CHAPTER 2

Panorama view of the universe with a space shot of the Milky Way galaxy and stars on a night sky background. The Milky Way is the galaxy that contains our Solar System.

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The Solar System

Chapter Outline

"Our solar system is actually a wild frontier, teeming with different, diverse places: planets and moons, millions of objects of ice and rock."

Carrie Nugent PH.D.
American Scientist and Asteroid Hunter

LESSON 1

The Earth and Moon

Quick Write

After reading the vignette about the composition of key ingredients that allow Earth to support life, which of the ingredients listed do you think is the most critical to life on Earth as we know it?

Learn About

- Earth – inside and out
- the Moon

Earth is a unique planet. It's currently the only one in our solar system that can sustain life as we know it. What makes Earth special? Let's examine the key ingredients that make life on Earth possible. First, we have the Moon; because of its stabilizing effect on our orbit, our climate is more stable and predictable. Secondly, the Earth's rotation is very stable; this regular rotation and frequency of day and night helps prevent extreme temperatures and promotes life.

Earth also has a strong, stable magnetic field. Without this magnetic field, we would be bombarded with cosmic rays and solar flares that would expose life on Earth to deadly radiation. Earth receives additional protection against radiation from the ozone layer. This layer of gas protects our atmosphere, which is made up of nitrogen, oxygen, argon, and carbon dioxide gases and provides the air we breathe. Earth's ozone layer not only absorbs solar radiation but also reduces temperature extremes between day and night.

Earth's Sun, which is called a yellow dwarf, is a rare type of star that's small and stable. Because the Sun is stable, it has a long life and is not expected to burn out for another five billion years. Because our Sun has such a long life and the Earth is around four billion years old, life on Earth was allowed to develop and flourish. Large stars tend to burn hotter and die off sooner, while smaller stars tend to expend large amounts of radiation.

Earth – Inside and Out

What are the components that make up Earth? What does Earth need to sustain living objects? Earth is in what scientists call the Goldilocks Zone. The Goldilocks Zone is *the habitable zone around a star in which planets can sustain life*. Earth is the only planet in the solar system with a large quantity of water on its surface and an atmosphere. In fact, 70% of Earth's surface is covered with water. Earth is the third planet from the Sun. An entire orbit around the Sun takes approximately 365 days.

The Earth itself is an extremely dense object. Density is *a measure of how much material (or mass) is packed into a given volume*. The density of an object can give us a clue as to its composition. Earth happens to be a large, rocky sphere hurtling through space. The spherical shape is due to the force of gravity on the Earth. The force of gravity crushes rock and pulls the Earth into its spherical shape. This process took millions of years. However, because of inertia, Earth is not a perfect sphere. Remember Newton's theories on inertia? Newton had suggested that the Earth's spin may cause the equator to bulge, and, indeed, it does. The result of inertia on the Earth is a bulge at the equator.

Composition of Earth

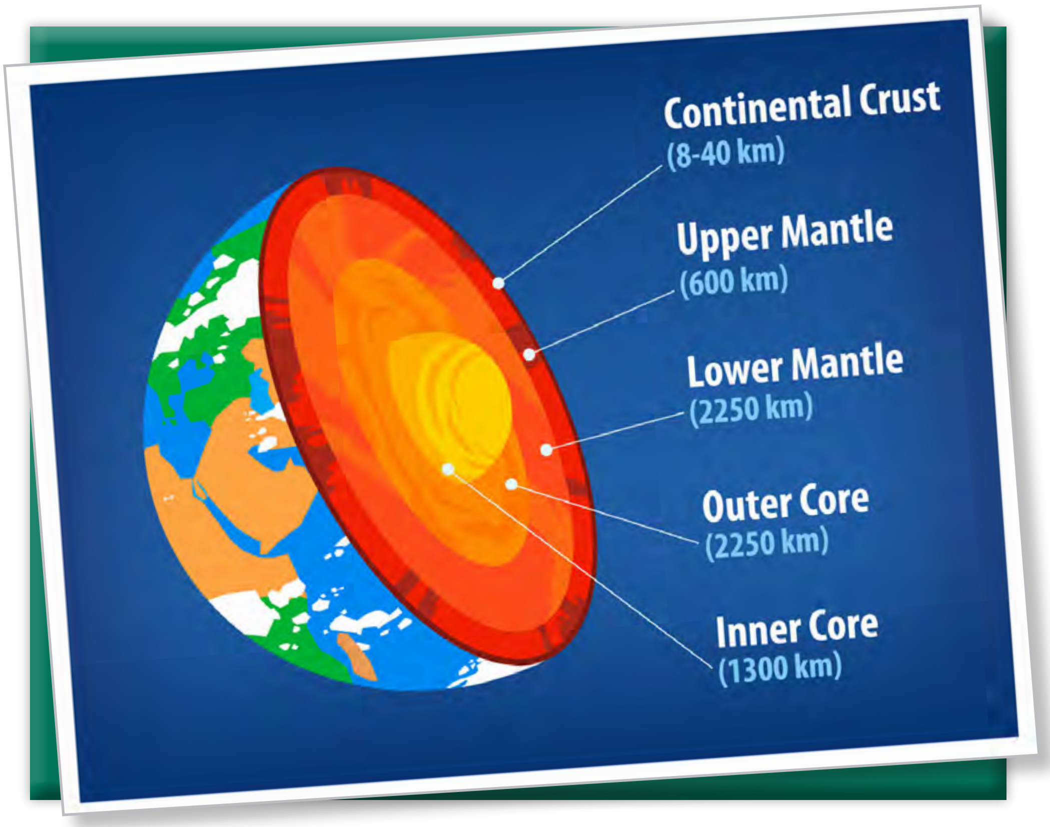
There are three main layers that make up the Earth. The core, mantle, and crust. The core can be thought of as an inner core and outer core. The inner core is a solid metal core that is comprised mostly of iron. The temperature of the inner core is hot enough to melt metal, but remains solid due the extreme pressure on the inner core. The outer core is a liquid layer made of iron and nickel. This liquid portion of the core creates the Earth's magnetic field.

Vocabulary

- Goldilocks Zone
- density
- plates
- margins
- seismic waves
- continental drift
- plate tectonics
- Mid-Atlantic Ridge
- ozone layer
- northern hemisphere
- southern hemisphere
- equinox
- magnetic field
- convection
- synchronous rotation
- perigee
- apogee
- tides
- Spring tides
- Neap tides
- precession

The Earth's mantle is partly liquid and makes up approximately 67% of Earth's mass. The crust is a rocky layer that is 5-30 miles deep. The crust is made up of various plates or *broken pieces*. As the plates move, the landscape on Earth can change. The *edges of the plates* are called margins, and when the margins crash together we end up with volcanic eruptions and earthquakes.

Through earthquakes, scientists can learn about the interior of the Earth. Seismic waves are *waves of energy that travel through the Earth during an earthquake*. The waves travel at different speeds, based on the material they are passing through. The speed of the waves helps scientists determine the type of material in the interior of the Earth.



