Motions of Earth, the Moon, and Planets

If you get up early in the morning and look for the Sun, you will see it low in the eastern sky. At sunset, the Sun is once again low in the sky, but in the west. This is why people often say that the Sun "rises in the east and sets in the west." Of course, the Sun does not really move across the sky, it only appears to do so.

Earth's Rotation

The apparent motion of the Sun in the sky is caused by the rotation of Earth on its axis. This motion is similar to the spinning of a top (Figure 1). Earth makes one complete rotation, in a west-to-east direction, once each day. During its rotation, the portion of Earth that faces the Sun experiences daylight. The portion facing away from the Sun experiences darkness.

Figure 1 Earth's axis is an imaginary line that goes through the planet from pole-to-pole.

orbital radius the average distance between an object in the Solar System and the Sun

Earth's Revolution and Planetary Orbits

While Earth spins on its axis, it also revolves, or travels around the Sun. Earth's orbit, like that of the other planets, is elliptical.

The distance of each planet from the Sun changes as it completes its orbit around the Sun. This is because the Sun is located closer to one end of the elliptical path. Earth, for example, is farthest from the Sun around July 4, and closest to the Sun around January 3. Astronomers calculate the average distance from the Sun for each planet and call this value the planet's **orbital radius**.

The shape and size of a planet's orbit affects the time that it takes it to complete a revolution around the Sun, a value which we call an orbital period. The farther a planet is from the Sun, the slower it moves along its orbit and the longer it takes to orbit the Sun (because its orbit is larger). Mars, for example, takes 687 days to orbit the Sun whereas Mercury orbits the Sun in only 88 days. Earth completes one revolution around the Sun approximately every 365.25 days (Figure 2). If you could look down on the Solar System (such that the North Pole of Earth is pointing toward you), you would see that the planets revolve in a counterclockwise direction.

DID YOU KNOW?

Leap Years
Most of our calendar years are 365 days. Since Earth completes one revolution around the Sun in 365.25 days, we fall 1/4 of a day behind each year. The extra quarter-days are added up every four years and added on as an extra day (February 29) in leap years. By inserting a 366th day, our calendar year closely matches Earth's revolution around the Sun.

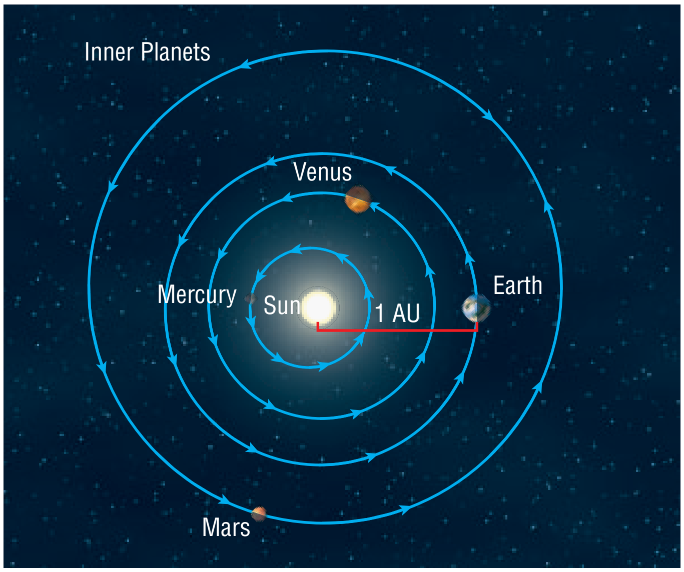

Figure 2 Earth has an orbital radius of 1 AU and an orbital period of 365.25 days.

Effects of Earth's Revolution

Earth's revolution affects our view of celestial objects in the sky. You will learn more about this in Section 8.9.

Motions of the Moon

The Moon also rotates on its axis. As it rotates, the Moon also revolves around Earth. The Moon completes one rotation on its axis in about the same time it takes to complete one revolution around Earth. The result of this is that the same side of the Moon faces Earth at all times. Together, the Earth-Moon pair revolve around the Sun.

The Force of Gravity

What keeps the planets orbiting the Sun, and the Moon orbiting Earth? There is a force of attraction between all objects in the Universe with mass, known as **gravitational force**, or gravity. The greater the mass of an object, the stronger its gravitational force. The gravitational force of our massive Sun is strong enough to keep Earth in orbit. Without the Sun's gravity, Earth would move away from the Sun into space (Figure 3). Similarly, the strong pull of Earth's gravity keeps the Moon in orbit.

