TOPIC 1

Beyond Earth

For thousands of years, people thought Earth was the only world in existence. As tools such as telescopes and spacecraft were developed to explore beyond Earth, people learned that Earth is a small part of a vast universe. Earth is one planet in a much larger solar system. Its sun is one of billions of stars that make up our galaxy. Beyond our galaxy are billions more galaxies that make up the universe. In this topic, you will learn about Earth's relationship to the Moon, the Sun, and the other planets in the solar system. You will also learn about the formation and evolution of stars, the characteristics of galaxies, and the theories of the origin of the universe.

SUBTOPIC A
THE SUN-EARTH-MOON SYSTEM

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; D.1, D.3, D.4

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Earth and Space Science

D.1	Energy in the Earth system
D.3	Origin and evolution of the Earth system
D.4	Origin and evolution of the universe

VOCABULARY

- rotation
- revolution
- Foucault pendulum
- Coriolis effect
- perihelion
- aphelion
- eccentricity
- Polaris
- summer solstice
- autumnal equinox
- winter solstice
- vernal equinox
- lunar phases
- waxing
- waning
- synchronous rotation
- solar eclipse
- perigee
- apogee
- lunar eclipse
- tide

The Sun, Earth, and the Moon are part of our solar system. The Sun is the star at the center of the solar system. Earth is a planet that orbits the Sun, while the Moon is a natural satellite that orbits Earth. The constant and regular movements of Earth and its moon, in relation to each other and to the Sun, produce noticeable effects on Earth. Gravitational attraction among these three bodies also affects Earth.

Objects in the solar system, including Earth and the Moon, constantly undergo two main types of regular movement. These movements are rotation and revolution. **Rotation** is the spinning of a planet, moon, or any object on an imaginary axis, much like a top spins around its central tip. **Revolution** is the movement of one object around another object in space.

Earth's Rotation

Earth rotates on an imaginary axis that runs through its poles. As Figure 1-1 shows, Earth's axis is tilted 23.5° from perpendicular to the ecliptic, the plane in which Earth orbits the Sun.

Earth makes one complete rotation every 24 hours. The 24-hour time period is one day. As Earth rotates from west to east each day, the Sun appears to rise above the eastern horizon, move across the sky, then set below the western horizon. In the night sky, the Moon, the planets, and the stars also appear to rise in the east and set in the west.

Evidence of Earth's Rotation

Before space travel, it was impossible to directly observe Earth's rotation. However, scientists were able to demonstrate that Earth rotates indirectly. They observed the rotation with an instrument called a Foucault pendulum and a natural global phenomenon called the Coriolis effect.

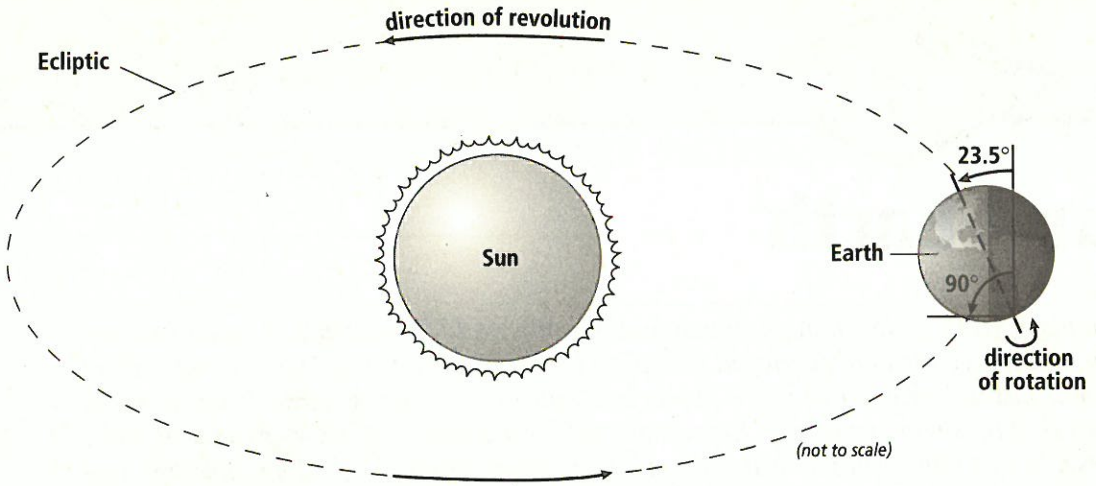

Figure 1-1 Earth remains tilted 23.5° in relation to the ecliptic as it orbits the Sun.

A **Foucault pendulum,** shown in Figure 1-2, is a heavy weight suspended from a long wire. Like all pendulums, it swings back and forth in a single plane. The rotation of Earth under a Foucault pendulum makes it appear as if the plane of the pendulum's swing is slowly rotating. This apparent rotation can be demonstrated by placing a ring of pegs on the floor beneath the pendulum. As Earth rotates under the pendulum, neighboring pegs are knocked over in succession at each end of the pendulum's swing. In the northern hemisphere, the swing of the pendulum appears to rotate clockwise.

Foucault Pendulum

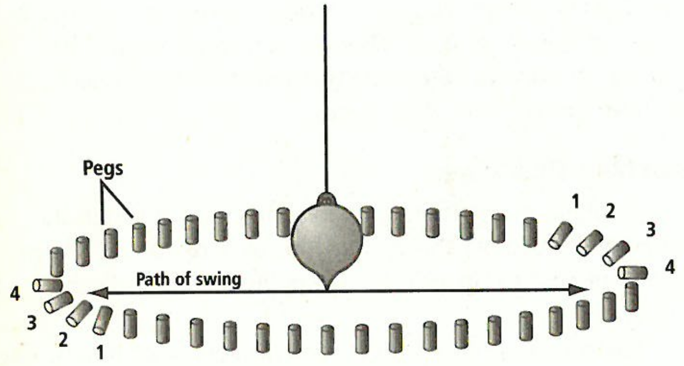

Figure 1-2 As Earth rotates, a Foucault pendulum appears to gradually shift the direction of its swing. As a result, pegs arrayed in a circle at the base of the pendulum are knocked over by the pendulum. In this figure, the pegs labeled 1 were knocked over first. Over a period of several hours, pegs 2, then 3, and then 4 were knocked over in succession.

The **Coriolis effect** is the apparent deflection from a straight path of moving objects and fluids on Earth's surface. This effect can be observed on any object that rotates, not just Earth. The Coriolis effect causes the deflection of winds and ocean currents to the right in the northern hemisphere and to the left in the southern hemisphere, as in Figure 1-3. If Earth were not rotating, winds and ocean currents would move in a straight line.

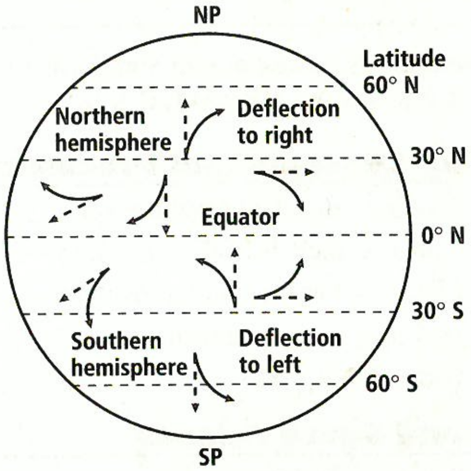

Figure 1-3 Earth's rotation causes an apparent deflection in objects and fluids as they move across Earth's surface. This is the Coriolis effect. Deflection in the northern hemisphere is to the right of a straight line. Deflection in the southern hemisphere is to the left of a straight line. The Coriolis effect influences the motion of global winds and ocean currents.

Relating Rotation and Time

Earth's rotation also provides a basis for our system of local time. Earth rotates on its axis at a constant rate. It rotates 360° every 24 hours. Therefore, Earth rotates at a rate of 360°/24 hours = 15° every hour. As Figure 1-4 shows, Earth is divided into 24 time zones, each roughly 15° of longitude in width. All clocks in a time zone are set to the same time. An hour is gained with each time zone eastward, and an hour is lost with each time zone westward. When it is 4:00 p.m. in Chicago, Illinois, it is 5:00 P.M. in New York City, which is 15°, or one time zone, farther east.

