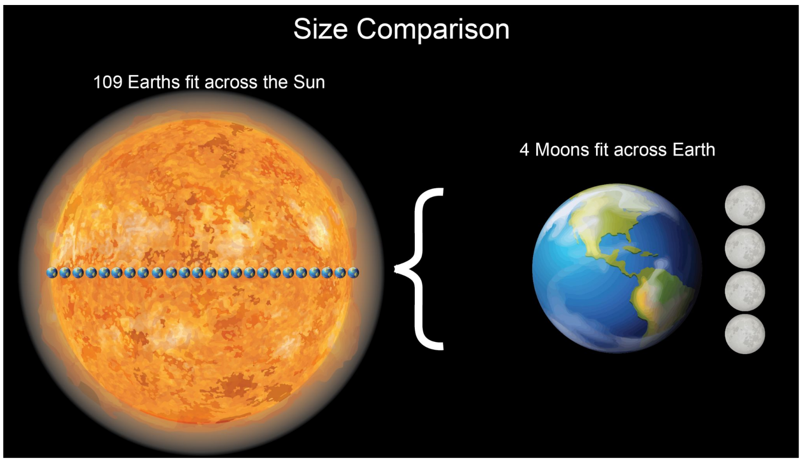
Reflect

In the image on the right, you see Earth in the foreground, the tiny Moon, and the Sun in the distance. The Moon orbits Earth, and the Earth-Moon system orbits the Sun. It is hard to imagine that the interactions of these three celestial objects, although so far away from each other, can cause day and night, seasons, moon phases, eclipses, and tides.

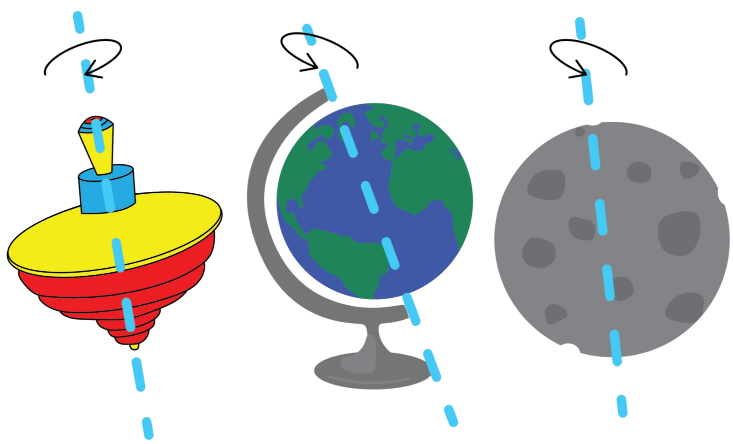


Understanding the size comparison of the Sun, Earth, and the Moon will help you understand their motion. Earth is much bigger than the Moon. About 50 Moons could fit inside Earth. To compare diameters, you could line up four Moons across Earth.

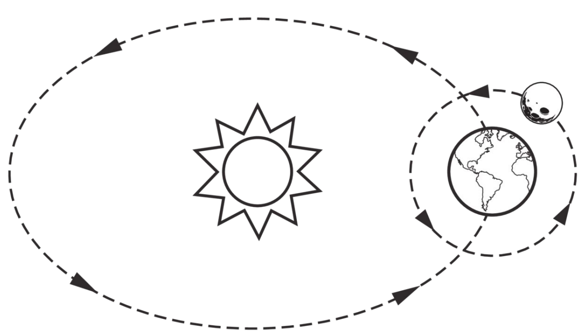
The Sun is even larger. About one million Earths could fit inside the Sun, and 109 Earths could fit across the face of the Sun.

Earth, Moon, and Sun System Motions

Rotation means the motion of a spinning object. The Sun and each of the planets and moons in our solar system rotate about their axes. An axis is an imaginary line about which each planet or moon spins. This imaginary line marks the center of a planet's or moon's rotation. Earth rotates on its axis about once every 24 hours. The Moon rotates very slowly over the course of a month.

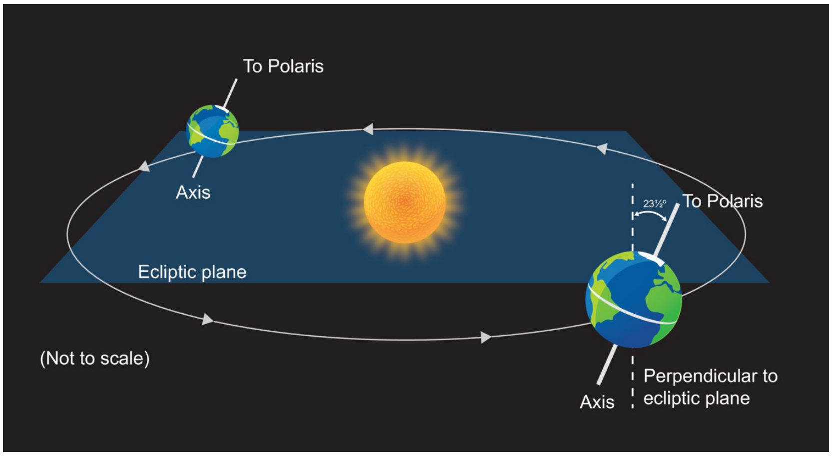


A revolution is the orbiting of another body. Earth (with the Moon) revolves around the Sun in one year (365 ¼ days). The Moon revolves around Earth in one month (approximately 27.3 days). Because the Moon rotates once and revolves once a month, the same side always faces Earth.