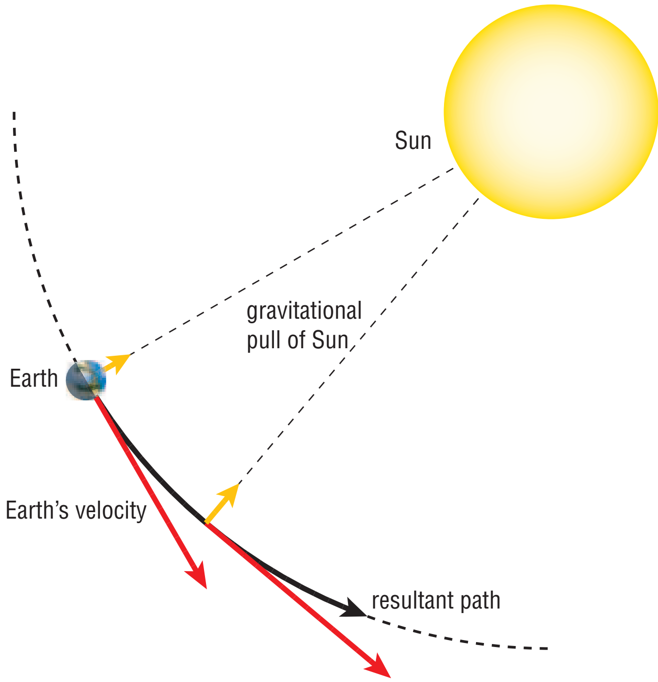

Figure 3 Earth stays in a stable orbit because of the balance between its forward speed and the Sun's gravitational pull.

Explaining Motion in the Solar System

Although today we understand that the planets, including Earth, revolve around the Sun, this was not always understood. About 2000 years ago, the Greek astronomer Claudius Ptolemy (87–150 CE) believed that the Sun and the planets revolved around Earth.

DID YOU KNOW?

Earth's Speed

Earth spins on its axis at a speed of about 1600 km/h at the equator. Meanwhile, Earth revolves around the Sun at a speed of 108 000 km/h.

gravitational force the force of attraction between all masses in the Universe

DID YOU KNOW?

Universal Law of Gravity

Isaac Newton (1643–1727) realized that the gravity that kept the Moon in orbit was the same force that made objects on Earth fall to the ground. He developed the Universal Law of Gravitation, which states that every object in the Universe attracts every other object. The more massive the objects are and the closer they are to each other, the greater the attraction.

This type of Solar System model is called a geocentric model of the Solar System (Figure 4). Ptolemy observed the apparent motion of the Sun and planets in the sky and assumed that these objects were revolving around Earth. This idea was widely accepted until the Middle Ages, when Nicholas Copernicus (1473–1543) proposed a model placing the Sun at the centre of the Solar System, called the heliocentric model of the Solar System (Figure 5). This model was much better at explaining the motion of the planets than the geocentric model.

LEARNING TIP

Word Origins
Geo means "Earth" and *centric* means "centre," so the term *geocentric* means "Earth centred." Likewise, *helios* means "Sun," so *heliocentric* means "Sun centred."

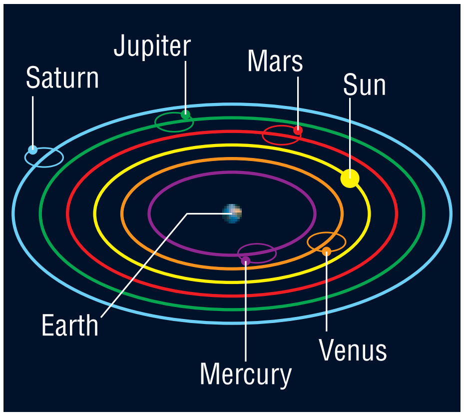

Figure 4 A geocentric model of the Solar System.

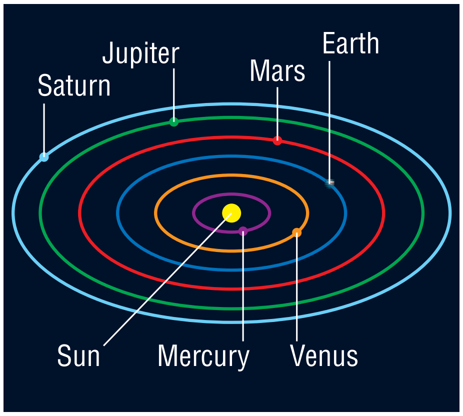

Figure 5 A heliocentric model of the Solar System.