This diagram shows a section of Earth's crust and each layer.
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In 1912, Alfred Wegener proposed the concept of continental drift, *the gradual movement of the Earth's surface*. He noticed that the coast of Africa and South America appeared as though they could join together like puzzle pieces. This is now known as the science of plate tectonics, *the theory used to explain the structure of the Earth's crust and its movement over time*. The shift of the Earth's surface is driven by hot magma rising and cool magma sinking inside Earth.

Before the continental drift, most of the continents were one large mass on Earth. After the continental drift, the continents started separating and the Earth took on its present form.
robin2/Shutterstock

Earth's Atmosphere

Earth is the only planet in our solar system with a breathable atmosphere for humans. Earth's atmosphere is made up of a mixture of gases. Oxygen is what we breathe and makes up 21% of the atmosphere. Nitrogen makes up 78% of the atmosphere; the last 1% is composed of water vapor, carbon dioxide, and ozone.

Earth's atmosphere is divided into layers:

- Troposphere – This layer extends 5-9 miles from the Earth's surface. This is the densest of all the layers and is where weather occurs.
- Stratosphere – This layer starts above the troposphere and extends about 31 miles high from the Earth's surface. The ozone layer, which *protects us from solar ultra-violet (UV) rays*, is included in the stratosphere.
- Mesosphere – This layer extends 53 miles from the Earth's surface. Typically, meteors that spiral toward the Earth are burned up in this layer.

Did You Know?

The Mid-Atlantic Ridge *is an area in the Atlantic Ocean where lava flows upward creating new mountains underwater*. The ridge supposedly caused the Americas and Euro-African land masses to split apart. In fact, the ridge continues to create new mountains underwater and pushes Europe and North America an inch farther apart each year.

- Thermosphere – This layer located above the mesosphere and below the exosphere and home to the international space station.
- Exosphere – This is the upper limit of the atmosphere.

The environment in each of these layers is vastly different. Figure 2.1 outlines the different in temperature and features of each layer of the atmosphere.