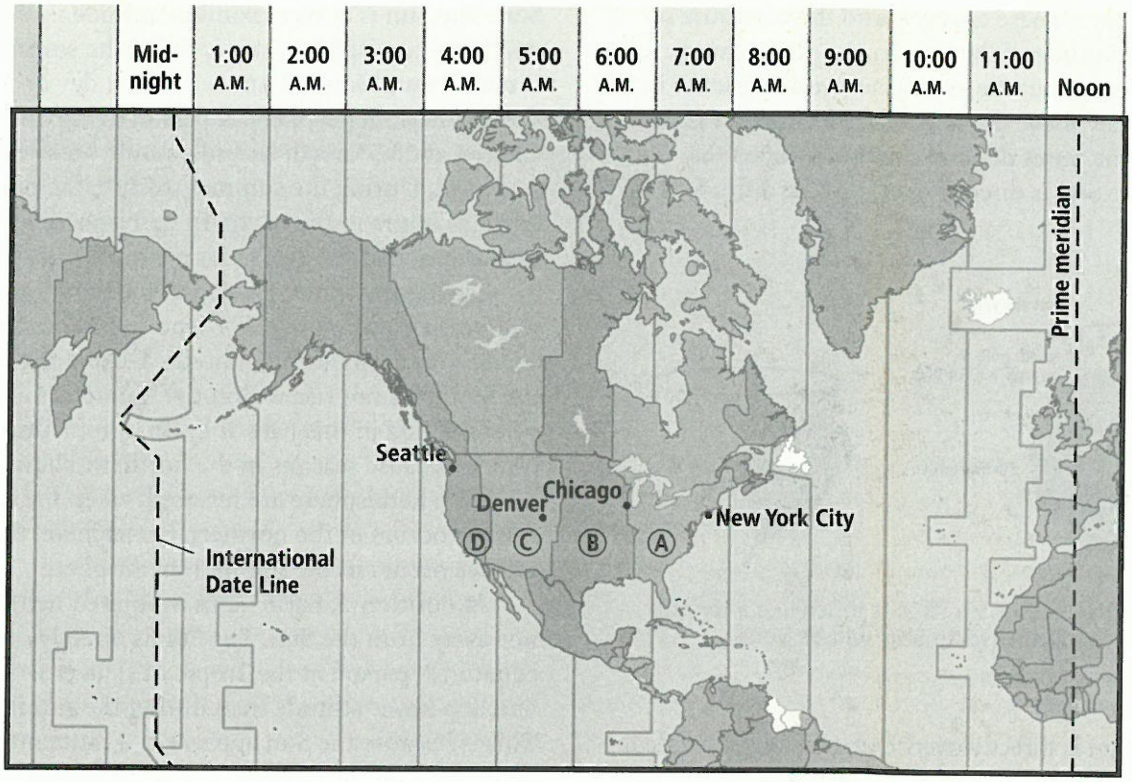

Figure 1-4 The contiguous United States stretches over four time zones: Eastern (A), Central (B), Mountain (C), and Pacific (D). Time moves ahead one hour with each time zone to the east. As a result, New York City is one hour ahead of Chicago.

Earth's Revolution

Like the other planets, Earth revolves around the Sun in an elliptical orbit. An ellipse has the shape of an oval or flattened circle. As shown in Figure 1-5, the Sun is at one of the foci of this ellipse. Because of the shape of an ellipse, a planet in an elliptical orbit is not a constant distance from the Sun. When the orbiting planet is closest to the Sun, it is at **perihelion.** When the planet is farthest away, it is at **aphelion.**

The shape of a planet's elliptical orbit is its **eccentricity.** Eccentricity values range from 0 to 1. An eccentricity of 0 corresponds to a perfect circle, while an eccentricity close to 1 corresponds to a very elongated ellipse. An eccentricity of 1 corresponds to a parabola. Earth and most other planets of the solar system have elliptical orbits that are not very eccentric. Their orbits are nearly circular.

The closer a planet is to the Sun in its orbit, the faster it moves. A planet moves faster in orbit at perihelion than at aphelion. Also, planets closer to the Sun revolve faster than planets farther away. As a result, Earth moves faster in its orbit than every other planet in the solar system except Mercury and Venus, which are closer to the Sun.

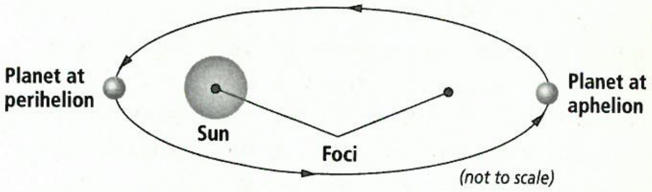

Figure 1-5 All planets move around the Sun in slightly elliptical orbits with the Sun located at one focus of the ellipse. The orbit shown here is much more eccentric or elongated than the orbit of a typical planet in our solar system. The orbits of most planets are more circular.

Earth's Revolution and Seasons

In most places on Earth, the climate changes throughout the year. The number of hours of daylight varies, and the weather can range from cold to hot. These yearly changes are the result of Earth's movement as it revolves around the Sun.

Earth makes one complete revolution around the Sun each year. The orientation of Earth's axis in space remains the same as Earth revolves around the Sun. Currently the axis points toward **Polaris,** the North Star. However, Earth's rotational axis wobbles as shown in Figure 1-6. It takes 26 000 years to complete this cycle, and during that time, Earth's axis will point at other stars. Because of Earth's tilt, the orientation of the axis in relation to the Sun changes throughout the year. These changes and the curvature of Earth cause the altitude of the Sun in the sky to change with latitude throughout the year. The Sun's altitude is its number of degrees above the horizon. The horizon is the circle 90° from the point directly overhead, called the zenith. When the Sun is directly overhead, its altitude is 90°.

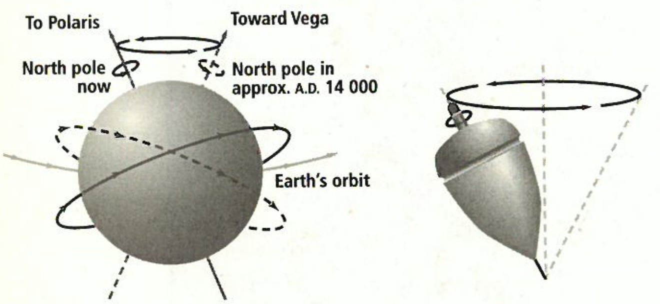

Figure 1-6 Earth wobbles on its axis much like a toy top. In 12 000 years, our new North Star will be Vega.

When the Sun is directly overhead and solar altitude is at its maximum, the Sun's rays are their most concentrated and most intense. As the Sun moves lower in the sky and its altitude decreases, solar radiation is less direct and becomes much less intense. Figure 1-7 shows how these changes occur. When the Sun is directly overhead, all of its energy falls inside a circular area. But when the Sun is at an angle, its energy is spread out over a larger area. If you were to consider the original circle size, you would find less energy in that same area than when the Sun was directly overhead. This variation in solar energy is a major factor in creating differences in climate and in the weather of the seasons.

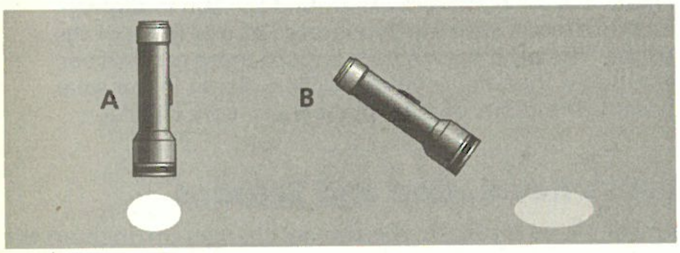

Figure 1-7 Light from a flashlight held perpendicular to a surface is like the Sun's direct rays on Earth (A). When the flashlight is at an angle to the surface, the same amount of light is spread out over a larger area, and the light is less intense. This is similar to the indirect rays of the Sun due to Earth's tilted axis (B).

Figure 1-8 shows how Earth travels around the Sun during a single year. A person looking at the sky will see the Sun in a different position depending on the latitude and the season. In fact, Earth's seasons are due to the tilt of Earth's axis and its changing position as it orbits the Sun.

At Position 1, Earth's north pole is tilted toward the Sun. The Sun is at its maximum altitude in the sky in the northern hemisphere. This is called the **summer solstice.** It occurs around June 21 and is the first day of summer in the northern hemisphere. A person living on the Tropic of Cancer, at 23.5° north latitude, would see the Sun directly overhead. During the summer solstice, the number of daylight hours in the northern hemisphere is at its maximum, and the Sun's rays are most direct.

During the summer solstice, the Sun does not set within the Arctic Circle. For a person living on the Arctic Circle, it is daylight for 24 hours. During the same period, the Sun does not rise within the Antarctic Circle. For a person living in this part of Earth, it remains dark for 24 hours. Because seasons in the northern hemisphere and southern hemisphere are reversed, when the summer solstice occurs in the northern hemisphere, the winter solstice occurs in the southern hemisphere.

At Position 2, Earth's axis is pointed neither toward nor away from the Sun. The Sun is directly overhead at the equator. A person at the Tropic of Cancer would see the Sun at a lower altitude than during the summer solstice. This is because the Sun appears in a different position depending on the latitude of a person's location and the time of the year. This period is known as the **autumnal equinox,** when both hemispheres experience equal hours of daylight and darkness. The autumnal equinox, or start of autumn, occurs around September 22 in the northern hemisphere. At the same time, the vernal equinox, or start of spring, is taking place in the southern hemisphere.