In the early 1600s, Galileo was an outspoken supporter of the heliocentric model. In 1610 he used the telescope he invented to observe four moons orbiting Jupiter. A planet with other celestial objects orbiting it did not conform to the geocentric model, so many astronomers of the time did not believe his discoveries. Galileo's further observations of other planets, especially his observations of Venus, eventually led to the conversion of the scientific community to the heliocentric model. The heliocentric model is the basis of our modern understanding of how the Solar System and other planetary systems in the Universe work.

Earth's Tilt

Earth's rotational axis is tilted 23.5° from the vertical when compared to the plane of Earth's orbit around the Sun (Figure 6). This tilt affects the average daytime temperature experienced by Earth's hemispheres.

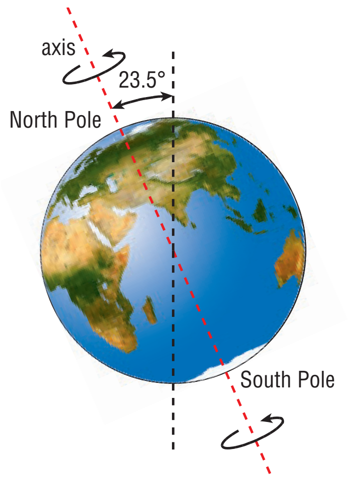

Figure 6 Earth's axis is tilted 23.5° from the vertical.

The Reason for Seasons

As Earth revolves around the Sun, the northern and southern hemispheres experience the seasons—spring, summer, autumn, and winter. Many people mistakenly believe that the seasons are caused by Earth's distance from the Sun. Although it is true that Earth's distance from the Sun changes over the course of the year, the changes in Earth-Sun distance are not enough to cause the changes of the seasons. Seasons change primarily because of Earth's tilt.

When Earth is farthest from the Sun, the northern hemisphere is tilted toward the Sun and sunlight spreads over a relatively small area of Earth's surface (Figure 7(a)). This causes intense heating of Earth's surface and atmosphere. During this time, the Sun appears to travel its highest path in the sky, and there are more hours of daylight.

When Earth is closest to the Sun, the northern hemisphere is tilted away from the Sun and sunlight spreads over a larger area of Earth's surface (Figure 7(b)). This causes less heating of Earth's surface and atmosphere. During this time, the Sun appears to travel a lower path in the sky and there are fewer daylight hours.

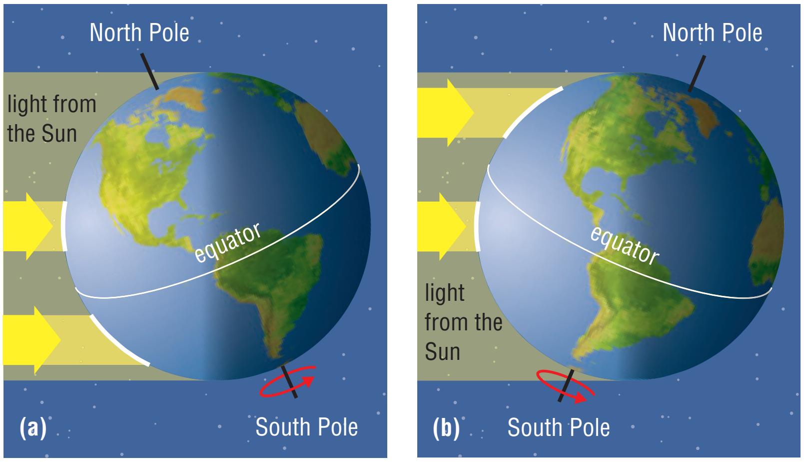

Figure 7 (a) The northern hemisphere receives more direct sunlight than the southern hemisphere when Earth is tilted toward the Sun. (b) The reverse effect occurs when Earth is tilted away from the Sun.

When Earth's axis is most inclined toward or away from the Sun, we call it a **solstice**. Solstices occur twice each year. Around June 21, Earth's northern hemisphere is tilted toward the Sun as much as possible. This is the longest day of the year, and is considered the first day of summer in the northern hemisphere. Around December 21, the northern hemisphere is tilted away from the Sun as much as possible. This is the longest night of the year, and is considered the first day of winter in the northern hemisphere.