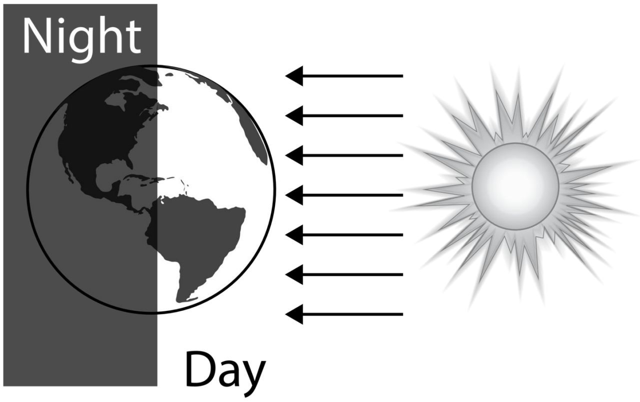


Look Out!

Earth does not tilt back and forth as it goes around the Sun. Earth revolves at a constant angle of 23.5° around the Sun. The northern end of Earth's axis, the geographic North Pole, always points to the North Star, Polaris.



What Do You Think?



Day and Night

What do you think causes day and night on Earth? Rotation! As Earth spins on its axis, the side facing the Sun experiences daytime (about 12 hours), while the side of Earth facing away from the Sun experiences night (about 12 hours). The same occurs on the Moon, except the Moon's slow rotation causes daytime to last about 2 weeks and night to last another 2 weeks. A full day on the Moon would last about one Earth month.

Reflect

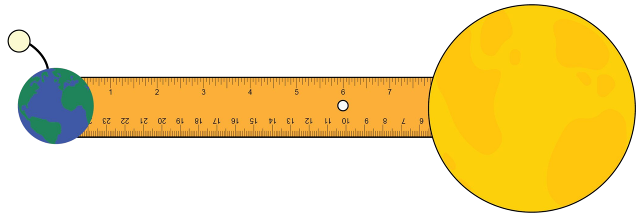
Even though you can't feel it, Earth rotates very fast. Earth's rotation is so fast that it causes the planet to bulge out slightly at the equator and shrink slightly at the poles.

Therefore, Earth is not a perfect sphere. In most photographs and diagrams, Earth typically looks like a perfect sphere. Earth's circumference is slightly wider at the equator than it is across the poles. This shape is called an *oblate spheroid*. Because of this shape, solar energy travels in a straight line from the Sun and hits different parts of the curved Earth at different angles—more directly at the equator and less directly at the poles.

This clementine is an oblate spheroid. Earth is more rounded than this clementine.

Try Now

To make a good model of the Sun, Earth, and the Moon system, you need to either choose objects that show size and location or objects useful for showing their movements. Now, you need to consider distance. Even though your distances will not be exact, your model will still help show the patterns of how these objects move. The Moon revolves around Earth at a distance of about 30 Earth diameters. The Moon is about one-quarter the diameter of Earth. Knowing those two dimensions should help you create a scale model inside the classroom. In the model above, the yellow balloon is the Sun and the table-tennis ball is Earth sitting on a golf tee poking through the hole in the ruler. The marshmallow is the Moon attached to Earth with a short straw.

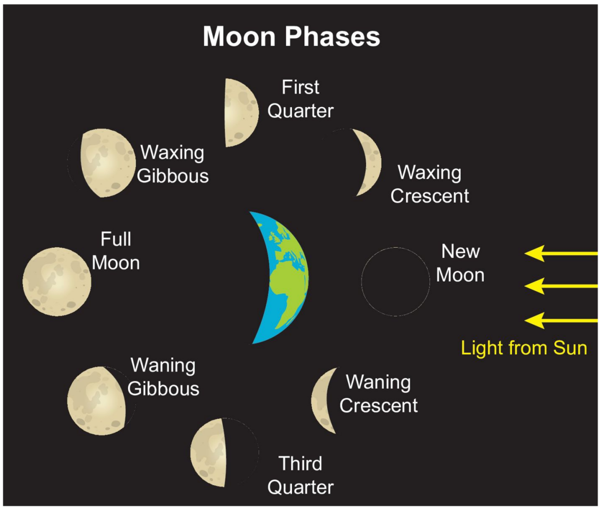


Reflect

Although it appears to be glowing, the Moon does not produce its own light. Instead, the face of the Moon is illuminated by the Sun. Solar energy travels in a straight line from the Sun to Earth and the Moon so that the side of Earth or the Moon that faces the Sun is illuminated. Solar energy reflects off the side of the Moon that faces the Sun and can travel to Earth. As it revolves around Earth, the Moon reflects different amounts of sunlight. As a result, we see different amounts of the Moon at different times of the month.