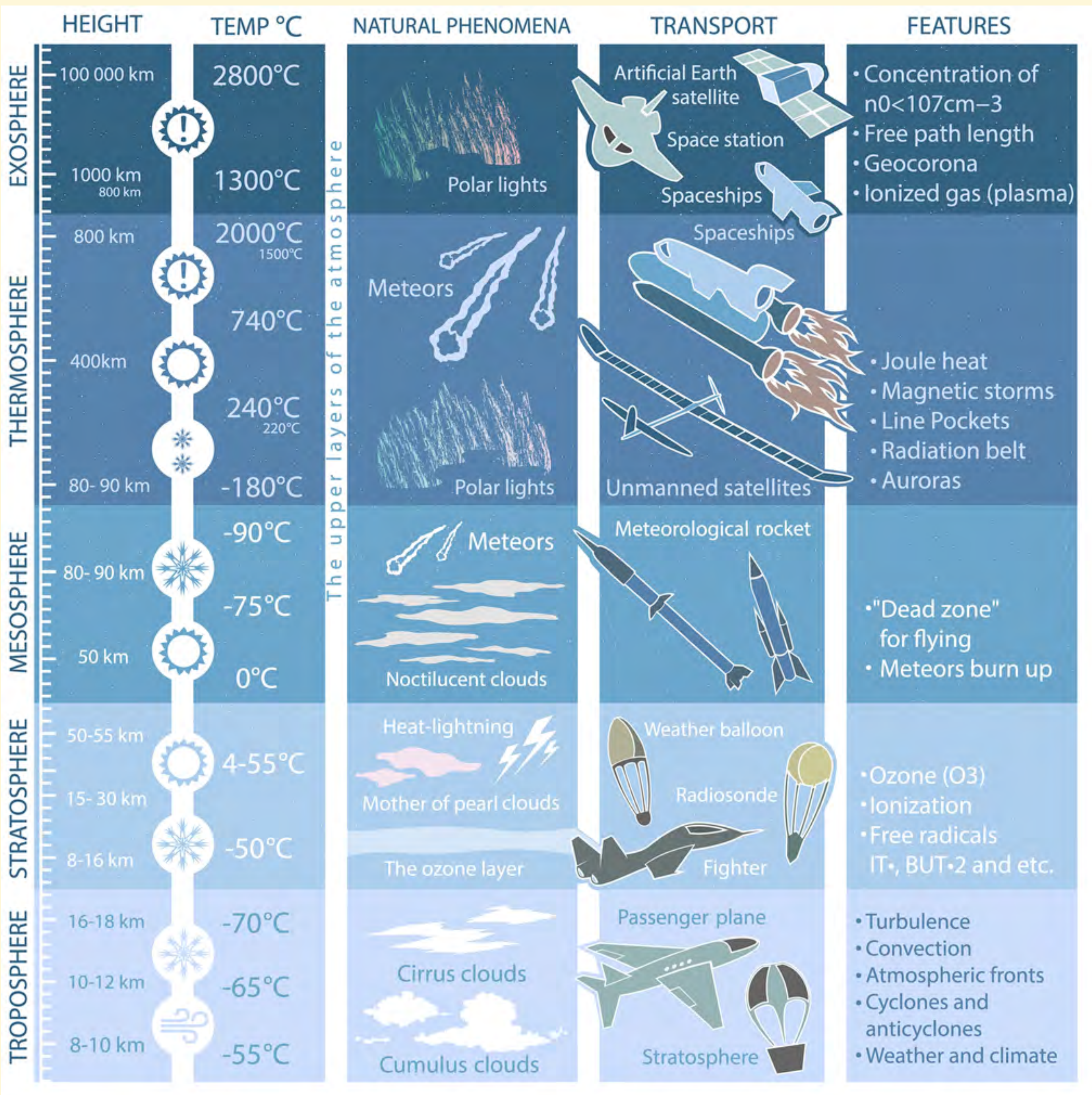

FIGURE 2.1

This diagram compares the structure of the Earth's atmosphere and the environment within each layer.
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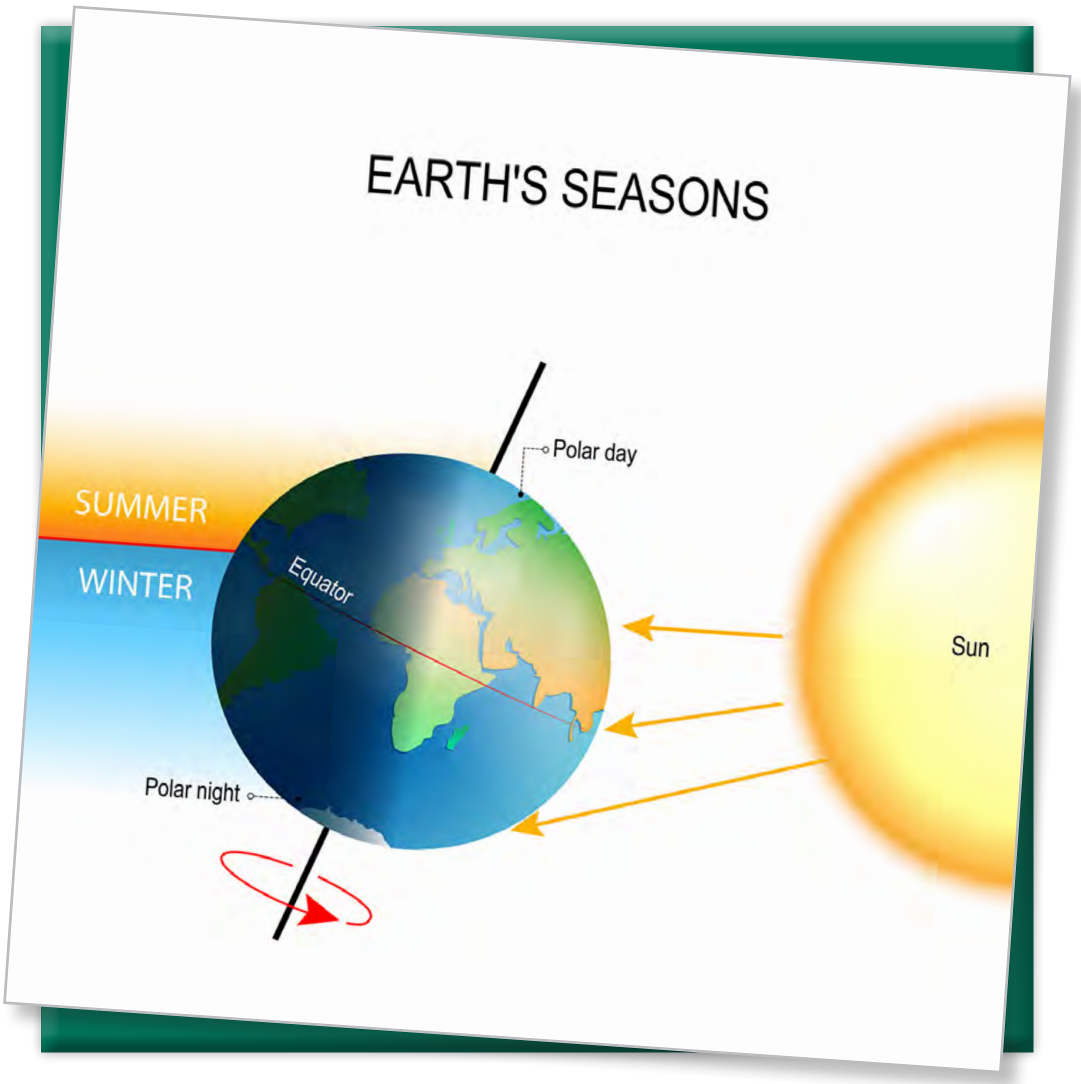
The Seasons

Earth is divided into two hemispheres. The northern hemisphere is *the half of the Earth that lies north of the equator*. The southern hemisphere is *the half of the Earth that lies south of the equator*.

Earth rotates at a tilted angle on its axis. The tilt of the Earth determines the seasons in the northern and southern hemispheres. During the summer, the northern hemisphere is tilted closer to the Sun, which means the Sun is in the sky longer during the day. This causes the temperature to be warmer during the day, with less chance for the temperature to cool during the nights because the nights are shorter. The northern and southern hemispheres always experience the opposite seasons. For example, because of the tilt, when it is summer in the northern hemisphere, it is winter in the southern hemisphere. So, if you lived in Australia, you would be wearing shorts and enjoying summer in December!



The tilt of the Earth's axis determines the season in the northern and southern hemispheres.
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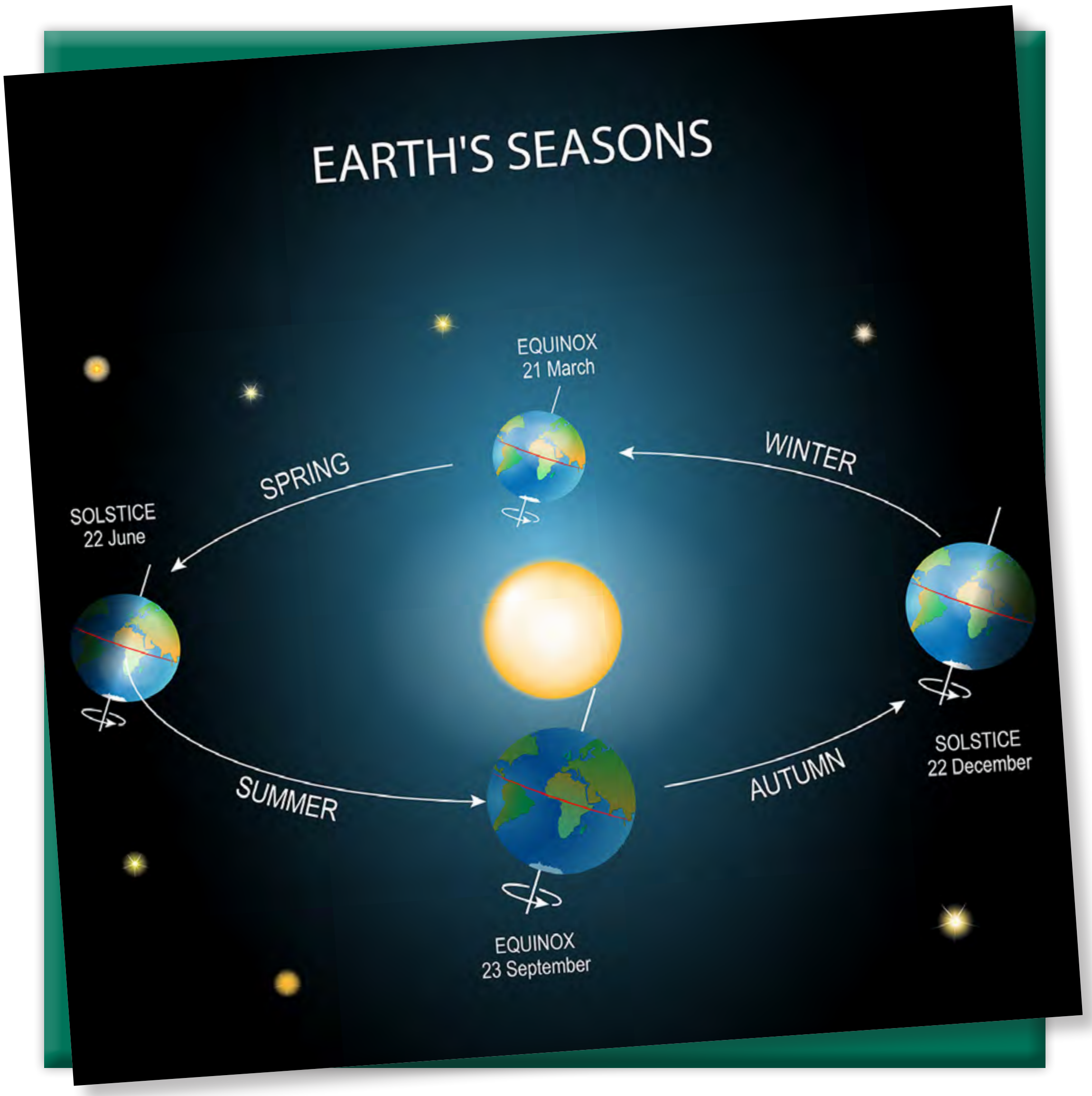
The solstice occurs twice a year and is the time when the Sun is at its highest and lowest point in the sky. The summer solstice occurs on or about June 21st for the northern hemisphere; it is the longest day of the year because the Sun is at the highest altitude from the equator. The winter solstice occurs on or about December 21st in the northern hemisphere; it is the shortest day of the year. In the southern hemisphere, these two dates are reversed.