When the northern hemisphere is tilted toward the Sun, the southern hemisphere is tilted away from the Sun, and vice versa. This means that when the northern hemisphere experiences summer, the southern hemisphere experiences winter, and vice versa. Between the solstices are two days of equal daytime hours and nighttime hours called the **equinoxes**. In the northern hemisphere, the vernal equinox occurs on about March 21 and the autumnal equinox occurs on about September 21 (Figure 8).

solstice an astronomical event that occurs two times each year, when the tilt of Earth's axis is most inclined toward or away from the Sun, causing the position of the Sun in the sky to appear to reach its northernmost or southernmost extreme

equinox the time of year when the hours of daylight equal the hours of darkness

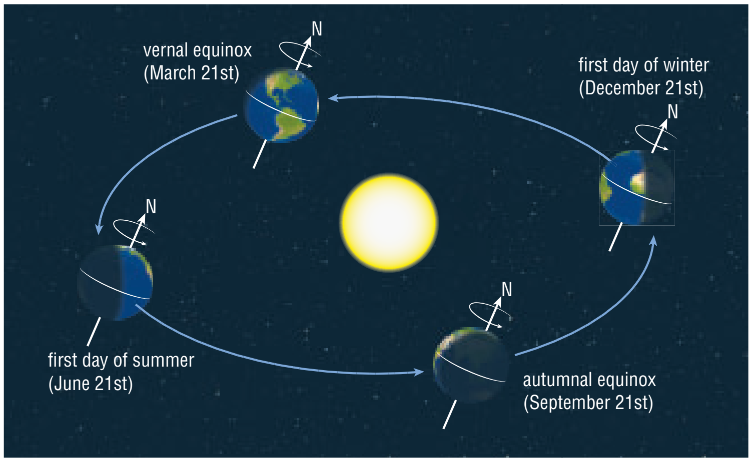

Figure 8 The seasons in the northern hemisphere.

LEARNING TIP

Night and Day

The word "equinox" comes from the Latin words *equi* meaning "equal" and *nox* meaning "night." The equinox is a period of "equal night," in which there are 12 hours of daylight and 12 hours of darkness.

Figure 9 This time lapse photo shows stars revolving around Polaris (indicated by arrow).

precession the changing direction of Earth's axis

Precession—Earth's Wobble

If you extend the line of Earth's axis from the North Pole into space, it would pass very close to the star Polaris. This is why Polaris is often referred to as the North Star, or Pole Star. Astronomers call this point in the sky the North Celestial Pole. For anyone living in the northern hemisphere, the entire sky appears to rotate around this one star (Figure 9).

Polaris has not always been the pole star. As Earth rotates, its axis slowly turns, pointing in different directions over time. This change in direction of Earth's rotational axis is called **precession**, and is a motion similar to the wobble of a spinning top. If you watch a spinning top closely, you will see its upper and lower tips trace circles as they wobble (Figure 10). Earth's axis also wobbles and traces a circle every 26 000 years. Precession will result in the North Celestial Pole pointing near the star Vega in about 12 000 years and back to Polaris in another 26 000 years.

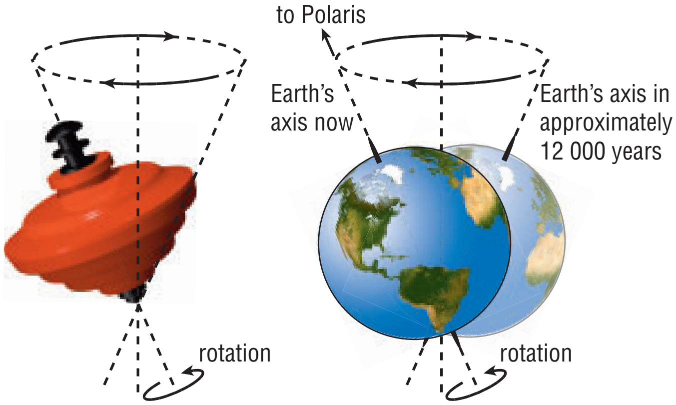

Figure 10 Precession of Earth's axis is similar to the wobble of a slowly spinning top.

READING TIP

Finding the Main Idea
The first sentence of a paragraph is called the topic sentence and this is where the main idea usually is stated. For example, *the lunar cycle begins with the new moon.* Sometimes the first sentence gives an introduction to the topic, so check the second sentence to see if it states the main idea.

Phases of the Moon

The Moon, like all celestial objects in the Solar System, is illuminated by the Sun. However, the illuminated side does not always face Earth, which means that we see different amounts of the lit side as the Moon orbits Earth. Over a period of about 4 weeks, the amount of the illuminated surface of the Moon we see (called phases) follows a predictable pattern. The eight phases of the Moon that we see over this period of time make up the **lunar cycle** (Figure 11).

lunar cycle all of the phases of the Moon

The lunar cycle begins with the new moon, when the Moon is not visible from Earth. We do not see the Moon during this phase because the side that is illuminated faces away from Earth. After this phase, the illuminated portion of the Moon visible from Earth waxes (increases in size). This occurs during the first half of the lunar cycle. First, we see the waxing crescent—a curved sliver of light. About a week after the new moon, the Moon reaches the first quarter phase. This appears as a half moon in the sky because half of the illuminated portion of the Moon is facing Earth. When the waxing gibbous phase arrives, we see more than half of the Moon's illuminated surface. The full moon phase appears as a lit circle in the sky, with the Moon's illuminated side facing Earth.