When Earth is at Position 3, the north pole is tilted away from the Sun, and the south pole is tilted toward the Sun. The Sun is at its lowest altitude in the sky in the northern hemisphere. People living on the Tropic of Cancer or the equator see the Sun at its lowest point in the sky for the year. But people who live on the Tropic of Capricorn, 23.5° south latitude, see the Sun at its highest point, directly overhead.

The **winter solstice** occurs around December 21 and is the first day of winter in the northern hemisphere. December 21 is also the first day of summer in the southern hemisphere. The number of daylight hours in the northern hemisphere is at its minimum, and the Sun's rays are least direct. The small amount of solar energy reaching the northern hemisphere causes the lower temperatures that occur during the winter. By contrast, the Sun's rays are most direct in the southern hemisphere. Because the southern hemisphere is heated strongly during this period, temperatures rise as summer begins. During the winter solstice in the northern hemisphere, the Sun does not rise within the Arctic Circle and does not set within the Antarctic Circle.

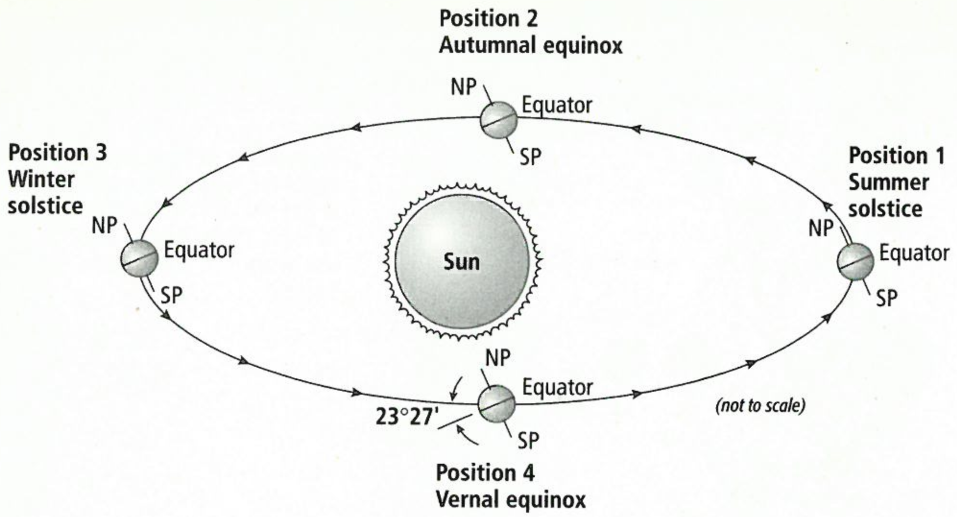

Figure 1-8 **Position 1:** At summer solstice in the northern hemisphere, Earth's north pole is tilted toward the Sun. The Sun is directly overhead at the Tropic of Cancer.
Position 2: At autumnal equinox in the northern hemisphere, neither pole is pointed toward the Sun. Day and night are of equal length in both hemispheres, and the Sun is directly overhead at the equator.
Position 3: During winter solstice in the northern hemisphere, the north pole is pointed away from the Sun. The Sun is directly overhead at the Tropic of Capricorn.
Position 4: At vernal equinox in the northern hemisphere, Earth has returned to a position where neither pole is pointed toward the Sun. Again, day and night are of equal length in both hemispheres.

At position 4, Earth's axis is again tilted neither toward nor away from the Sun. This period is called the **vernal equinox,** or first day of spring, in the northern hemisphere. The vernal equinox occurs around March 20 in the northern hemisphere. This date is the beginning of fall, or the autumnal equinox, in the southern hemisphere. All parts of Earth receive equal hours of daylight and darkness during the equinox. Table 1-1 shows how the length of daylight varies throughout the year at different latitudes.

Seasonal Variation in Length of Daylight at Different Latitudes

Hours of daylight per day	Latitude				
	60° North	30° North	Equator	30° South	60° South
Jan 1	5.7	10.1	12.0	13.9	18.3
Feb 1	7.5	10.6	12.0	13.4	16.5
Mar 1	10.0	11.3	12.0	12.7	14.0
Apr 1	12.8	12.3	12.0	11.7	11.2
May 1	15.6	13.2	12.0	10.9	8.4
Jun 1	17.9	13.8	12.0	10.2	6.1
Jul 1	18.4	13.9	12.0	10.1	5.6
Aug 1	16.6	13.5	12.0	10.5	7.4
Sep 1	13.9	12.6	12.0	11.4	10.1
Oct 1	11.1	11.7	12.0	12.3	12.9
Nov 1	8.3	10.8	12.0	13.2	15.7
Dec 1	6.1	10.2	12.0	13.8	17.9

Table 1-1 At locations in the northern hemisphere, the number of daylight hours is greatest from June to July and least from December to January. The opposite is true for locations in the southern hemisphere. On the equator, the number of daylight hours is constant throughout the year. Locations farther from the equator experience a greater seasonal variation in the length of daylight.

Phases of the Moon

Although the Moon appears bright in the night sky, it produces no light of its own. It reflects light from the Sun. Half of the Moon's surface is always illuminated by reflected sunlight. However, we see different parts of the Moon's illuminated half as it revolves around Earth. The **lunar phases** are the cycle of changes in the Moon's appearance. These changes in appearance occur because of the Moon's changing position in relation to Earth and the Sun.

Refer to Figure 1-9 to follow the cycle of lunar phases. When the Moon is located between the Sun and Earth, its illuminated half faces away from Earth. Its dark side faces Earth, and the Moon is not visible. This phase is called a new moon.

As the Moon continues in its orbit for approximately the next two weeks, its phases are **waxing.** This means the amount of the illuminated side of the Moon that can be seen from Earth increases each day. First, a small sliver of light is visible at the edge of the Moon. This phase is called a waxing crescent. When half of the Moon's sunlit side is visible, the Moon is at first quarter. As the Moon continues in its orbit, more than half of its sunlit side becomes visible. This phase is waxing gibbous.

Halfway through the Moon's cycle of phases, Earth is between the Moon and the Sun. All of the Moon's illuminated side is visible. This is the full moon. For approximately two weeks, as the phases move toward a new moon, the phases are **waning.** This means the visible amount of the illuminated side of the Moon decreases each day. The Moon's waning phases are waning gibbous, third quarter, and waning crescent. The cycle then begins again with the return to a new moon.

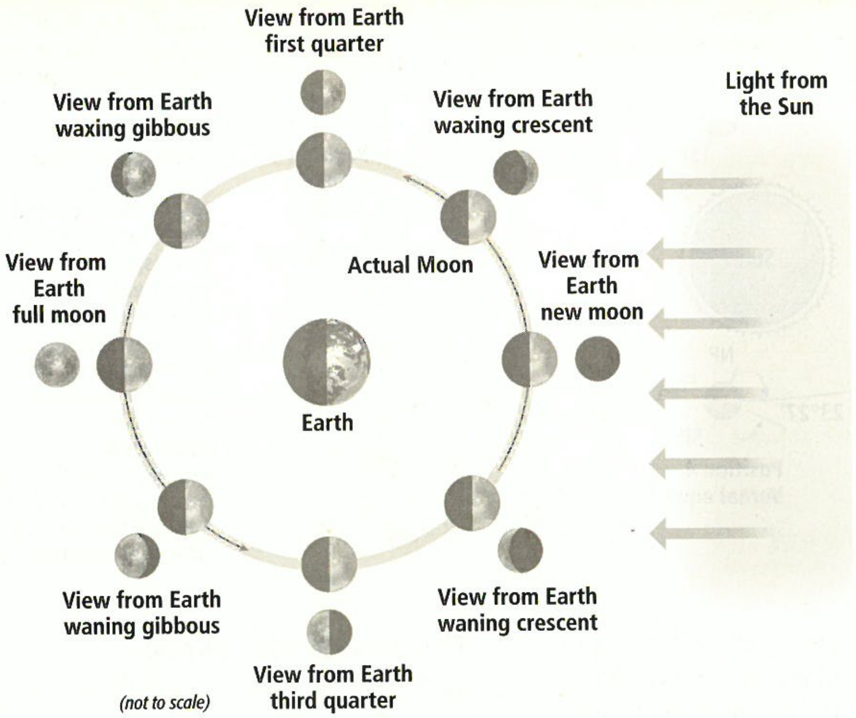

Figure 1-9 As the Moon revolves around Earth, different portions of the Moon's illuminated half are visible to people on Earth.

The period of the Moon's revolution around Earth is 27.3 days, but the lunar cycle has a period of 29.5 days. Figure 1-10 shows why these two periods are different. In Figure 1-10A, the Moon appears as a new moon because the Sun is directly behind it. A person on Earth cannot see the sunlit side of the Moon because that side is facing away from Earth. In Figure 1-10B, the Moon has made one complete orbit around Earth. But Earth has moved also. A person on Earth can still see a small part of the sunlit side of the Moon. The Moon will have to travel a bit farther before it is once more directly in front of the Sun and at a new moon again. It takes 2.2 days for the Moon to travel this additional distance.