The Lunar Cycle

Our view of the sunny side of the Moon depends on the relative positions of Earth, the Moon, and the Sun. This happens in a predictable pattern called the lunar cycle, in which we observe different phases of the Moon. This diagram shows the eight phases of the lunar cycle. For example, in the diagram you can see that the full moon phase occurs when the Moon, Earth, and the Sun are in a straight line, resulting in the full moon appearing all night. However, when the Moon comes between Earth and the Sun, as in the new moon phase, the Moon rises and sets during the day and is not visible. Each phase is described in greater detail on the next two pages.



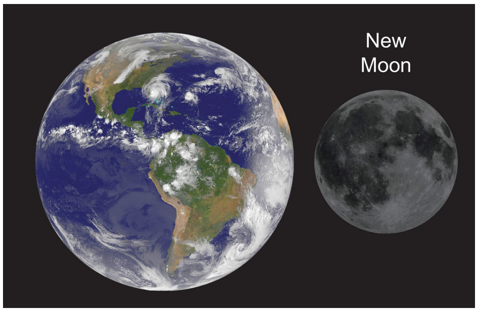
The lunar cycle occurs because the Sun illuminates varying amounts of the Moon facing Earth observers.

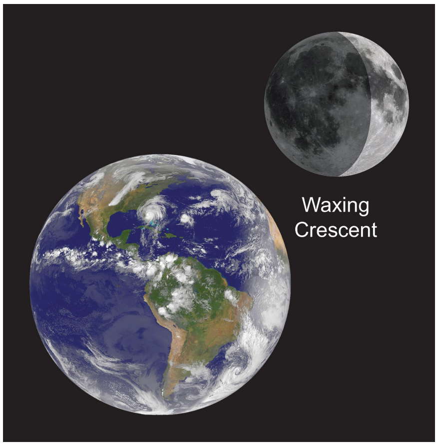
lunar cycle: the pattern that describes how the Moon's appearance in the sky changes over the course of a month

Look Out!

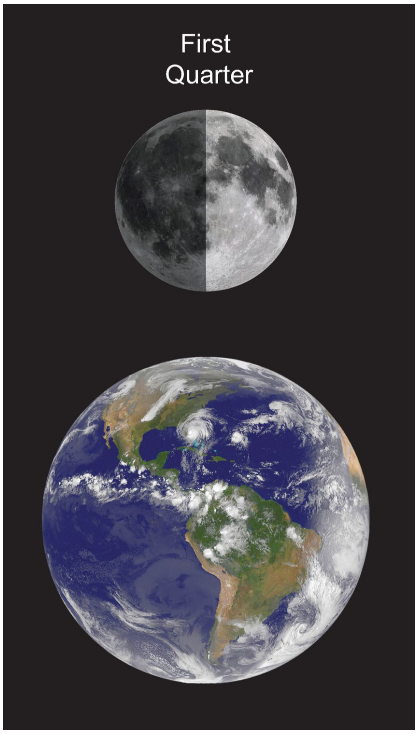
The Phases of the Moon

The new moon phase occurs when the Moon is located directly between Earth and the Sun. As a result of this alignment, the Sun illuminates the side of the Moon that faces away from Earth. The Moon is not visible from Earth at night during the new moon phase because it rises and sets during the day.

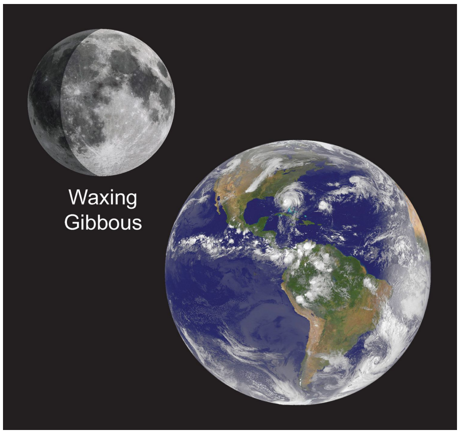




The waxing crescent phase occurs when the new moon begins to change to a first quarter moon. (*Waxing* describes the period when we see more and more of the Moon from Earth.) During this phase, the Sun illuminates less than half the side of the Moon facing Earth. As a result, the Moon appears as a crescent shape in the sky.

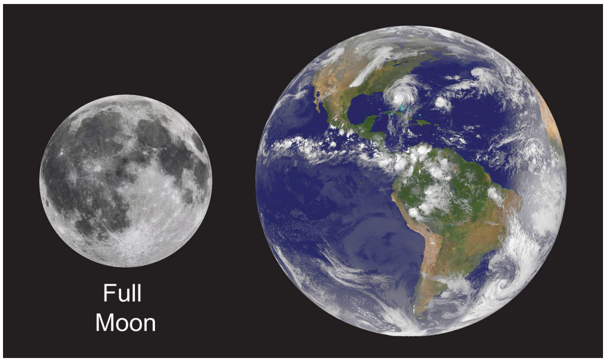


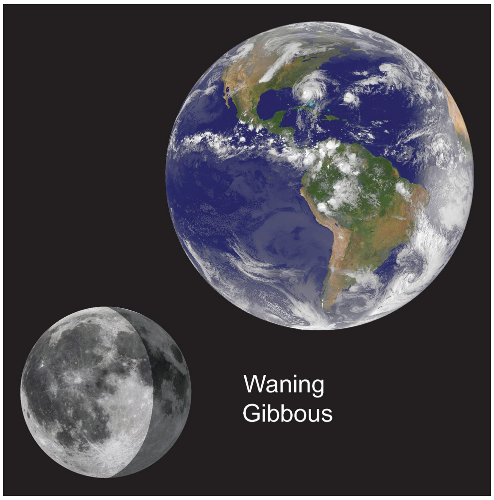
The first quarter phase occurs when the waxing moon is at a 90° angle relative to Earth and the Sun. During the first quarter phase, the Sun illuminates exactly half the side of the Moon facing Earth.