DID YOU KNOW?

Misconception
Some people mistakenly believe that the phases of the Moon are caused by Earth's shadow. This is incorrect. The phases of the Moon are caused by how much of the Moon's illuminated surface we can see.

During the second half of the lunar cycle, the illuminated portion of the Moon visible from Earth wanes (decreases in size). The lunar cycle progresses to waning crescent moon and then begins the lunar cycle again.

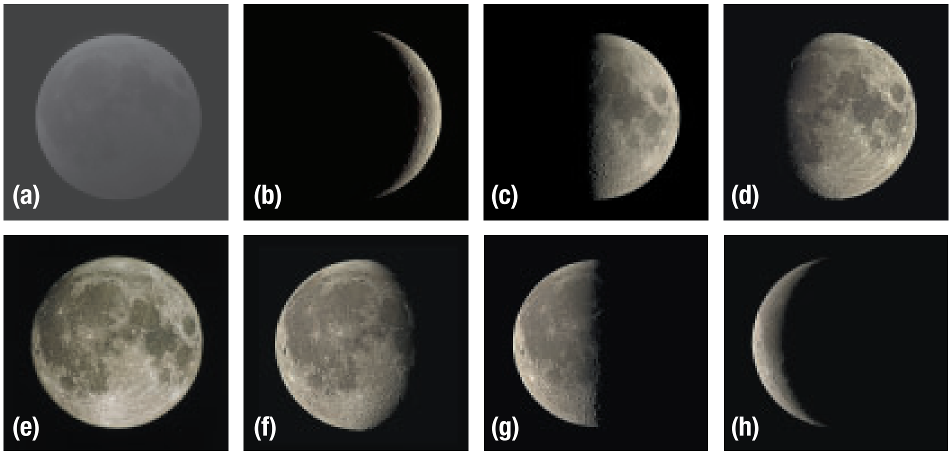

Figure 11 The phases of the Moon as seen from Earth.
(a) New moon (darkened image to represent the new moon, which we cannot see)
(b) Waxing crescent
(c) First quarter
(d) Waxing gibbous
(e) Full moon
(f) Waning gibbous
(g) Third quarter
(h) Waning crescent

TRY THIS MODELLING THE LUNAR PHASES

SKILLS: Observing, Communicating, Analyzing

SKILLS HANDBOOK 3.B.

You will be creating a model of the Earth–Moon system in order to view the Moon cycle through its phases (Figure 12).

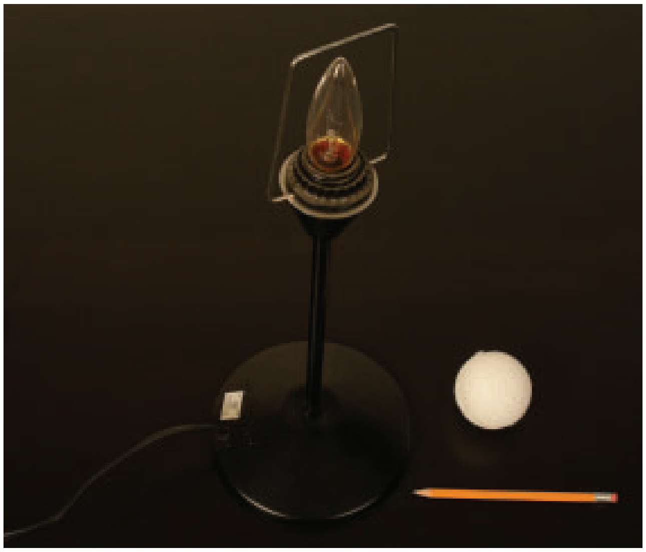

Figure 12

Equipment and Materials: **a lamp with a 40- to 60-watt light bulb (lamp shade removed); polystyrene ball; pencil**

1. Choose one person in your group to represent Earth.
2. Have another member of your group stick the pencil into the polystyrene ball. This is the Moon.
3. Turn out the classroom lights and turn on the lamp, which represents the Sun.
4. Ask Earth to stand several metres away from the Sun.
5. Have the Moon revolve around Earth in a counterclockwise direction, while the Earth-bound observer watches the lighted part of the Moon and determines the phases visible as the Moon continues in its orbit.
6. Have each member of your group take a turn being Earth and observing the Moon go through its phases.