Moonrise and moonset—the appearance of the Moon above the horizon and the disappearance of the Moon below the horizon, respectively—occur later each day. To understand why the times of moonrise and moonset change, note that the Moon takes 27.3 days to complete one revolution (360°) around Earth. Dividing 360° by 27.3 days gives 13° per day. In other words, the Moon moves 13° in its revolution during a 24-hour period, so Earth must rotate an additional 13° each day before moonrise and moonset occur. Since Earth rotates 15° per hour, moonrise and moonset occur 13/15ths of an hour, or about 50 minutes, later each day.

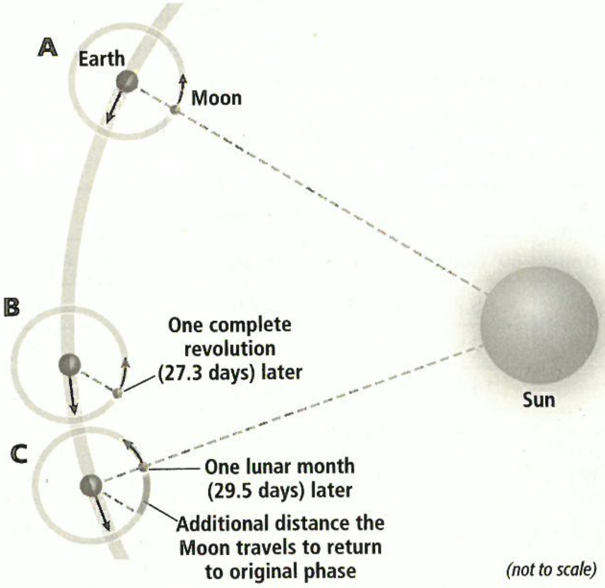

Figure 1-10 The Moon is in the new moon phase when it is located between the Sun and Earth (position A). After 27.3 days, the Moon has completed one revolution around Earth, but Earth has also moved in its orbit around the Sun; as a result, Earth, the Moon, and the Sun are not aligned (position B). After another 2.2 days, the Moon is again located between the Sun and Earth (position C), marking the completion of one lunar cycle. Therefore, the lunar cycle has a period of 27.3 days + 2.2 days = 29.5 days.

A person on Earth sees only one side of the Moon. The Moon spins on its axis at the same rate that it travels around Earth. As a result, the Moon spins once each time it orbits Earth. This is known as **synchronous rotation,** in which the orbital and rotational periods are the same. Hence the Moon takes 27.3 days to revolve around Earth and 27.3 days to rotate on its axis. The only way to see the far side of the Moon is to travel or send a space probe to that side.

Although the Moon is Earth's only natural satellite, many artificial satellites orbit Earth. They include weather and communications satellites as well as observatories, such as the *Hubble Space Telescope.* These artificial satellites are sometimes visible as relatively bright, moving points of light in the night sky.

Eclipses

The movements of Earth and the Moon in relation to the Sun also cause solar and lunar eclipses. During an eclipse, either Earth or the Moon moves in front of the Sun, blocking the Sun's light and casting a shadow in space. Eclipses occur only when the Sun, Earth, and the Moon are in a straight line in Earth's ecliptic. This condition exists only during certain full and new moon phases. Because the Moon's orbit is inclined 5° with respect to Earth's ecliptic, the Moon usually passes above or below the ecliptic during these phases. When that happens, no eclipse occurs.

A **solar eclipse** occurs when the Moon passes between the Sun and Earth on the Earth's ecliptic. As Figure 1-11A shows, the Moon casts a shadow on Earth. The Sun's light is blocked within that shadow, and people within this area on Earth see a solar eclipse.

Solar eclipses can be total or partial, depending on where an observer on Earth's surface is located within the shadow. The inner part of the shadow is called the umbra. People inside the umbra area where it intersects Earth see a total eclipse in which the Moon totally blocks the sunlight in this area. The Moon is seen as a dark disk surrounded by a halo that consists of the Sun's gaseous outer layers. The umbra is usually no wider than 270 kilometers on Earth, so a total eclipse is visible only from a very small part of Earth. The outer part of the Moon's shadow is called the penumbra. The area inside the penumbra receives some sunlight. In this area, the Moon blocks only part of the Sun's disk, causing a partial solar eclipse. A partial solar eclipse is visible from a much wider area on Earth's surface than a total solar eclipse.

The Moon's distance from Earth changes as it moves around Earth in its elliptical orbit. When the Moon is closest to Earth in its orbit, it is at **perigee.** When the Moon is farthest from Earth in its orbit, it is at **apogee.** When the Moon is near apogee, it appears smaller from Earth than at other times. As a result, the Moon does not cover the whole solar disk when it moves in front of the Sun. Therefore, the Moon appears as a dark circle in the middle of the Sun. This is called an annular eclipse.

Lunar Eclipses

Earth is much larger than the Moon, so it casts a much larger shadow in space. Earth's shadow can cover the entire Moon. A **lunar eclipse** occurs when the Moon passes through Earth's shadow, as Figure 1-11B shows. A total lunar eclipse occurs when the entire Moon is located within Earth's umbra. During a total lunar eclipse, the Moon is still faintly visible because red light from the Sun is bent through Earth's atmosphere towards the Moon, while blue light is scattered away from the Moon by Earth's atmosphere. This is why the Moon has a reddish tint during a total lunar eclipse.

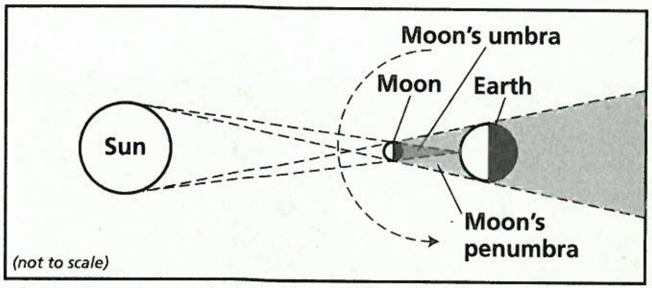

Figure 1-11A During a solar eclipse, Earth, the Moon, and the Sun are aligned, and the Moon passes between Earth and the Sun. The Moon's shadow falls on part of Earth's surface. People within the inner part of the shadow, the umbra, see a total solar eclipse. Those in the penumbra see a partial eclipse.

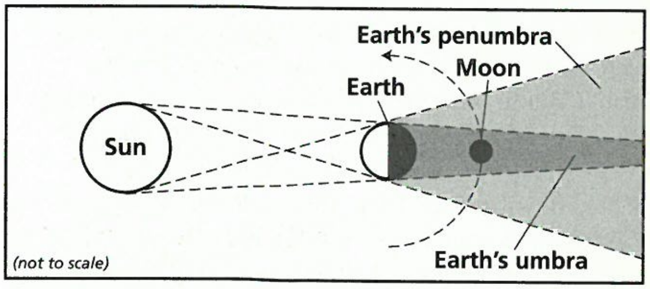

Figure 1-11B During a lunar eclipse, Earth is between the Sun and the Moon, resulting in Earth's shadow falling on the Moon. Because of Earth's size and its closeness to the Moon, the entire Moon lies within Earth's shadow. People on Earth's night side may see either a total or a partial lunar eclipse.

Lunar eclipses occur only during a full moon, but not during every full moon because the alignment of the Sun, the Moon, and Earth is not perfect each month. Unlike total solar eclipses, which last for a short time, total lunar eclipses can last for up to 100 minutes. Lunar eclipses also can be viewed over a much wider area on Earth than solar eclipses. Everyone on the night side of Earth can view a total lunar eclipse. Partial lunar eclipses also occur. During a partial lunar eclipse, Earth's shadow moves over a part of the Moon.

Tides

A **tide** is the daily rise and fall of the waters of the oceans, which cover about 70 percent of Earth. Tides are the result of the gravitational forces of the Moon and, to a somewhat lesser extent, the Sun. The Moon's gravity pulls on Earth along an imaginary line connecting the two bodies. This creates a bulge of water in the ocean on the side of Earth that is facing the Moon, as Figure 1-12 shows, as well as a bulge on the opposite side of Earth. As Earth rotates, the bulges move around the planet, remaining aligned with the Moon. Remember that while the Moon pulls on Earth, Earth also pulls on the Moon. If the Moon were covered with oceans, it would also experience tides.

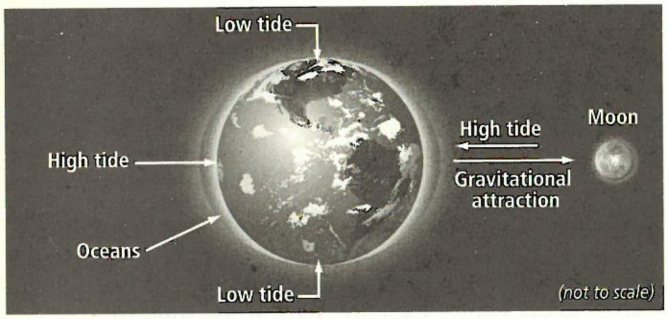

Figure 1-12 As Earth rotates, tidal bulges and troughs move around the planet, producing daily high and low tides.