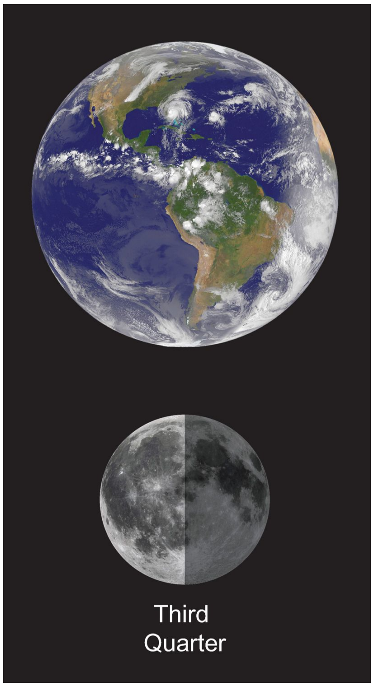
The waxing gibbous phase occurs as the first quarter moon changes to a full moon. During the waxing gibbous phase, the Sun illuminates more than half the side of the Moon facing Earth. As a result, the Moon appears nearly full in the sky.

The full moon occurs when Earth is located between the Moon and the Sun. During the full moon phase, the Sun illuminates the whole side of the Moon facing Earth. During this phase, the Moon appears as a full circle in the sky.





The waning gibbous phase occurs as the full moon changes to a last quarter moon. (*Waning* describes the period when we see less and less of the Moon from Earth.) The waning gibbous phase is the mirror image of the waxing gibbous phase.



The last (third) quarter phase occurs when the waning moon is at a 90° angle relative to Earth and the Sun. The last quarter phase (also called a half moon) is the mirror image of the first quarter phase.

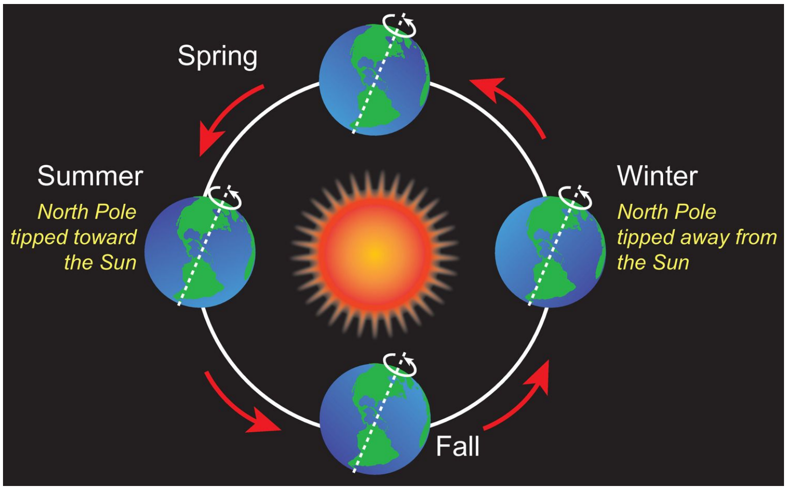
The waning crescent phase occurs when the last quarter moon changes to a new moon. The waning crescent phase is the mirror image of the waxing crescent phase. A new moon follows the waning crescent phase, starting the cycle over again. The Moon takes approximately 28 days to complete one cycle.

The fact that Earth's distance from the Sun changes throughout the year might seem like a good explanation for the seasons. You might think that Earth is colder when it is farther from the Sun and warmer when it is closer to the Sun; however, this explanation is incorrect. In fact, the distance between Earth and the Sun stays relatively constant throughout Earth's orbit. Also, not every part of Earth experiences the same seasons at the same time. When it is summer in the northern hemisphere, it is winter in the southern hemisphere. What, then, causes the seasons?

Reflect

Seasons

Earth's axis is tilted at a 23.5° angle. If Earth's axis were not tilted, we would not experience different seasons. As Earth revolves around the Sun, sometimes the northern hemisphere is tilted toward the Sun. When the northern hemisphere is tilted toward the Sun, it receives more direct rays of sunlight; it is summer. During summer, days are longer and weather is warmer in the northern hemisphere. Plants there have plenty of sunlight for photosynthesis, and animals have plenty to eat.