A. Starting with the new moon phase, use the model to describe the main phase of the Moon during one lunar cycle. T/I

B. How could the activity be changed to make the phases of the Moon appear more distinct? T/I

Eclipses—In the Shadow

Eclipses are spectacular astronomical events that occur when the position of one celestial object blocks, or darkens, the view of another celestial object from Earth. Throughout history, these events have been interpreted in different ways by various cultures. Solar eclipses were often associated with bad omens, such as disease epidemics, deaths of kings, and wars. Lunar eclipses were believed by some to be caused by a mythological creature swallowing the Moon.

eclipse a darkening of a celestial object due to the position of another celestial object

Solar Eclipse

The Sun has a diameter 400 times greater than the Moon. It is also 400 times farther from Earth than the Moon is. As a result, the Moon and the Sun appear approximately the same size in the sky.

DID YOU KNOW?

Moon Drift

The Moon is slowly drifting away from Earth. As a result, in about 3000 years, a total eclipse will no longer be possible.

When the Moon is aligned between Earth and the Sun, it blocks the Sun from being observed from Earth–an event that we call a solar eclipse (Figure 13(a)). A solar eclipse is only possible during a new moon phase and is quite rare. During a total solar eclipse, only the outer atmosphere of the Sun, the corona, remains visible. This is because of the relative sizes of the Sun and the Moon in the sky. Total solar eclipses allow scientists to study the Sun's corona (Figure 13(b)). To view a total eclipse from Earth, observers must be located along the lunar shadow path, which is only a few dozen kilometres wide.

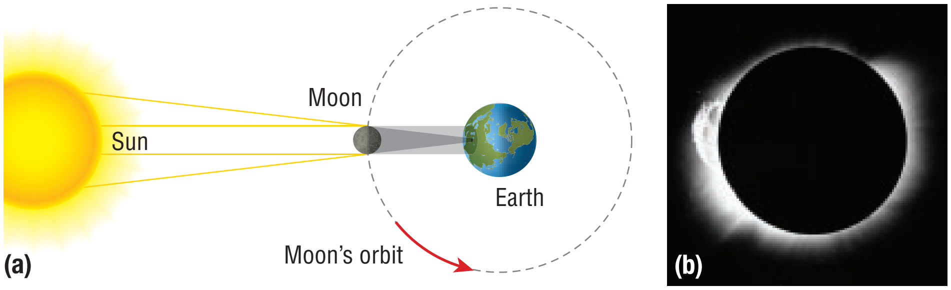

Figure 13 (a) This view of the Sun and Earth, looking down from the North Pole, shows a total eclipse. A total eclipse occurs somewhere on Earth once every two years. (b) During a total eclipse, astronomers can safely study solar flares from the Sun without damaging their eyes because the Sun is covered by the Moon.

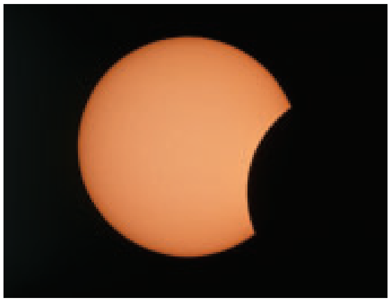

Figure 14 A partial solar eclipse does not fully block out the Sun and should not be observed without special eye protection.

Partial solar eclipses occur when the Moon does not cover the entire Sun (Figure 14). Solar eclipses should be viewed through a suitable solar filter or by projection, and not with the naked eye. The Sun's powerful rays can damage your eyes when it is not fully hidden behind the Moon.

Lunar Eclipse

A lunar eclipse occurs when Earth is positioned between the Sun and the Moon, casting a shadow on the Moon (Figure 15(a)). During a total lunar eclipse, the entire Moon passes through Earth's shadow. If only part of the Moon passes through Earth's shadow, a partial lunar eclipse occurs. A lunar eclipse can be seen anywhere on Earth where the Moon is visible above the local horizon.

A lunar eclipse can appear orange or red (Figure 15(b)). This colouration is caused by the refraction of sunlight as it passes through Earth's atmosphere. This is also why sunsets appear orange-red.

DID YOU KNOW?

Volcanic Eruption

In June 1991, Mount Pinatubo, a volcano in the Philippines, erupted in the second largest volcanic explosion of the twentieth century. The eruption ejected billions of tonnes of ash and dust high into Earth's atmosphere. This debris circled Earth for more than a year. The lunar eclipses that followed in 1992 were such a deep red that some people saw the eclipsed Moon completely disappear in the sky.