In deep areas of the ocean, the difference in water level between the bulges and the troughs of tides is not very noticeable. But in most areas of shallower water, especially near continental shorelines, the water levels rise and fall about every 12 hours as the bulges and troughs pass. These are known as high tides and low tides, respectively. The Sun's gravity also contributes to tides. But, because it is so far away, yet still very massive, the Sun's effect is about one-half the effect of the Moon.

When the Sun and Moon are aligned, their effects combine to cause a larger tidal bulge. This causes spring tides, in which high tides are extremely high and low tides are extremely low. When the Sun and Moon are at right angles in relation to Earth, their gravitational effects partially cancel each other, resulting in neap tides. Neap tides are characterized by weak high and low tides.

SUBTOPIC B
OUR SOLAR SYSTEM

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; D.1, D.3, D.4

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
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UCP.4	Evolution and equilibrium
UCP.5	Form and function

Earth and Space Science

D.1	Energy in the Earth system
D.3	Origin and evolution of the Earth system
D.4	Origin and evolution of the universe

VOCABULARY

- universe
- galaxy
- solar system
- nuclear fusion
- planetesimal
- terrestrial planet
- gas giant planet
- asteroid
- meteoroid
- meteor
- meteor shower
- meteorite
- comet
- nucleus
- coma

The **universe** is everything that exists. Many scientists believe the universe formed between 12 and 14 billion years ago in a process called the Big Bang. According to the Big Bang theory, the universe began as a point and has been expanding ever since. The Big Bang was an expansion of space, carrying matter along with it. Much of the matter formed during the Big Bang now exists in the form of galaxies. A **galaxy** is a very large collection of stars, gas, and dust. Astronomers have calculated that the universe is still expanding with all galaxies moving away from one another. Our galaxy, the Milky Way, formed from particles of gas and dust produced during the Big Bang. The Milky Way is composed of billions of stars, including the Sun.

The Formation of the Solar System

The **solar system** formed about 5 billion years ago from a rotating disk of interstellar dust. Scientists hypothesize that the cloud, composed primarily of hydrogen and helium, began to slowly condense as the result of the gravitational attraction between particles. The collapse accelerated as the cloud became denser at its center. The cloud was probably rotating and began to spin faster as it contracted. As the cloud spun and collapsed, the rotation slowed the collapse in the equatorial plane, and the cloud took the shape of a rotating disk with a dense center. This disk is known as the solar nebula.

The Birth of the Sun

The dense concentration of gas at the center of the solar nebula became the Sun. As the collection of gas and dust continued to shrink, the temperature and pressure in its center increased. Eventually, the temperature and pressure became so great that nuclear fusion reactions began. In **nuclear fusion,** light atoms fuse to form heavier atoms. An example is the fusion of hydrogen into helium. At this point, the center of the solar nebula became a star producing great amounts of energy, some in the form of thermal energy and light. All stars produce energy through nuclear fusion and do so for millions or billions of years.

The Formation of the Planets

The materials in the disk surrounding the young Sun became the solar system's planets and other objects. The characteristics of each planet were affected by where it formed in the disk. Temperatures varied within the disk. The hottest areas were closest to the Sun, and the coolest areas were near the disk's edge. As a result, different elements and compounds condensed in different areas of the disk. Heavier elements condensed in the hotter region closer to the Sun, and some lighter elements, unable to condense in intense heat, condensed farther out in the disk. Figure 1-13 shows how temperature and distance from the Sun influenced the condensing of various substances.

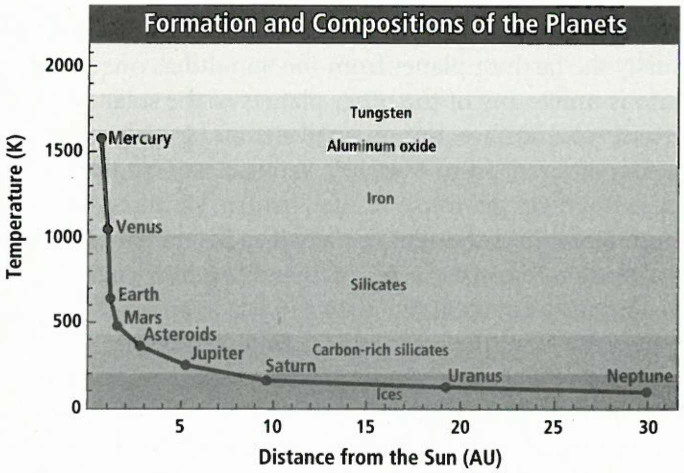


Figure 1-13 Because temperature decreases with distance from the Sun, different substances condensed in different parts of the early solar system. As a result, planets that formed near the Sun have different compositions than planets that formed farther from the Sun. (The label "Ices" refers to solid water, ammonia, methane, and nitrogen.)

Once the condensing slowed, the grains of condensed material merged together to form larger bodies, which eventually reached hundreds of kilometers in diameter. These bodies were **planetesimals.** Through the collision and merger of planetesimals, the planets began to form. The densest material sank to the center of the forming planets. Lighter materials formed layers closer to the surface. This arrangement of materials dictates the structure of planets today. For example, dense elements, such as iron and nickel, make up Earth's core. Less dense elements, such as oxygen and silicon, make up much of Earth's outer crust.

The Terrestrial Planets

The planetesimals that formed nearest to the Sun were made of refractory elements, which are elements and compounds able to condense where the temperature was greatest. These elements comprise the rocky, dense **terrestrial planets,** which are the planets closest to the Sun. The Sun's gravitational force is thought to have accumulated much of the gas in the area of the terrestrial planets. This prevented the terrestrial planets from acquiring much additional material from their surroundings. For this reason, the terrestrial planets initially had no satellites.

All of the terrestrial planets are close in size to Earth and have solid surfaces like Earth. The terrestrial planets, in order from the Sun, are Mercury, Venus, Earth, and Mars.

Mercury has no moons (satellites) and is about one-third the size of Earth. Because Mercury has virtually no atmosphere to moderate its surface temperature, the temperature can range from more than 400°C in daylight to well below –150°C at night. Mercury's barren surface is rocky and covered with features such as impact craters and cliffs.

Venus is also a small, rocky planet. It is about the same size as Earth and has no moons. Venus is the brightest planet in the night sky, but astronomers cannot see its surface from Earth. A thick atmosphere of carbon dioxide and nitrogen always obscures the surface of Venus. The atmosphere of Venus has such a high concentration of carbon dioxide, a greenhouse gas that prevents infrared energy (thermal energy) from escaping, that the surface of Venus is the hottest of any planet in the solar system. Radar images of Venus show that the surface of Venus is relatively young.

Earth is an unusual planet compared with the other planets in the solar system. It is a small, rocky planet with one fairly large moon. Earth is the only known planet whose surface is covered mostly by liquid water. It is also the only known planet with an atmosphere of primarily nitrogen and oxygen. So far, Earth is the one planet in the solar system known to support life.

The average distance between Earth and the Sun has been defined by astronomers as an Astronomical Unit (AU). $1 \text{ AU} = 1.496 \times 10^8$ km, and is often used to measure the distances to the other planets.

Mars is the fourth planet from the Sun and the outermost of the small, rocky terrestrial planets. Mars is about half the size of Earth and less dense. It has two small, irregularly shaped moons and a thin atmosphere of mostly carbon dioxide. It is much colder than Earth because it is located much farther from the Sun. The surface of Mars has been explored and photographed by several Earth probes that show it to be dry, rocky, and dotted with impressive features. These features include craters, canyons, several huge volcanoes, and what appear to be dry river channels. These channels suggest that Mars might have once had liquid water on its surface. The planet also has two polar ice caps that expand and shrink with the seasons.

The Gas Giant Planets

The fifth through eighth planets from the Sun formed in the outer part of the solar system. They are the **gas giant planets,** also called Jovian planets. They are large, less dense, and more gaseous than the terrestrial planets. They lack solid surfaces and are thought to have relatively small, solid cores. The gas giant planets, in order from the Sun, are Jupiter, Saturn, Uranus, and Neptune.

The gas giant planets formed farther from the Sun where it was cooler. In this outer part of the solar system, lighter and more volatile elements condensed to form planets. Volatile elements include ices and gases, such as hydrogen.

Jupiter was the first planet in the solar system to develop. As it increased in size through the merger of many icy planetesimals, its gravity attracted even more gas, dust, and other matter. The other gas giants formed in a similar way, but they did not become as large as Jupiter, because Jupiter had already collected much of the planet-forming material. A disk formed in each planet's equatorial plane. In this disk, matter coalesced to form satellites.