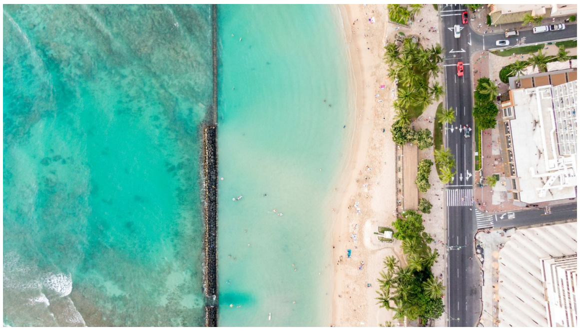


Earth's tilted axis and its revolution around the Sun—not Earth's distance from the Sun—cause the seasons. When the northern hemisphere is tilted toward the Sun, it receives more direct rays of sunlight than the southern hemisphere. During this time, the northern hemisphere experiences summer and the southern hemisphere experiences winter.

When Earth reaches the opposite side of its orbit—a process that takes about six months—the southern hemisphere is tilted toward the Sun. It will receive more direct and intense solar energy, and the northern hemisphere will receive less. As a result, the southern hemisphere will experience summer and the northern hemisphere will be in the middle of winter. The change in season at a given place on Earth is directly related to the orientation of tilted Earth and the position of Earth in its orbit around the Sun. This is due to the change in the directness and intensity of the solar energy at that place over the course of the year.

Reflect

Arriving at a sandy ocean beach early in the day, you set up a blanket and chairs within a few meters of the water. After a swim in the surf, you decide to go off the beach to a refreshment stand for a snack and to an amusement park to ride the roller coaster. You return to the beach later, only to discover the ocean has flooded your chairs and soaked your blanket. What force has moved the ocean-water level up the beach? What force will later move the ocean-water level back down?



Gravity in the Sun-Earth-Moon System

Throughout the day, water levels in oceans and lakes around the planet rise and fall. These regular movements, or tides, are produced by the motions and positions of three objects in space. These objects are Earth, the Moon, and the Sun.

The Moon revolves around Earth as Earth revolves around the Sun. Although the Sun is much bigger than the Moon, the Moon is nearly 400 times closer to Earth. (This diagram is not drawn to scale.)

As they move through space, the Moon, Earth, and the Sun exert gravitational forces on one another. The force of gravity is affected by two variables: the masses of the objects and the distances between them. Although the Moon is much less massive than the Sun, the Moon is much closer to Earth than Earth is to the Sun. As a result, the force of the Moon's gravity on Earth is more than double the force of the Sun's gravity on Earth. Substances that are free to move on Earth's surface, such as ocean water, are more greatly affected by the Moon's gravity than by the Sun's. This is particularly important for Earth's tides. As the Moon revolves around Earth, it pulls water in oceans and lakes toward it. This causes water levels to rise in some places and to fall in others.

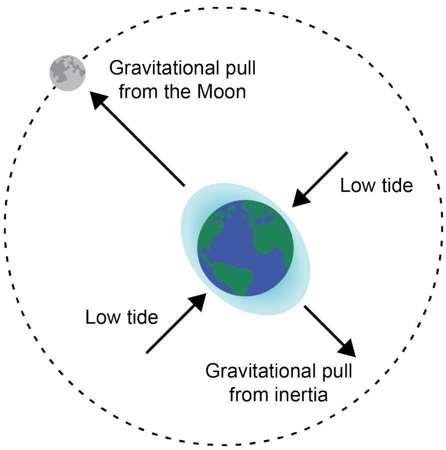
Look Out!

All things in the universe that have mass also have gravity and pull on each other. We can see the effect of the Moon's gravity as tides rise and fall. As the Moon's gravity pulls on Earth, Earth pulls back on the Moon. If the Moon had any oceans or lakes, the water in those bodies would also experience tides.

Gravity and Ocean Tides

Each day, tides on Earth rise and fall between two extremes. A high tide is the highest point on a shore that water will reach, mainly due to the gravitational attraction of the Moon. At any given time of day, high tides are produced on whichever shores are facing the position of the Moon relative to Earth. At the same time, high tides are also produced on the shores opposite the position of the Moon relative to Earth. In other words, at any given time on Earth, one tidal bulge faces the Moon, and one tidal bulge faces the opposite direction.

What causes this second tidal bulge? A combination of gravity and inertia. Inertia is the tendency for something to remain at rest or in motion unless acted on by an unbalanced force. Water on Earth has inertia; it tends to stay in place unless acted on by an unbalanced force. For example, forces from winds cause waves as air moves across the surfaces of oceans and lakes. Another force that overcomes water's inertia is gravity.



The Moon's gravity and the inertia of water create two high tides on opposite sides of Earth. Two low tides happen at right angles to the tidal bulges.

Look at the diagram. On the side of Earth facing the Moon, the pull of the Moon's gravity is greater than the water's inertia—its tendency to stay in place. So the water on that shore bulges toward the Moon. At the same time, the Moon's gravity pulls Earth slightly toward the Moon. The Moon's gravity does not affect water on the side of Earth opposite the Moon. Therefore, as the planet is pulled in one direction toward the Moon, the water on the opposite side of the planet remains in place. The result is a second tidal bulge due to inertia. As Earth rotates under the Moon, the bulges move around the planet. However, they are always opposite each other.

A low tide is the lowest point on a shore that water will reach. Low tides always happen at places on Earth that are at right angles to the tidal bulges. Like high tides, two low tides occur at the same time on opposite sides of Earth.