Another key concept to discuss is the occurrence of equinoxes. The equinoxes are *the points where the Sun crosses the celestial equator*. The equinoxes also help mark the changing of the seasons. On or about March 21st, we experience an equinox in the northern hemisphere; this date also represents the first day of spring. On or about September 22rd, another equinox occurs in the northern hemisphere, marking the first day of autumn. Again, these dates are reversed in the southern hemisphere.



The effect of the solstices and equinoxes on Earth's seasons.
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Earth's Magnetic Field

Earth itself is a magnet and has a magnetic field in which *magnetic forces are communicated*. The compass is a tool that uses the Earth's magnetic field to determine which direction is north. Using the Earth as a magnet, the compass employs the magnetic pull of the North Pole to identify north to the reader.

In Figure 2.2, you can see the magnetic poles of the Earth close to the North and South poles. The magnetic poles of the Earth don't align directly with the geographic poles of the Earth. You'll also notice that the North Pole is actually the south magnetic pole and the South Pole is the north magnetic pole. The magnetic field lines represent the direction a compass would point when using the magnetic field. The more lines you see in a magnetic field drawing, the stronger the magnetic field.

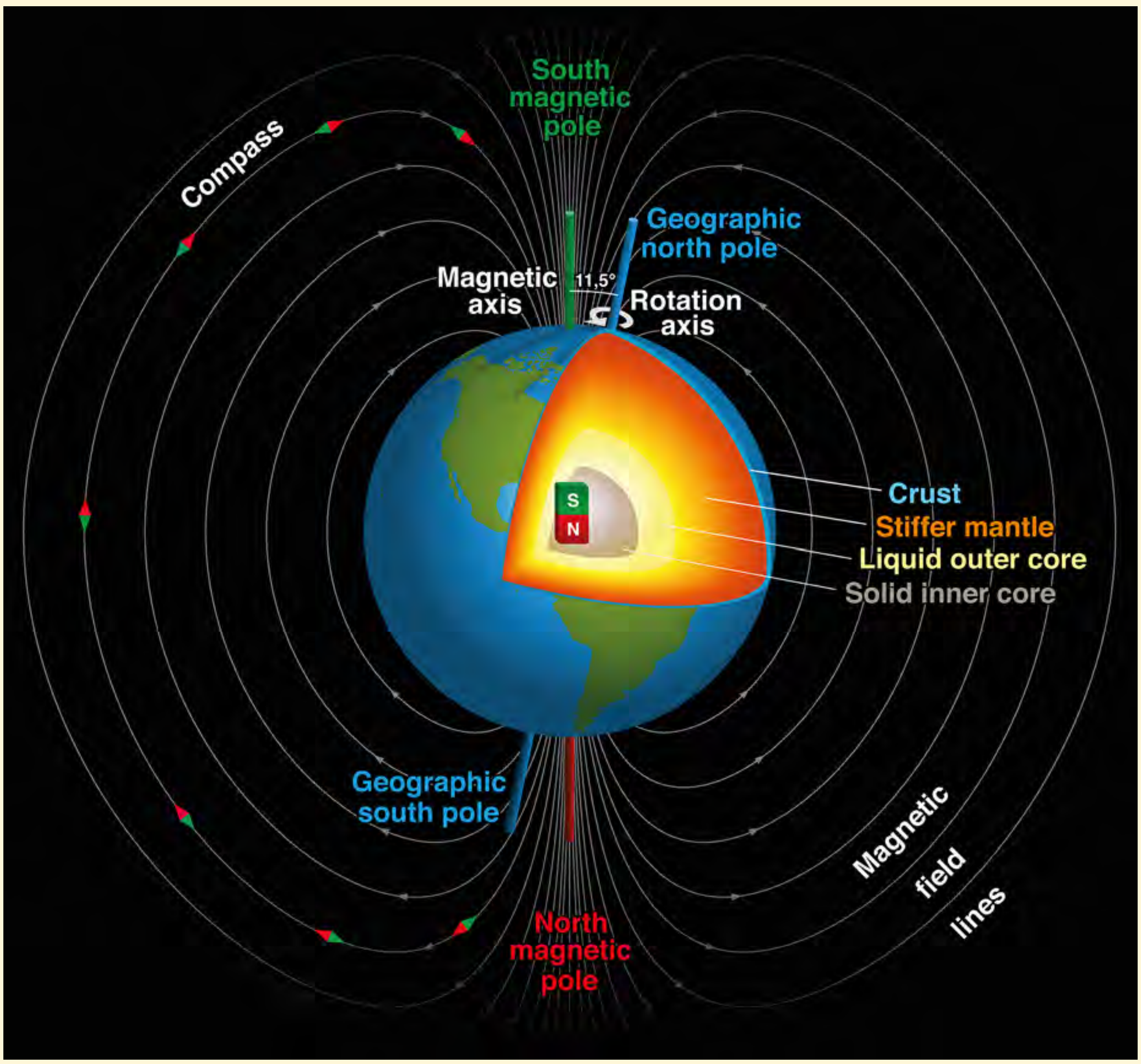


FIGURE 2.2

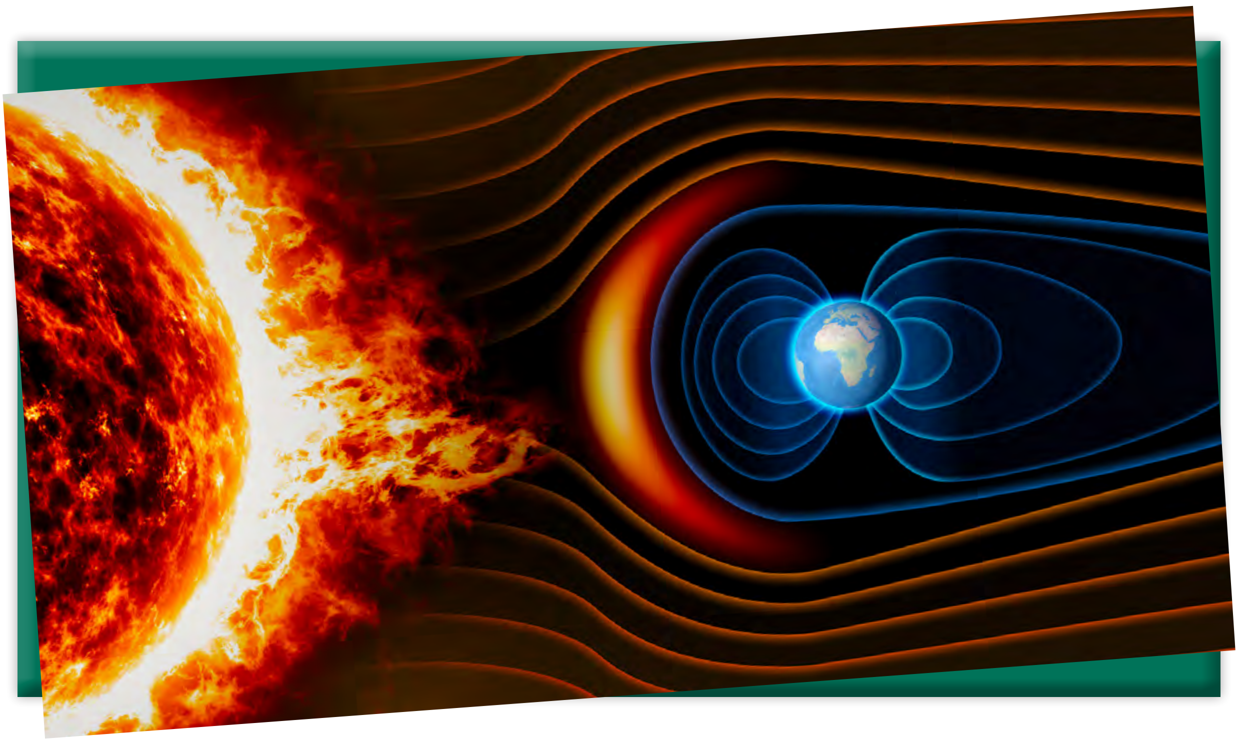
Earth's Magnetic Field

Peter Hermes Furian/Shutterstock

The magnetic field gets its origins from the electric currents flowing in the molten iron core of the Earth. Scientists aren't quite sure how these currents originated but suspect a combination of the rotational motion of the Earth and convection, *the generation of heat*.

Earth's magnetic field is a shield for us on Earth. It is constantly deflecting the subatomic particles that are being sent from the Sun. These particles could greatly damage the atmosphere and life on Earth; we have the magnetic field to thank for keeping us protected from these particles.