Jupiter is the solar system's largest planet. It has a diameter 11 times greater than that of Earth. Jupiter has at least 16 moons. The bands that characterize Jupiter, as seen from Earth, are not its surface. The bands are the flow pattern of gases and clouds that make up Jupiter's atmosphere. Most of Jupiter's atmosphere is composed of gaseous hydrogen and helium. Jupiter is composed of liquid in the lower layers closer to the center of the planet. Jupiter probably has a solid core composed of heavier elements that sank to the planet's center. The planet's most noticeable feature, the Great Red Spot, is a huge storm that has raged on Jupiter for more than three centuries. Jupiter also has a set of thin rings that were discovered by the *Voyager 1* space probe.

Saturn is the second-largest planet in the solar system. Like the other gas giants, it has a low density. Saturn's atmosphere is made up mostly of hydrogen and helium with ammonia ice near its cloud tops. Like Jupiter, Saturn is thought to have a solid core surrounded by liquid. Saturn's most striking feature is the broad, thin band of rings in its equatorial plane. The rings are made of pieces of ice and rock that can be as small as specks of dust or as large as houses. Many astronomers hypothesize that the rings are remnants of a moon that was destroyed by a collision or ripped apart by Saturn's strong gravity. Saturn's 18 known moons include Titan, which is larger than Earth's moon.

Uranus, the seventh planet, is a gas giant four times the size of Earth. It has at least 18 moons, with 3 more awaiting verification, and a system of 10 rings. The atmosphere of Uranus is composed mostly of hydrogen, helium, and methane. The surface of Uranus, as seen from Earth, appears bluish and featureless. It lacks the colored bands formed by the atmosphere of Jupiter and Saturn. Like Jupiter and Saturn, Uranus is composed of a small, solid core surrounded by fluid. Uranus's atmosphere and its distance from the Sun keep the planet's temperature at a frigid −215°C.

Neptune is smaller and denser than Uranus and, as seen from space, it has a bluish tint. Its atmosphere, like that of Uranus, is composed of hydrogen, helium, and methane. But unlike Uranus, Neptune displays distinctive bands in its atmosphere. Neptune has eight known moons and a system of six rings composed of microscopic dust particles. Most of the time, Neptune is the solar system's eighth planet from the Sun. But due to the alignment of Neptune's and Pluto's orbits, Neptune periodically becomes the ninth planet. The orbits of Neptune and Pluto do not actually intersect, so a collision between them is not possible.

Pluto is the smallest planet in the solar system and usually the farthest planet from the Sun. It has one moon. Pluto is unlike any of the other planets of the solar system. It has a solid surface, but its small size and low density make it different from Mercury, Venus, Earth, and Mars. It is also not a gas giant like Jupiter, Saturn, Uranus, and Neptune. Pluto is thought to be half rock and half ice, with an atmosphere consisting of methane and nitrogen.

Pluto is located 50 AU from the Sun at aphelion but only 30 AU from the Sun at perihelion. While near perihelion, Pluto is closer to the Sun than Neptune and becomes the eighth planet.

Because Pluto is so unusual, some astronomers do not think Pluto formed in the same way as the other planets. One idea is that Pluto was once a moon of Neptune that escaped after a near-collision with Neptune's large moon, Triton. This would help to explain Pluto's strange orbit and extreme tilt on its axis. Another idea is that Pluto's eccentric orbit and tilted axis suggest that it is related to a comet. Pluto is the only planet in the solar system that has not been visited by Earth space probes.

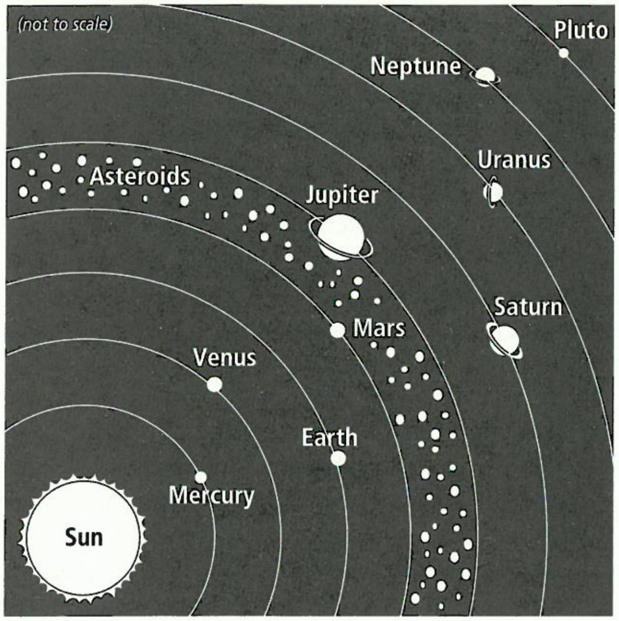


Figure 1-14 The solar system has nine planets that revolve around the Sun. Thousands of asteroids are located in a belt between Mars and Jupiter.

Other Objects in the Solar System

The Sun and the planets are the largest objects in our solar system, but they are not the only ones. There are thousands of smaller, rocky bodies that orbit the Sun between the planets. These rocky bodies are known as **asteroids.** Asteroids are thought to be leftover pieces of planetesimals that did not become planets when the solar system formed. Asteroids range from a few kilometers to about 1000 km in diameter and have irregular surfaces. Most asteroids are located in a belt between the orbits of Mars and Jupiter, as shown in Figure 1-14.

When asteroids collide and break into fragments, the fragments sometimes head toward Earth. When a fragment of rocky material enters Earth's atmosphere, it is called a **meteoroid.** A meteoroid that burns up as it passes through Earth's atmosphere creates a streak of light called a **meteor.** However, most meteors are caused by dust particles from comets. A **meteor shower** is the result of Earth intersecting a comet's orbit. Meteoroids that do not burn up completely in Earth's atmosphere and fall to Earth's surface are called **meteorites.** Most meteorites are fragments of asteroids. When these fragments reach Earth's surface, they can cause huge impact craters on Earth's surface, although many such craters are no longer visible due to erosion.

Comets are also remnants from the formation of the solar system. A **comet** is a small, icy body that has a highly elongated orbit around the Sun. Comets are made of ice and rock and range from 1 to 10 km in diameter. A comet consists of three main parts, as Figure 1-15 shows. The **nucleus** of a comet is the small, solid core of rock and ice. When a comet passes close to the Sun, its nucleus is heated. The ice in the nucleus evaporates, releasing gas and dust particles, which form the comet's coma and tail. The **coma** is an extended volume of glowing gas that surrounds and includes the nucleus. The tails are elongated trails of glowing gas and dust. The tails point away from the Sun because they are pushed away by the solar wind, which is discussed in subtopic C.

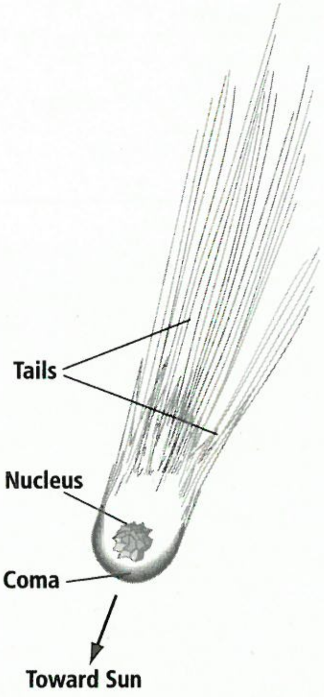


Figure 1-15 A comet has a small nucleus of rock and ice. When a comet nears the Sun, the ice in its nucleus starts to evaporate, forming a coma and tails. The tails always point away from the Sun.

There are two clusters of comets in the solar system. One cluster is in the Kuiper belt, which is located close to the orbit of Pluto, between 30 and 50 AU from the Sun. The second cluster is in the Oort Cloud, which lies more than 100 000 AU from the Sun.

Comet orbits are very elongated. Some stretch far beyond the orbit of Pluto at aphelion, while coming very close to the Sun at perihelion. It is only when a comet comes within 3 AU of the Sun that the ice surrounding its nucleus starts to evaporate, forming its coma and one or more tails.

SUBTOPIC C
STARS

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; D.1, D.3, D.4

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Earth and Space Science

D.1	Energy in the Earth system
D.3	Origin and evolution of the Earth system
D.4	Origin and evolution of the universe

VOCABULARY

photosphere
chromosphere
corona
solar wind
sunspot
solar flare
prominence
apparent magnitude
parallax
absolute magnitude
luminosity
spectrum
Hertzsprung-Russell (H-R) diagram
main sequence
constellation
binary star
nebula
protostar
neutron star
supernova
black hole

The universe contains trillions of stars, which are large celestial objects that emit light and other forms of electromagnetic radiation. The Sun is a star. Because it is much closer to Earth than any other star, the Sun has provided much of the information scientists have gathered about stars.