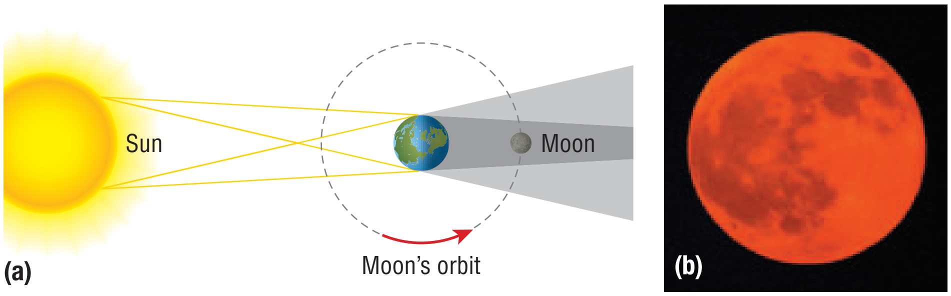

Figure 15 (a) This view of the Sun and Earth, looking down from the North Pole, shows a total lunar eclipse. A total lunar eclipse can last up to an hour. (b) The colour of the Moon during a total eclipse depends on the amount of dust and clouds in Earth's atmosphere.

Tides—The Pull of the Moon

If you have spent much time at an ocean beach, you may have noticed that the beach gets wider or narrower at certain times of the day. This change is due to the rise and fall of the water level, or tides. **Tides** are the rising and falling of the surface of oceans, and are caused by the gravitational pull of the Moon and, to a lesser extent, the Sun. The Moon's gravitational force pulls Earth and its oceans toward it. This causes a bulge of water to form on the side of Earth facing the Moon. As Earth is pulled toward the Moon, a bulge of water also forms on the opposite side of Earth, where the Moon's gravitational force is weakest. (Figure 16). This results in two high tides and two low tides on Earth each day. The time between low and high tide is approximately six hours.

tide the alternate rising and falling of the surface of large bodies of water; caused by the interaction between Earth, the Moon, and the Sun

To find out more about tides,
GO TO NELSON SCIENCE

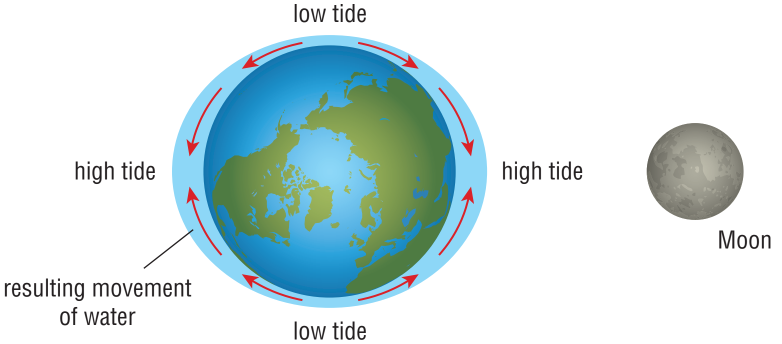

Figure 16 When the Moon is directly overhead, coastal areas experience high tide. At the same time, coastal areas on the opposite side of Earth also experience high tide. The regions on Earth between the two tidal bulges experience low tide.

The Sun also has an effect on tides, but its tidal effect is much smaller because it is so much farther away than the Moon. During the new and full moon phases of the lunar cycle, Earth, the Moon, and the Sun are aligned. The combined gravitational force of the Moon and the Sun causes very high tides, called spring tides, to form (Figure 17(a)). When the Moon and the Sun are perpendicular to each other with respect to Earth (during the quarter phases) the gravitational pull of the Sun somewhat counteracts the gravitational pull of the Moon. This forms weaker tides, called neap tides (Figure 17(b)).

DID YOU KNOW?

Bay of Fundy
Canada is home to the world's highest tides. The Bay of Fundy, a narrow finger of salt water between New Brunswick and Nova Scotia, experiences tides that can rise and fall the height of a four-storey building. Twice a day, 100 billion tonnes of water flow into and out of the bay. Researchers hope to one day use this massive daily flow of water as a renewable energy source.