However, magnetic fields do not last forever. Earth's magnetic field is diminishing over time, and it is estimated that in 15,000 years it will disappear completely. Magnetic fields can also reverse. Over the past 170 million years, it is believed that the Earth's magnetic field has reversed over 300 times. The last reversal was 780,000 years ago. It is impossible to predict when the next reversal will occur, or what a reversal would mean for life on Earth. This is a topic scientists continue to study today.



Earth's magnetic field, the Earth, the solar wind, the flow of particles deflected by the Earth's magnetic field. Elements of this image furnished by NASA.

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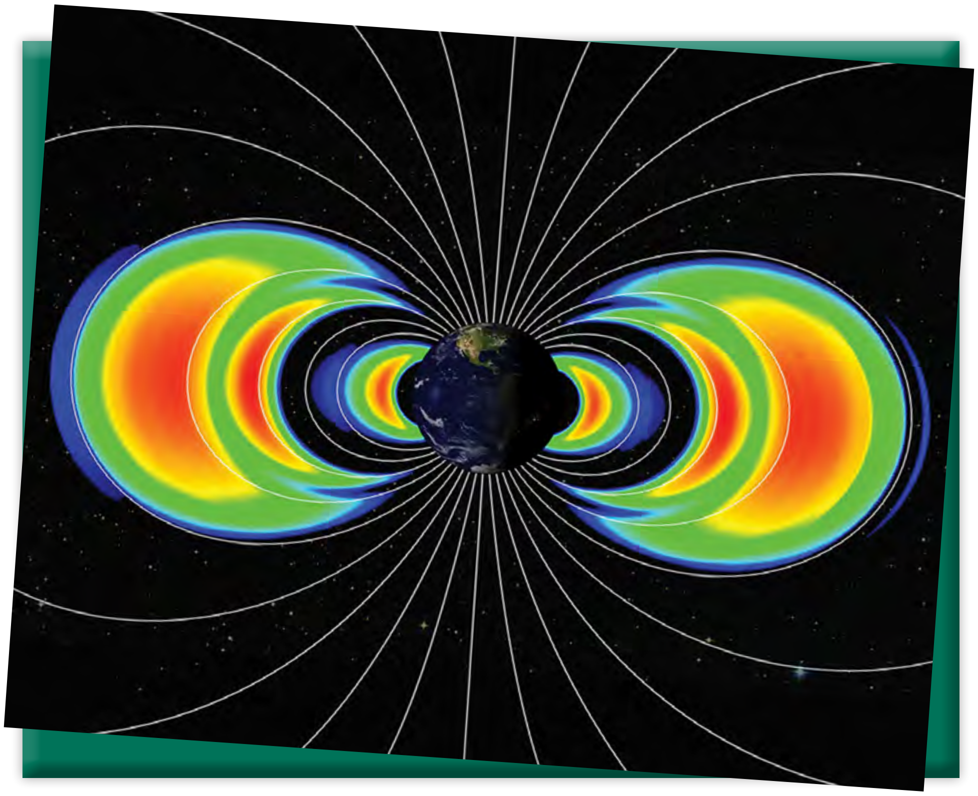
The Van Allen Belts

In 1958, the United States launched its first satellite into space, the Explorer 1. The satellite picked up radiation in an area that was considered void of all particles. These high energy particles provided the first glimpse of the Earth's radiation belts.

Two concentric rings of energy particles surround the Earth. They were named the Van Allen belts, after James Van Allen, a scientist who led the studies of the radiation data. The inner belt consists mostly of protons, and the outer belt consists of electrons. These particles are captured by Earth's magnetic field and spiral around the belt.



The Van Allen Belts

NASA's Goddard Space Flight Center/John Hopkins University, Applied Physics Laboratory

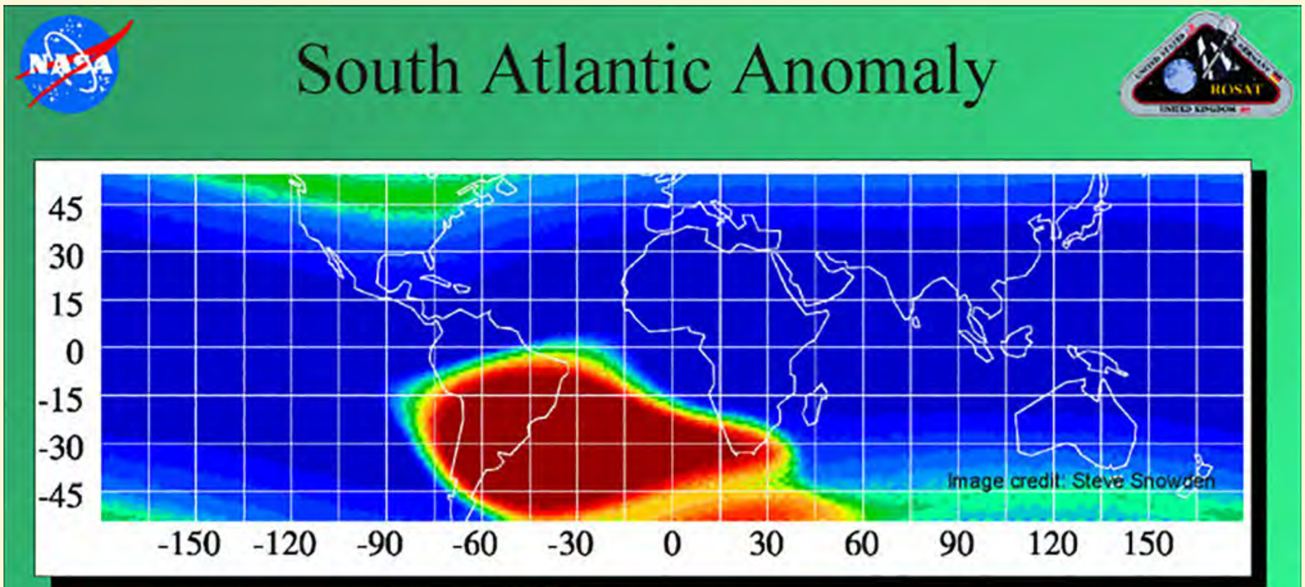
While scientists continue to study the Van Allen belts and their impact on Earth, we know the belts are responsible for one spectacular phenomenon: the Northern Lights. The Northern Lights are an aurora, which is a natural light display in the Earth's sky caused by charged particles colliding with atoms and molecules in our atmosphere. The fantastic light shows are typically seen in the Arctic region.