Physical Properties of the Sun

The Sun is the largest and most massive object in the solar system. Its diameter of 1.39×10^6 km is 109 times that of Earth and almost 10 times that of Jupiter. Its mass of 1.99×10^{30} kg represents more than 99 percent of all the mass in the solar system. The Sun's enormous mass enables it to influence the motions of the planets and other objects in the solar system. Hydrogen accounts for about 73 percent of the mass of the Sun, and helium accounts for 25 percent. A variety of other elements, of which the most abundant are oxygen and carbon, make up the remaining 2 percent. This composition resembles that of most other stars and is thought to be similar to that of the interstellar cloud from which the solar system formed.

The Sun has an average density of 1.4 g/cm^3. However, the center of the Sun, called the core, is much denser at about 150 g/cm^3. Despite being very dense, the core is gaseous because of its high temperature of more than 10 million K (Kelvin). At this temperature, many of the gases are completely ionized, consisting only of atomic nuclei and electrons, which is a state of matter known as plasma.

The Sun's Interior

The Sun's interior is divided into three regions, as shown in Figure 1-16 below. The nuclear fusion reactions that produce the Sun's energy occur in the core. In the basic reaction, hydrogen nuclei combine to form a helium nucleus. The combined mass of the hydrogen nuclei is greater than the mass of the helium nucleus. The mass that is lost in the reaction is converted into energy according to the equation $E = mc^2$, where E is the energy in joules (J), m is the mass in kilograms, and c is the speed of light in meters per second. Scientists calculate that there is enough fuel remaining in the Sun to continue nuclear fusion for approximately another 5 billion years.

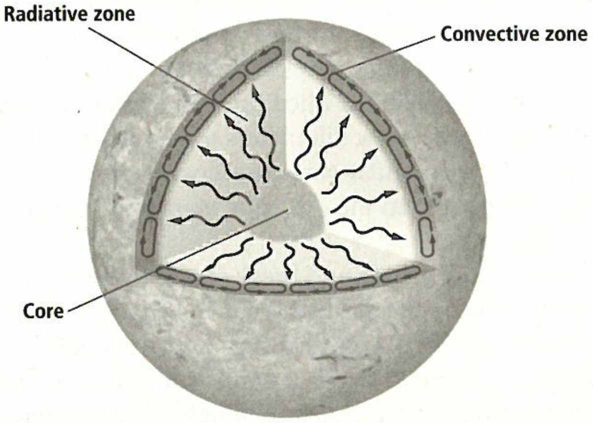


Figure 1-16 At the center of the Sun's interior is the core, where nuclear fusion reactions occur. Energy produced in the core is absorbed and reemitted by atoms in the radiative zone. Moving gases in the convective zone transfer the energy to the Sun's surface.

Just outside the core is the radiative zone, in which atoms absorb the energy released by the core and then reemit the energy by radiation. The radiative zone extends roughly 86 percent of the way to the Sun's surface. Above the radiative zone is the convective zone, where moving volumes of gas carry the energy the rest of the way to the surface through convection. It takes about 170 000 years for energy to be transferred from the core to the surface.

The Sun's Atmosphere

Surrounding the Sun's interior is an atmosphere that is also divided into three regions. The lowest region, called the **photosphere,** extends outward approximately 400 km from the surface. Most of the visible light emitted by the Sun comes from the photosphere. The average temperature of the photosphere is about 5800 K.

Above the photosphere is the **chromosphere,** which is approximately 2500 km thick. Normally, the chromosphere is visible only during a solar eclipse, when light from the photosphere is blocked. Under these conditions, the chromosphere appears as a red ring. The temperature at the outermost portion of the chromosphere is nearly 30 000 K.

The top layer of the Sun's atmosphere is known as the **corona.** It is several million kilometers thick and has a temperature of 1–2 million K. The density of the gas in the corona is very low. As a result, the corona, like the chromosphere, is visible only when light from the photosphere is blocked. Areas in the corona where the gas density is especially low appear as dark regions on X-ray images and are called coronal holes.

Gas escapes continuously from the corona as a stream of charged particles. These particles are called the **solar wind,** and they flow through the entire solar system. Most of these particles arise from coronal holes. Moving at about 400 km/s, the particles in the solar wind that reach Earth are deflected by Earth's magnetic field and trapped in two huge rings around Earth. The rings are called the Van Allen belts. When gases in Earth's atmosphere collide with the high-energy particles in these belts, the gases give off a light display known as the aurora.

Solar Activity

The Sun's magnetic field disturbs the solar atmosphere periodically and causes new features to appear. The most obvious features are **sunspots,** areas on the surface of the photosphere that appear dark relative to their surroundings because they are cooler than surrounding areas. Sunspots are located where the Sun's magnetic field prevents hot gases inside the Sun from rising to the surface. Sunspots occur in pairs that last an average of 2 months. The pairs have opposite magnetic polarities; that is, they have a north pole and a south pole.

The number of sunspots changes regularly with a period of about 11 years. This recurring phenomenon, called the solar activity cycle, is caused by the Sun's magnetic field, which reverses polarity every 11 years. Pairs of sunspots also reverse polarity each time the Sun's magnetic field does. When the polarity of the Sun's magnetic field is taken into account, the period of the solar activity cycle is about 22 years. During the first 11 years of a cycle, the number of sunspots increases and then decreases. The magnetic field then reverses, and the number of sunspots increases and decreases again during the second 11 years of the cycle.

Two other signs of solar activity, known as solar flares and prominences, are associated with sunspots. A **solar flare** is a violent eruption of particles and radiation from the atmosphere. The released particles often escape from the Sun in the solar wind. When such particles reach Earth, they can disrupt radio communications and damage satellites. A **prominence** is a collection of gas that becomes trapped above the surface of the Sun for a few hours to a few days. Prominences usually condense in the inner corona and rain back on the surface, but occasionally they are ejected from the chromosphere into space. The temperature in a prominence can exceed 50 000 K.

Impact of Solar Activity on Earth

On average, each square meter of the outer edge of Earth's atmosphere receives 1350 J of energy from the Sun each second. Only a fraction of this energy actually reaches the surface of Earth; the rest is absorbed or scattered by Earth's atmosphere. Variations in solar activity affect the amount of energy that reaches Earth, and that, in turn, can influence Earth's climate.

Scientists have found cyclic climate changes that have an 11-year period, which corresponds to half of a solar activity cycle. During the latter half of the 1600s, the solar activity cycle mysteriously stopped, and there were no sunspots for nearly 60 years. The weather in Europe and North America was so cold during those years that the time period is often referred to as the "Little Ice Age."

Physical Properties of Stars

Astronomers often use our own Sun as a basis for describing other stars in the universe. Astronomers express the physical properties of stars by telling how they compare with those properties for the Sun. The physical properties of stars include diameter, mass, magnitude, luminosity, and surface temperature.

Diameter and Mass

Stars range in diameter from 0.1 to hundreds of times the diameter of the Sun. Star masses range from a little less than 0.01 to more than 20 times the Sun's mass. The most massive stars can be as massive as 50 to 100 Suns, but are extremely rare.

Magnitude

The brightness of a star or any other celestial object is indicated by the object's magnitude. The brighter an object is, the smaller its magnitude is. Two objects that differ by 1 in magnitude differ by a factor of 2.512 in brightness. Thus, a magnitude $+1$ star is 2.512 times as bright as a magnitude $+2$ star and 2.512×2.512, or 6.310, times as bright as a magnitude $+3$ star. The brightest objects in the sky have negative magnitudes.

Magnitude can be measured two ways—by apparent magnitude and by absolute magnitude. **Apparent magnitude** is a measure of how bright a celestial object appears on Earth without regard to its distance from Earth. As the top half of the scale in Figure 1-17 shows, the Sun has the smallest apparent magnitude of any celestial object (-26.7). This means that it appears to be the brightest object in the sky. After the Sun, the brightest-appearing star in the sky is Sirius; its apparent magnitude is -1.5. The difference between the apparent magnitudes of Sirius and the Sun is $-1.5 - (-26.7) = 25.2$. Therefore, the Sun appears $2.512^{25.2}$ or 10 billion times as bright as Sirius.

A star that produces less light than another star can appear brighter than the other if it is much closer to Earth. To compensate for this effect, astronomers must take distance into account. To estimate the distance of stars from Earth, astronomers make use of the fact that nearby stars appear to shift their position with respect to more distant stars as Earth moves along its orbit. This apparent shift in position, which is caused by the motion of the observer, is called **parallax** and is illustrated in Figure 1-18. The closer a star is to Earth, the larger its parallax. The distance at which a star has a parallax of 1 arcsecond (1/360th of a degree) is defined as 1 parsec (pc), which equals 3.08×10^{13} km or 3.26 light-years (ly). One light-year is the distance that light can travel in one year.

Absolute magnitude is a measure of the brightness a celestial object would have if it were placed at a distance of 10 pc. By looking at the bottom half of the scale in Figure 1-17, you can see that the Sun has an absolute magnitude of $+4.8$ and Sirius has an absolute magnitude of $+1.4$. Both are much dimmer on the absolute-magnitude scale than the most powerful stars.

