core would have to be less dense. Maybe it wouldn't even be metal (although we know it is because we have a magnetic field).
3. It is heated by the inner core, which is kept hot by the radioactive decay of some long-lived elements.

1.14 Lithosphere and Asthenosphere

- Define lithosphere and asthenosphere, and describe their characteristics.

Can you think of a solid that can flow?

You use one twice a day! Toothpaste is a solid that can flow. Is the asthenosphere made of toothpaste? Only if the toothpaste is ultramafic in composition, and then it would only be able to flow if it were really, really hot. Still the toothpaste analogy gives you a good image of how the asthenosphere might behave if you squeezed it!

Lithosphere

The **lithosphere** is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid. The lithosphere is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. How are crust and lithosphere different from each other?

The definition of the lithosphere is based on how Earth materials behave, so it includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stresses act on the lithosphere, it breaks. This is what we experience as an earthquake.

Although we sometimes refer to Earth's plates as being plates of crust, the plates are actually made of lithosphere. Much more about Earth's plates follows in the chapter "Plate Tectonics."

Asthenosphere

The **asthenosphere** is solid upper mantle material that is so hot that it behaves plastically and can flow. The lithosphere rides on the asthenosphere.

Summary

- The lithosphere is the brittle crust and uppermost mantle.
- The asthenosphere is a solid but it can flow, like toothpaste.
- The lithosphere rests on the asthenosphere.

Explore More

Use this resource to answer the questions that follow.

https://www.khanacademy.org/science/cosmology-and-astronomy/earth-history-topic/plate-techtonics/v/compositional-and-mechanical-layers-of-the-earth

1. What does he mean by the mechanical properties of a layer?
2. In the compositional model: What is the outermost layer? What are the two types of this layer and what are their main features?
3. What is the next layer down? What are its main features?
4. What is the deepest layer? Why is this the densest layer?
5. What is the composition of this layer?
6. What is the lithosphere?
7. What are the mechanical properties of the material below the lithosphere and what is the layer called?
8. What is the composition and mechanical property of the mesosphere relative to the asthenosphere?

Explore More Answers

1. Is it solid, liquid or in between, a putty-like, non-rigid solid.
2. The crust is the outermost layer. The two types are oceanic and continental. Continental is thicker (10 to 70 km) and less dense. Oceanic is thinner (5 to 10 km)and denser.
3. The mantle is below the crust. It is the thickest layer, going about 2900 km deeper than the crust.
4. The core is deeper. The dense materials sunk to the center by gravity.
5. Iron and nickel metal.
6. The crust and the topmost part of the mantle where it is brittle.
7. The asthenosphere is not liquid, it's putty-like. It's a solid that can flow.
8. The composition is the same but the pressure is so high that the material is solid.

Review

1. Where is the lithosphere? What layers does it include?
2. What is the asthenosphere?
3. How do the lithosphere and asthenosphere differ?
4. If the lithosphere is resting on the asthenosphere and you put a lot of weight on the lithosphere, say ice in a glacier, how would the lithosphere respond?

Review Answers

1. The lithosphere is the outermost, brittle layer of the Earth. It is the crust and the uppermost mantle.
2. The asthenosphere is a plastic layer. It is also in the upper mantle, but it is not brittle.
3. They differ by mechanical properties. If you hit the lithosphere with a hammer it will break. If you hit the asthenosphere with a hammer it will flow out of the way.
4. The lithosphere would sink into the asthenosphere.

Summary

A planet must (1) orbit a star, (2) have enough mass to be nearly spherical, and (3) have cleared the area around its orbit of smaller objects. Earth is and does all these things! The planet rotates on its axis, so that one half is always facing the Sun and another half is always facing away from the Sun. This rotation creates the day-night cycle. Earth's axis of rotation is tilted relative to its plane of orbit, which creates the seasons. Like other planets, Earth also revolves around the Sun. Earth's trip takes a 365 day year. Earth has a magnetic field, due to convection in its liquid metal outer core. Besides an iron and nickel metal core, the planet has a mantle made of dense rock and a crust made of lighter rock, mostly mafic rock makes up the seafloor and a variety of rocks that have a less dense composition overall make up the crust. The crust and uppermost mantle make up the brittle lithosphere, which rides on the ductile asthenosphere, which is made up of the upper mantle below the lithosphere.

1.15 References

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