The Northern Lights in Norway

Stas Moroz/Shutterstock

The South Atlantic Anomaly

The South Atlantic Anomaly (SAA) is a region of dense radiation above the Atlantic Ocean off the coast of Brazil. Satellites and spacecraft that pass through this area are bombarded with high-energy protons. In this area, there is a dip in the Van Allen belts where charged particles reach farther down into our atmosphere. The area is sometimes referred to as the Bermuda Triangle of space, as it can produce anomalies in astronomical data and problems with electrical systems. Many satellites are shut down as they move through this area, and astronauts who travel through the SAA receive high levels of radiation.



The South Atlantic Anomaly (SAA) is a dip in the Earth's magnetic field which allows cosmic rays and charged particles to reach lower into the atmosphere and interfere with communication with satellites, aircraft, and the Space Shuttle. The geologic origin is not yet known.

The enhanced particle flux in the SAA also strongly affects X-ray detectors, which are in essence particle detectors. The ROSAT PSPC had to be turned off during passage through the SAA to prevent severe damage. While the ROSAT HRI could be left on during the passage, it could collect no useful data. The light blue and green bands at the top and bottom of the image are due to an enhanced particle flux above Earth's auroral zones (particle belts).

FIGURE 2.3

South Atlantic Anomaly

NASA's Goddard Space Flight Center/Astrophysics Science Division (ASD)

The Moon

The Moon is only a quarter the size of Earth, but it is the fifth largest moon in the solar system. The gravity of Earth causes the Moon to spin. *The Moon spins very little and takes 27 days to complete one rotation, so we only see one side of the Moon*; this is called synchronous rotation. As a result, the Moon does not seem to be spinning but appears to observers from Earth to be keeping almost perfectly still. The Moon orbits the Earth once every 28 days. All the phases of the Moon can be seen within this 28-day period. The beginning of the cycle starts with the Moon growing until it reaches a Full Moon, and then waning until it is completely dark, or a New Moon.

The phases of the Moon.
Castleski/Shutterstock

How the Moon was Formed

The Moon was formed ~4.5 billion years ago, about 30–50 million years after the origin of the solar system, out of debris thrown into orbit by a massive collision between a smaller Earth and another planetoid, about the size of Mars. A planetoid is planet-size version of an asteroid. Initially, the Moon spun much faster. However, it is not perfectly spherical and bulges out slightly at its equator. These bulges along the Earth-Moon line caused a torque, slowing the Moon spin, much the same way a figure skater gradually opens to decelerate a spin. When the Moon's spin slowed enough to match its orbital rate, the bulge was in line with Earth, which is why we always see the same side of the Moon. In our solar system, almost all moons spin at the same rate as they orbit.

Earth would be a very different place if the Moon did not exist. Not only did the Earth slow down the Moon's rotation, but the Moon is slowing down the rotation rate of the Earth. Since the Moon's formation, the Earth's rotation has been slowing due to the friction of the tides caused by the Moon; in reaction to this exchange of energy, the Moon has been moving farther away from the Earth. In fact, at the time of the Moon's formation the Earth rotated much faster than it does today: a day on early Earth was only a few hours long. But the Moon, being small in relation to Earth, will take more than twice the age of the solar system to slow Earth's spin rate to the Moon's orbital rate.

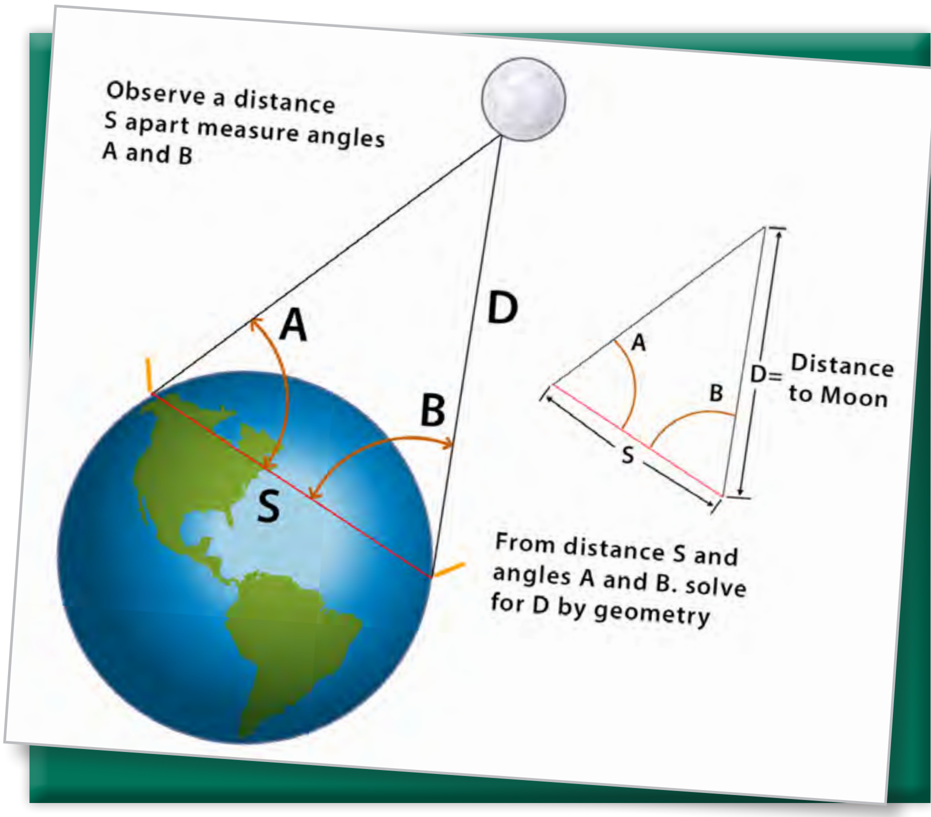
The Distance from Earth to the Moon

How do astronomers actually measure the distance from the Earth to the Moon? There are two ways to measure the distance to the Moon: lunar eclipse and parallax.