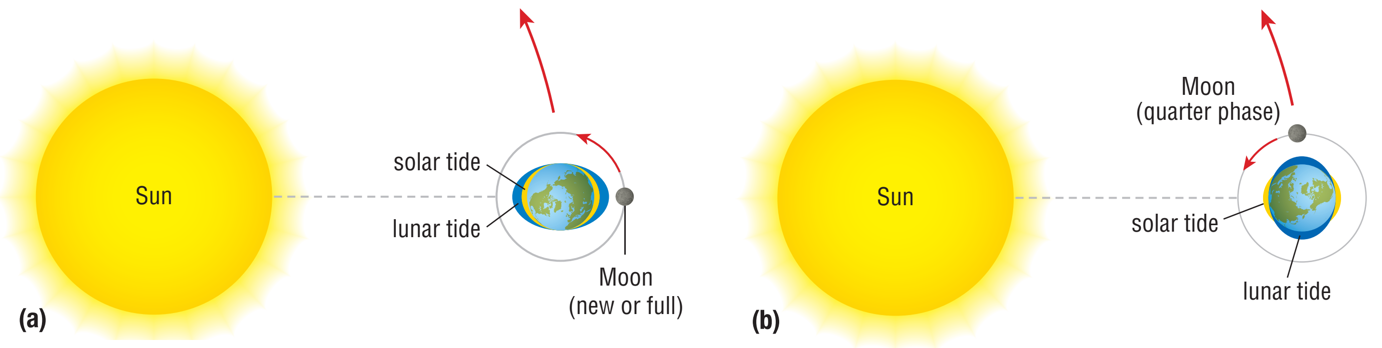

Figure 17 (a) When the Moon, the Sun, and Earth are aligned, spring tides occur. (b) When the Moon and the Sun are on perpendicular sides of Earth, weaker neap tides occur.

UNIT TASK Bookmark

How can you apply what you learned about gravity and the motion of celestial objects in this section to the Unit Task described on page 446?

IN SUMMARY

- Earth rotates around its own axis once a day and revolves around the Sun once a year.
- Precession is the gradual change in direction of Earth's rotational axis.
- Gravity causes all of the planets in the Solar System to orbit the Sun at an average distance known as their orbital radius.
- Seasons are caused by the tilt of Earth's axis.
- Equinoxes and solstices are astronomical events that that can be tracked based on the changing length of daylight.
- As the Moon orbits Earth, we see it change phases, based on the relative positions of the Sun, the Moon, and Earth.
- The alignment of the Sun, the Moon, and Earth also results in solar and lunar eclipses.
- A combination of the Sun's gravity and the Moon's gravity causes tides on Earth.

CHECK YOUR LEARNING

1. Which planets have larger orbital radii, terrestrial planets or gas giants? K/U
2. Imagine that you are explaining to Grade 3 students why it gets dark at night and bright during the day. What would you tell them? K/U C
3. Using Earth as an example, explain the difference between the terms "rotation" and "revolution." C
4. Explain Earth's motion, using the terms "precession" and "rotation" in your answer. C
5. (a) What type of force is responsible for keeping the Moon in orbit around Earth? K/U
   (b) What evidence is there that this force also pulls on objects closer to the surface of Earth? K/U
   (c) Who was the scientist who explained this force? K/U
6. Where is the North Star located, and what is its other name? K/U
7. Create two drawings that show the difference between the geocentric model of the Solar System and the heliocentric model of the Solar System. K/U C
8. Many people think that because summer is the warmest season, it must be when Earth is closest to the Sun. Explain why this is incorrect and give the proper explanation for the seasons on Earth. K/U
9. (a) When do the solstices occur? K/U
   (b) Compare the length of daylight during the winter and summer solstices. K/U
10. Figure 18 shows Earth in its orbit around the Sun. In your notebook, write down which season is represented at each of the four positions.

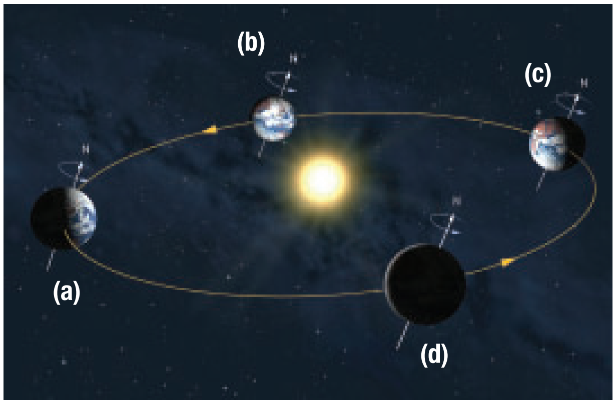

Figure 18

11. Match each of the following terms with the correct length of time: K/U

(a) revolution of Earth	(i) 27.3 days
(b) rotation of Earth	(ii) 26 000 years
(c) revolution of Moon	(iii) 23 h 54 min 4.1 s
(d) precession of Earth	(iv) 365.25 days

12. How many phases are there in the lunar cycle? K/U
13. What are the two kinds of eclipses we can see from Earth? Explain how they occur, using diagrams to show the positions of the Sun, the Moon, and Earth. K/U
14. What is the cause of the spring tides? Do these tides occur only in the spring season? K/U