At any given place on Earth, high tides occur twice most days, and low tides occur twice most days. For example, suppose a beach in New Jersey faces the Moon at noon. That beach will experience a high tide at noon (as will a beach on the opposite side of the planet). Approximately 12 hours later, that beach will face away from the Moon. This will produce another high tide around midnight. Low tides on the same beach will occur at approximately 6 p.m. and 6 a.m.

Tides do not occur at the same times every day. At any beach, high tides are separated by approximately 12 hours and 25 minutes. The same is true of low tides. Therefore, each day, high tides and low tides happen slightly later than they happened the previous day.

What Do You Think?

Find the Virginia coast on a globe of Earth. (If you do not have a physical globe, you can find many globes online. Enter the terms *virtual globe* into a search engine.) When it is high tide in Virginia, where on Earth is also experiencing a high tide? Where is it low tide?

Choose one other location on another part of the globe. When it is high tide in this location, and where else on Earth is it also high tide? Where is it low tide?

Tidal Variations

If you measured high and low tides every day for a month, you would discover that some high tides are higher than others. You would also discover that some low tides are lower than others. If you did the same thing over the course of a year, you would discover that the range between high and low tides is greatest around January 2. You would also discover that the range between high and low tides is least around July 2.

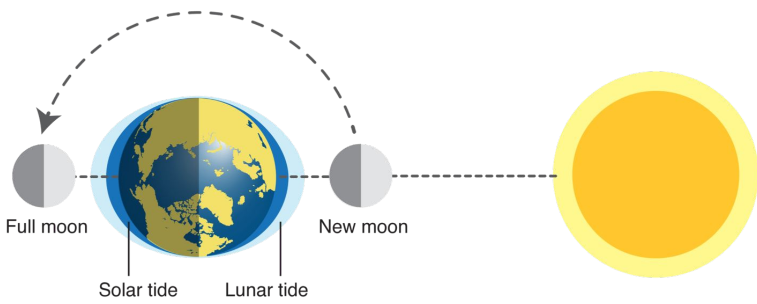
All of these variations are caused by three factors:

- How the Moon, Earth, and the Sun are aligned with each other
- Where the Moon is positioned relative to Earth
- Where Earth is positioned relative to the Sun

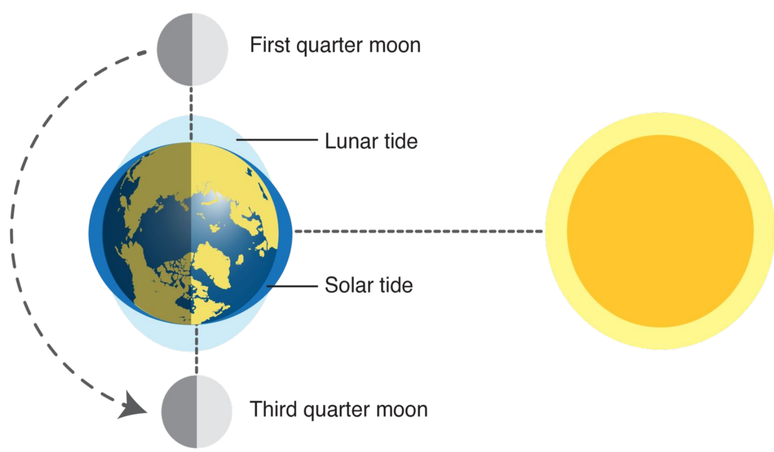
Let us examine these in order. As the Moon revolves around Earth, it reaches a point between Earth and the Sun. This happens once each month, during the new moon phase of the **lunar cycle**, when the side of the Moon facing Earth is dark. When Earth, the Moon, and the Sun are aligned like this, the effect of the Sun's gravity combines with the Moon's gravity.

The same thing happens about two weeks later when Earth is between the Moon and the Sun. (In this alignment, the side of the Moon facing Earth is completely bright—the full moon phase.) These two alignments produce higher than average high tides and lower than average low tides. We call these tides spring tides.

About one week after a new moon or a full moon, the Moon and the Sun form a right angle relative to Earth. In this position, the Sun's gravity works against the Moon's gravity. High tides are lower than average, and low tides are higher than average. We call these tides neap tides.



During a spring tide (above), the Moon, Earth, and the Sun are aligned. High tides are higher than average, and low tides are lower than average. During a neap tide (below), the Moon, Earth, and the Sun form a right angle. The difference between high and low tides is relatively small.



Why is the range between high and low tides greatest in early January and least in early July? Earth follows an elliptical, or oval-shaped, path around the Sun. Earth's path takes it closest to the Sun around January 2 of each year. On that date, called perihelion, the gravitational force between Earth and the Sun is strongest. This produces a greater than average range of tides. Earth's path takes it farthest from the Sun around July 2 of each year. On that date, called aphelion, the gravitational force between Earth and the Sun is weakest. This produces a lower than average range of tides.

Looking to the Future: Harnessing the Energy of Tides

To reduce our dependence on fossil fuels such as oil, coal, and natural gas, many countries have turned to alternative sources of energy. These include wind energy, solar energy, geothermal energy, and the energy of moving water. Another benefit of these alternative resources is they create less pollution than fossil fuels do.