Ancient Greeks used the lunar eclipse by timing how long it takes Earth's shadow to cross over the Moon. If you know the diameter of Earth (8,000 miles) and the speed of the orbit of the Moon (28 days), you can calculate the distance. Greek astronomers observed that the Earth's shadow was 2.5 times the size of the Moon and lasted about 3 hours. Aristarchus, a Greek astronomer, determined that the Moon was about 239,000 miles from Earth using this method.

The second method is using the parallax, the change of an objects position based on the viewpoint. If you view the Moon from one location and a friend views the Moon from 3,200 km (2,000 miles) away you can compare the images. You, your friend, and the Moon create a triangle. You know the distance between you and your friend and using simple geometry you can determine the distance to the Moon. Ptolemy was the first to use this method for determining the distance from the Earth to the Moon. He calculated the distances to be 27.3 Earth diameters (about 218,400 miles). His calculations were very close to the distance calculated today!

Typically, we calculate the average distance from the Earth to the Moon, because the Moon is not always the same distance from the Earth. At its farthest point, the Moon is 252,088 miles away. At its closest point, the Moon is 225,623 miles away. The average distance of the Moon to the Earth is about 239,000 miles. Today, scientists bounce lasers off the Moon's surface and use the speed at which the laser beam returns to accurately measure the distance from Earth to the Moon.



Using triangulation to calculate the distance from Earth to the Moon.

The Size of the Moon

Now that we know how far away the Moon is from the Earth, we can calculate the size of the Moon. Because it's impossible to determine the size of the Moon by just observing it, we rely on angular sizes and distances to determine the Moon's size. An object's angular size is determined by an object's size and its distance from the observer. Imagine the celestial sphere as a 360-degree circle. The angular size of the Moon, as seen from Earth, is half of a degree. Using this information, along with the distance to the Moon, we can calculate the size of the Moon using the small-angle formula. The Moon is approximately 2,160 miles in diameter using this calculation.

Although the size of the Moon is constant, the Moon may appear larger at certain times from Earth. This is due to the elliptical orbit of the Moon. When the Moon is at perigee, *closest to the Earth*, it appears much larger. When the Moon is at apogee, *farthest from the Earth*, it appears much smaller.

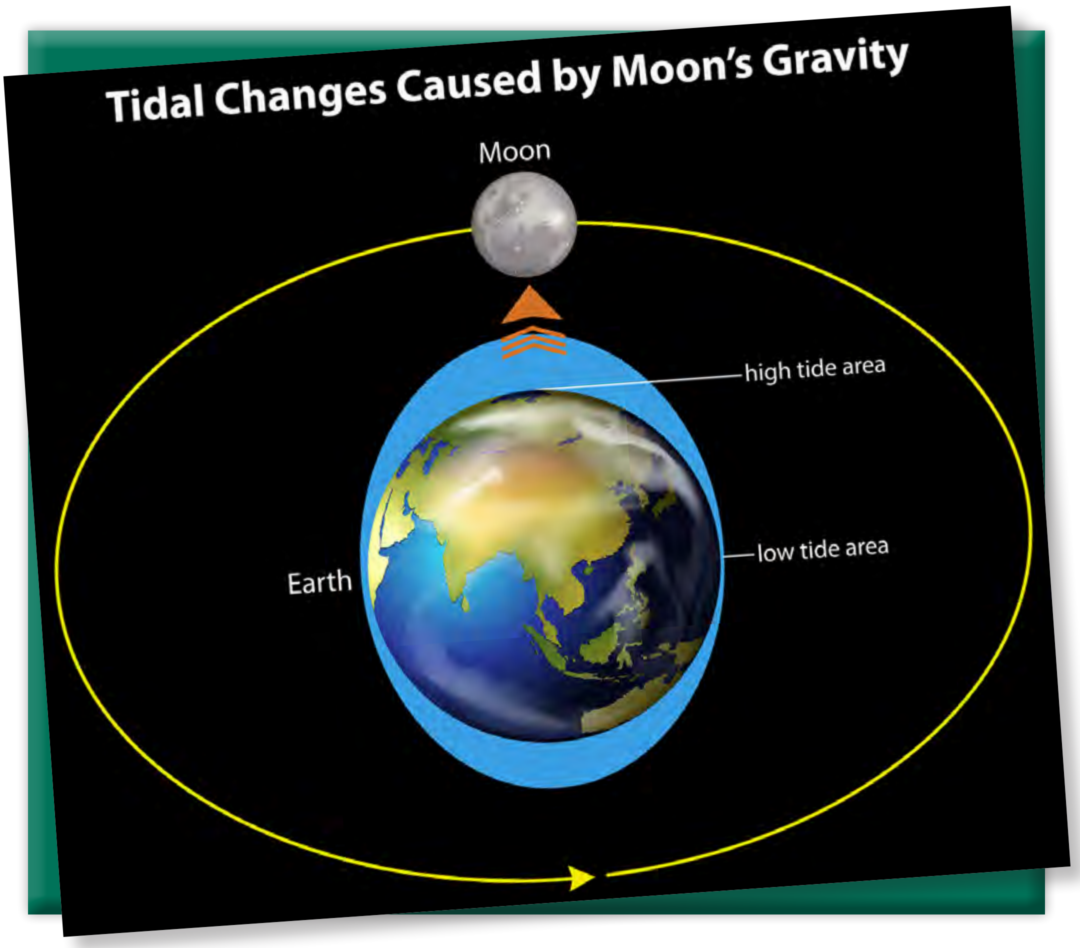
Did You Know?

The Moon (and Sun) appear larger in the sky when they are rising and setting. The Moon is not closer to the Earth during these times; it is an optical illusion. Take a piece of 3-ring binder paper and hold it at arm's length when the Moon is rising so that the Moon fits in the hole. Now wait until the Moon is fully in the sky and try the experiment again. The Moon will still fit in the hole.

The Moon's Effect on the Tides

The Moon has one-sixth the amount of gravity of Earth. But this is enough gravity to affect Earth's oceans. As the Moon's gravity pulls at Earth, the tides change. The tides are *the reaction of gravity that causes the sea levels to rise and fall*. Tidal changes occur when the Earth is nearest and farthest from the Moon. During high tide, the water surges up. During low tides, the water level drops. When one side of the ocean is at high tide, the opposite side is at low tide. The high tide is the point on Earth that is closest to the Moon. So, as the Earth rotates, this point changes and thus the tides change.

The Sun also has an effect on the tides, but the Moon is so much closer to Earth that it exerts 2.2 times the force of the Sun. Near the Full Moon and New Moon, the Sun lines up with the Moon and the Earth causing an intensified force on the tides.