Until recently, the energy of moving water has mainly been harnessed by damming rivers to produce electricity. Since the 1960s, some countries, such as France, have built tidal power plants. Other countries, including Canada and the United States, are investigating ways to transform the movements of tides into electrical energy.

Here is how a tidal power plant works: As tides rise and fall, they have kinetic energy—the energy of motion. This kinetic energy is used to turn the blades of a machine called a turbine. Gears and other devices transmit this motion to an electric generator. This machine transforms the tidal energy into electrical energy. The electrical energy is transmitted through cables to homes, factories, and communities.

Try Now

The relative positions of the Moon, Earth, and the Sun produce different kinds of tides. In the spaces below, draw the positions of the Moon, Earth, and the Sun that produce each kind of tide or condition.

NOTE: The same kind of tide may be produced by more than one set of positions of the Moon, Earth, and the Sun. In such cases, draw all sets of positions that produce the tide.

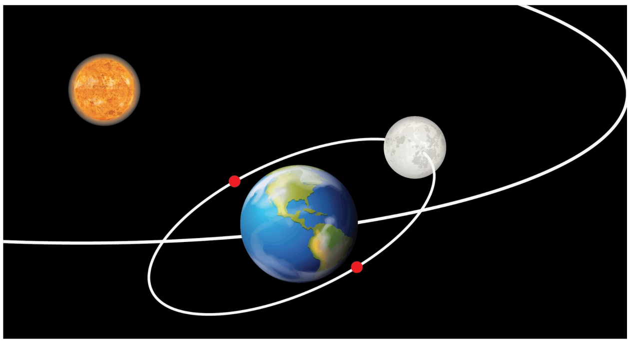
Tide or Condition	Relative Positions of the Moon, Earth, and the Sun
Spring Tide (above-average range of tides)	
Neap Tide (below-average range of tides)	
Earth at Perihelion (above-average range of tides)	
Earth at Aphelion (below-average range of tides)	

What Do You Think?

Eclipses

How do you think system of Earth, the Sun, and the Moon can explain eclipses of the Sun and the Moon? An eclipse occurs when one celestial object passes through the shadow of another celestial object.

- A solar eclipse is when the Moon blocks the Sun and the Moon's shadow falls along a small path on Earth.
- A lunar eclipse is when the Moon moves into Earth's shadow.

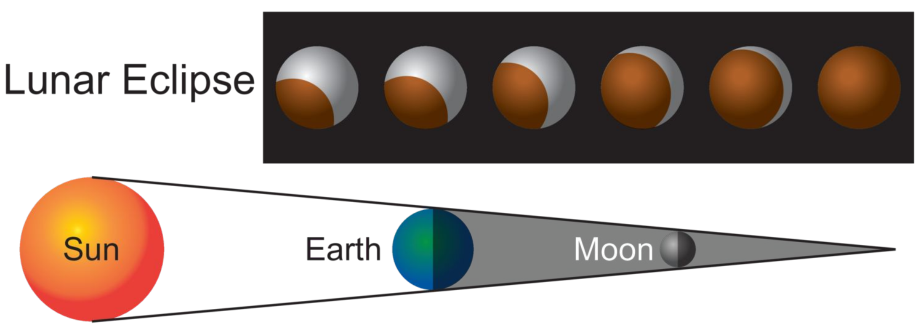


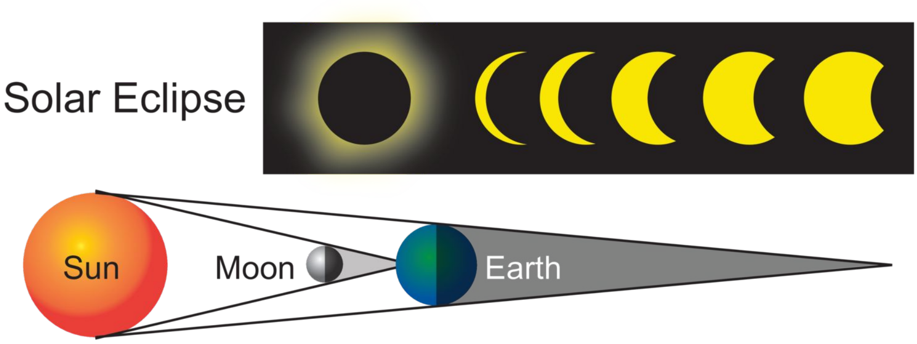
We do not see solar and lunar eclipses every month because the Moon's orbital path around Earth is tilted with respect to the plane of Earth's orbit. Eclipses only occur when all three celestial bodies line up in the same plane. The points in the Moon's orbit where this occurs are called nodes (shown on the left as red dots). Eclipses only occur at these nodes.

During a solar eclipse, sunlight is prevented from reaching only a very narrow path on Earth because the Moon casts a very small shadow.

During a lunar eclipse, Earth's shadow covers the entire Moon because Earth's shadow is much larger than the Moon.

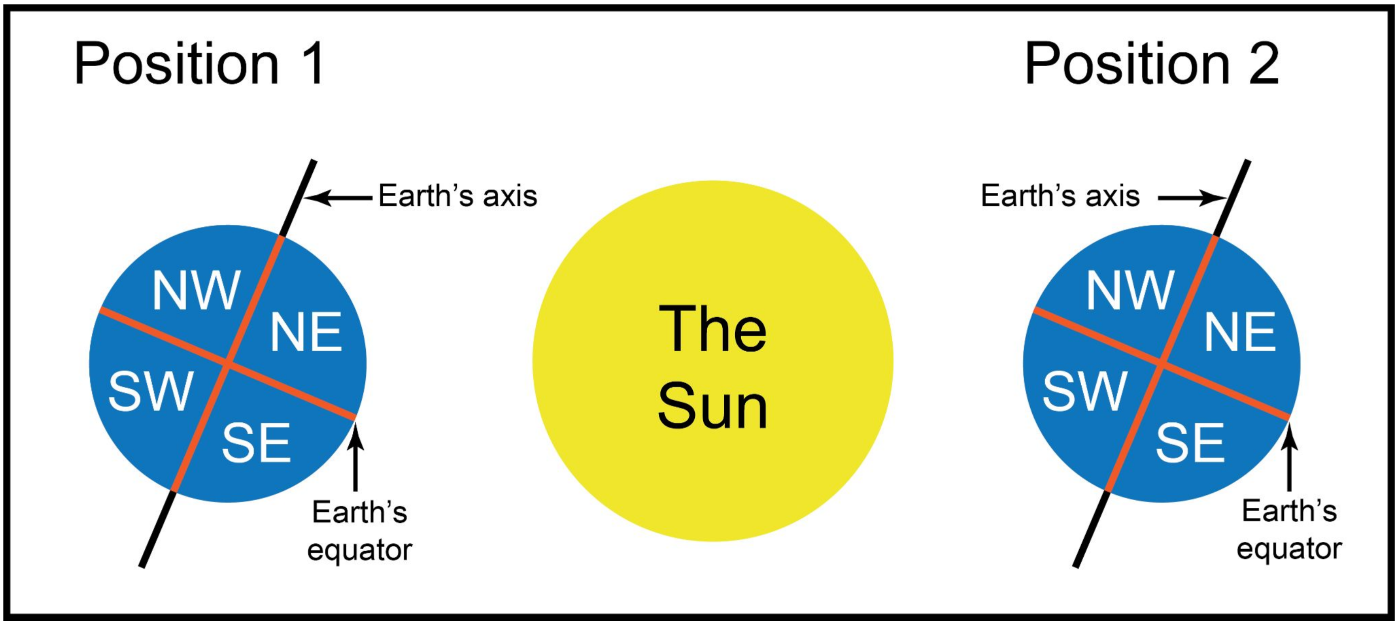
Often, the Moon will appear a copper-red color during a lunar eclipse because light is refracted or bent through Earth's atmosphere and appears red. This is called a blood moon.





Try Now

Earth's rotation and revolution affect day-and-night cycles as well as the seasons. The following diagram shows Earth at two positions in its orbit around the Sun. (This diagram is not drawn to scale.)



For each position, decide whether each section is experiencing day or night and winter or summer. Write your answers in the charts below.

Position 1				Position 2			
NE Section		NW Section		NE Section		NW Section	
Day or Night?	Winter or Summer?	Day or Night?	Winter or Summer?	Day or Night?	Winter or Summer?	Day or Night?	Winter or Summer?

Position 1				Position 2			
SE Section		SW Section		SE Section		SW Section	
Day or Night?	Winter or Summer?	Day or Night?	Winter or Summer?	Day or Night?	Winter or Summer?	Day or Night?	Winter or Summer?

Connecting With Your Child

Exploring Rotation and Revolution at Home

To help your child learn more about rotation and revolution, try a few simple experiments.

1. First, gather a flashlight and a round object such as a globe or ball (preferably about the size of a basketball or beach ball).
2. Create an axis for the ball by taping two drinking straws, pencils, or similar objects to opposite ends of the ball.
3. In a darkened room, hold the ball a few feet away from your child. Have your child shine the flashlight on the ball. Hold the ball so that the axis is pointing up and down at a slight tilt toward the flashlight.
4. Holding the ball steady at this tilt, walk in a circle around your child. Keep the flashlight aimed at the ball. As you revolve around your child, discuss how the ball represents Earth on its tilted axis and the flashlight represents the Sun.
5. Stop periodically at different points in the "orbit." Ask your child to explain which season each hemisphere is experiencing and where it is day and where it is night.
6. Try the exercise again. This time, hold the ball so that the axis is perfectly straight up and down, rather than at a tilt.
7. Ask your child how this changes the effect of Earth's orbit on each hemisphere.
   Earth will still experience day and night as it rotates. But without a tilted axis, Earth's different hemispheres will not experience different seasons.

Here are some questions to discuss with your child:

- How does Earth's tilted axis affect each hemisphere as the planet revolves?
- Point to different spots on the ball. What would people living here experience when Earth was at this point in its orbit?
- If Earth's axis *weren't* tilted, what would change?