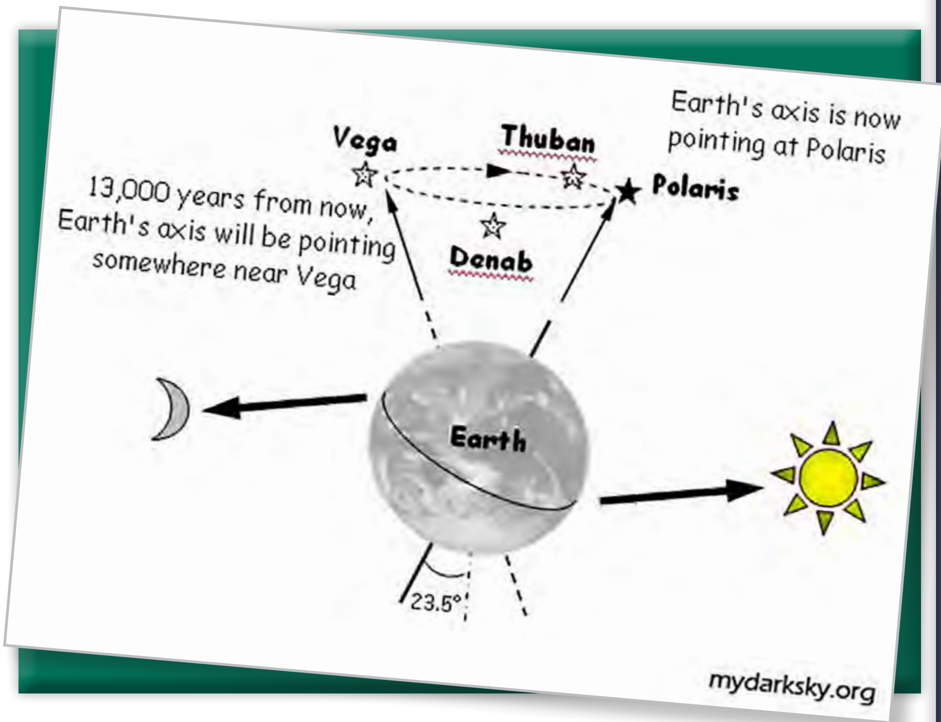


The tidal changes caused by the Moon's gravity.
BlueRingMedia/Shutterstock

Spring tides *occur when the Sun and Moon are aligned and cause the oceans to bulge more than usual, producing a higher tide than usual*. The spring tides occur twice each lunar month and are not associated with the seasons. The term "spring" is derived from the concept of the tide "springing forth." Neap tides *occur when the difference between the high tide and low tide is the smallest*.

Earth's Wobble

Earlier we discussed how Newton had suggested that the Earth's spin may cause the equator to bulge. The gravitational pull from the Sun and Moon isn't uniform across the Earth because of the bulge, which causes the Earth to wobble like a spinning top that is about to fall off its axis. The wobble is technically called precession and is defined as *the slow and gradual shift of the Earth's axis*. The force by the Sun and Moon affects the Earth's axis. A complete precession cycle takes approximately 26,000 years.



Earth's Wobble

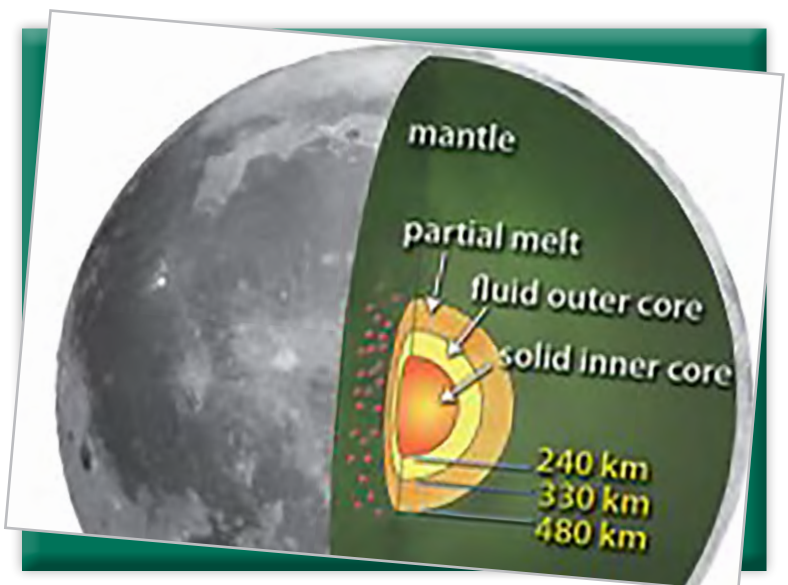
This precession on Earth will eventually cause Earth's axis to move. So instead of the axis pointing to Polaris (the North Star), in 13,000 years Earth's axis will point somewhere near the star Vega.

Did You Know?

The gravitational pull of the Moon is slowing the Earth's rotation, which means our day lengthens by 2.3 milliseconds per century.

The Moon's Surface

The Moon's structure is similar to Earth in that it is composed of a core, rocky mantle, and crust. The inner core of the Moon is likely very small and consists mostly of iron. The rocky mantle is composed of dense rocks that have high levels of iron and magnesium. The mantle is about 825 miles thick and very dense. The crust is about 42 miles deep and is the top layer of the Moon's surface.



The composition of the Moon.
NASA/MSFC/Renee Weber

The surface of the Moon is very mountainous. In fact, the Moon has peaks that are as high as Mt. Everest. In addition, the Moon has many craters that were created when space debris, asteroids, comets, etc. crashed into it.

The surface of the Moon showing impact craters in the southern lunar highlands.

Procy/Shutterstock

Scientists used to think that the dark stretches of the Moon were oceans, so these were named Maria, which is Latin for "seas." These darkened spots are actually pools of hardened lava. Early in the history of the Moon, the interior was molten enough to produce lava from volcanoes or when a large asteroid hit the surface

Is there water on the Moon? Scientists have found traces of water on the lunar surface. They suspect that water may be more abundant on the slopes facing the lunar South Pole. However, the amount of water is comparable to a dry desert. Another study, in 2017, suggested that the Moon's interior could include water.

The Moon has a very thin atmosphere. The atmosphere on the Moon is not sufficient to sustain life, and the temperature varies widely between -274⁰F to 257⁰F. This thin atmosphere can explain why Neil Armstrong's footprint will remain undisturbed on the Moon for centuries.

Did You Know?

Gene Shoemaker was a geologist who helped prove that Arizona's Meteor Crater is an impact scar from a meteor. He also trained the Apollo astronauts and lobbied NASA to send a scientist to the Moon. Gene Shoemaker died in 1997, and in 1999 his ashes were taken to the Moon by the Lunar Prospector space probe. He is the only person to be buried on the Moon.

✔ CHECKPOINTS

Lesson 1 Review

Using complete sentences, answer the following questions on a sheet of paper.

1. What is the Goldilocks Zone and why is Earth in this zone?
2. How can scientists learn about the interior of the Earth?
3. What makes up the Earth's atmosphere?
4. How are the seasons determined on Earth?
5. How does the magnetic field protect us on Earth?
6. What is the most recent theory on how the Moon was created?
7. What are two methods you can use to measure the distance to the Moon without lasers?
8. Why does the Moon appear larger at different times throughout the month?
9. How does the Moon affect the tides?
10. How long is a complete precession cycle for Earth?

APPLYING YOUR LEARNING

11. Suppose you lived 2,000 year ago. Provide a short description of observations you could make that would lead you to conclude that the Moon plays a role in the Earth's tides?