Luminosity

A property that is closely related to magnitude is **luminosity,** which is the energy output from the surface of a star per unit of time. When energy output is measured in joules and time is measured in seconds, the units of luminosity are watts (W), which are units of power. The Sun's luminosity is about 3.85×10^{26} W. The luminosity of other stars ranges from about 0.0001 to more than 1 million times the Sun's luminosity. An astronomer can calculate a star's luminosity from its apparent magnitude and its distance from Earth.

Temperature

The surface temperatures of stars range from 2000 K to about 50 000 K. As you read earlier, the Sun's surface temperature (the average temperature of the photosphere) is about 5800 K. Each star is assigned to a class based on its surface temperature. Arranged from highest to lowest temperature, the classes are O, B, A, F, G, K, and M. Each class is further divided into 10 types designated by the numbers 0–9, with 0 representing the hottest stars in a class and 9 the coolest. For example, the Sun is a type G2 star.

Astronomers can estimate a star's surface temperature by examining its spectrum. A **spectrum** is a rainbowlike series of colors that is produced when visible light is split into its component colors and those colors are arranged by wavelength. A glowing solid or liquid, or a highly compressed glowing gas, produces a continuous spectrum, or a spectrum with no interruptions. However, as Figure 1-19 shows, the spectrum produced by a star is interrupted by a series of dark bands, indicating that light at specific wavelengths has been absorbed by elements in the star's atmosphere. Such a spectrum is called an absorption spectrum. The lines in an absorption spectrum are called absorption lines. The absorption spectrum of a

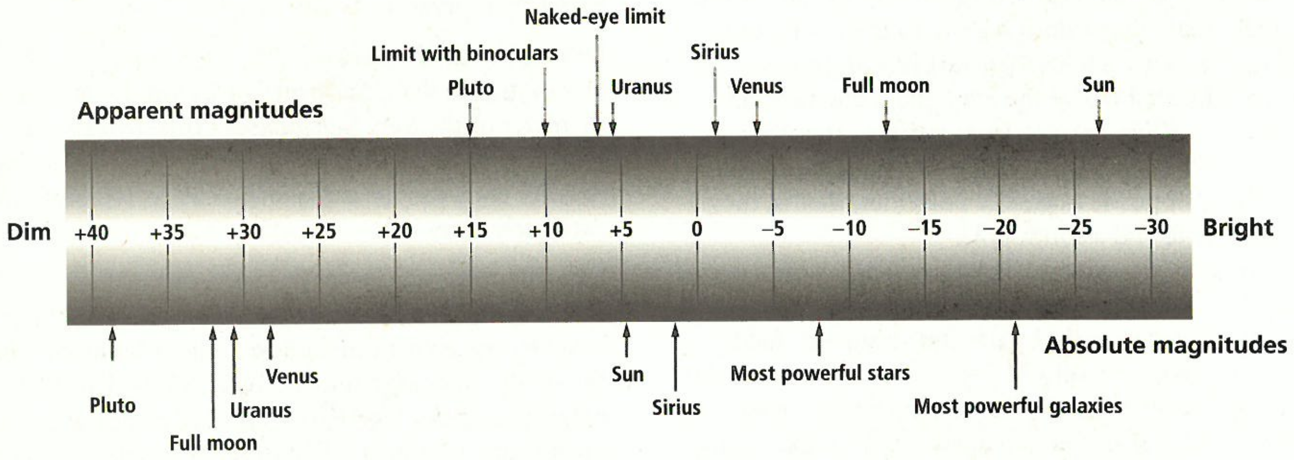


Figure 1-17 The brightness of a celestial object is indicated by the object's apparent magnitude, which is independent of its distance from Earth, and its absolute magnitude, which is adjusted for distance. Note that brighter objects have smaller magnitudes. A difference of 5 in apparent or absolute magnitude corresponds to a factor of 100 in brightness.

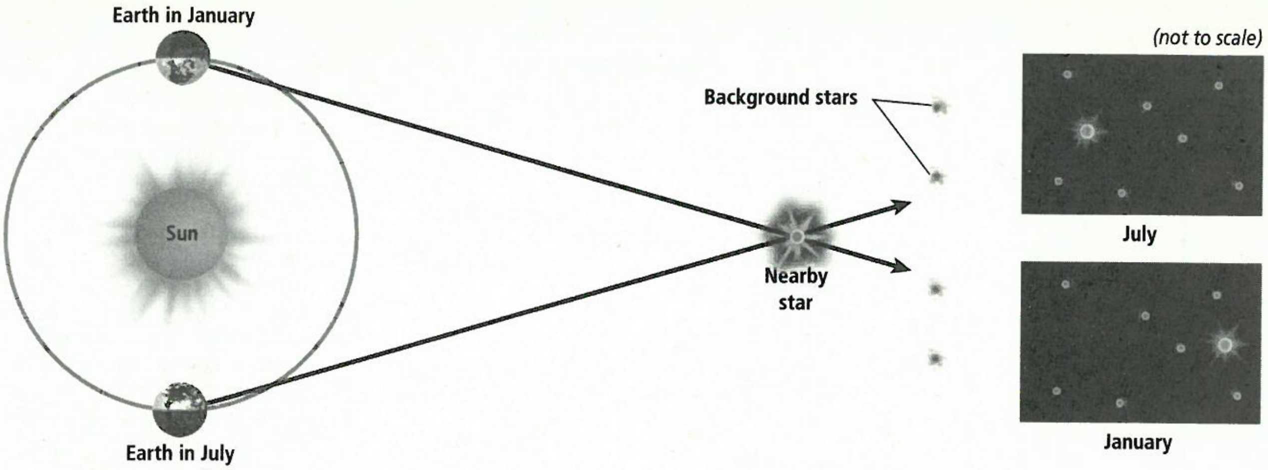


Figure 1-18 Nearby stars are aligned with different background stars at different times of the year as the line of sight from Earth changes as Earth orbits the Sun. The result is parallax, the apparent shift in the position of nearby stars.

star depends almost entirely on the star's temperature. Hotter stars have fairly simple spectra, while cooler stars have spectra with more absorption lines. The coolest stars have absorption lines due to atmospheric molecules, such as titanium oxide.

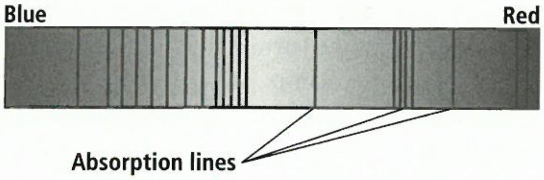


Figure 1-19 Dark absorption lines in the spectrum of a star indicate that certain wavelengths of light have been absorbed by elements in the star's atmosphere.

H-R Diagram

The stellar properties of diameter, mass, magnitude, luminosity, and surface temperature are closely related. One way to show the relationships involving these properties is with a graph called a **Hertzsprung-Russell (H-R) diagram,** which is illustrated in Figure 1-20 on the next page, and also appears in the *Earth Science Tables and Charts.* On an H-R diagram, luminosity or absolute magnitude is plotted on the vertical axis and temperature is plotted on the horizontal axis. Points representing about 90 percent of all stars, including the Sun, lie along a diagonal band called the **main sequence,** which runs from the upper-left corner of the diagram to the lower-right corner. Stars represented in the upper-left corner, known as blue supergiants, are hot and very luminous. Stars represented in the lower-right corner, known as red dwarfs, are relatively cool and dim.

Most points that do not lie in the main sequence are found in one of two groupings. Points in the upper-right portion of the diagram represent stars that are cool but very luminous. Because cool surfaces emit less energy per unit area than hot ones do, these cool stars must have large surface areas to be so luminous. Hence, these stars are called red giants. Points in the lower-left portion of the diagram represent stars that are fairly hot, but dim. These stars must be very small or else they would be far more luminous. Therefore, they are called white dwarfs. A typical white dwarf has a diameter roughly equal to that of Earth, but has a mass about as large as the Sun's.

Groups of Stars

The brightest stars are placed in 88 groups established by ancient peoples. These groups, called **constellations,** were named after mythological characters, animals, or everyday objects. Some constellations are visible all year long to observers in either the northern or southern hemisphere. These constellations appear to revolve around the pole in the same hemisphere and are known as circumpolar constellations. Ursa Major, also called the Big Dipper, is a circumpolar constellation for the northern hemisphere.

Other constellations can be seen only at certain times of the year, as explained in Figure 1-21. For example, observers in the northern hemisphere can see the constellation Orion only in winter and the constellation Hercules only in summer. For this reason, noncircumpolar constellations are classified as summer, fall, winter, or spring constellations.

The stars that make up a constellation are very far apart from one other. The force of gravitational attraction between them is very small, almost zero. Other groups of stars are much closer to one another. The stars that make up these groups are held together by gravitational attraction. Such groups are known as clusters. Clusters are described as globular if the stars are densely packed into a spherical shape, or open if the stars are not densely packed.

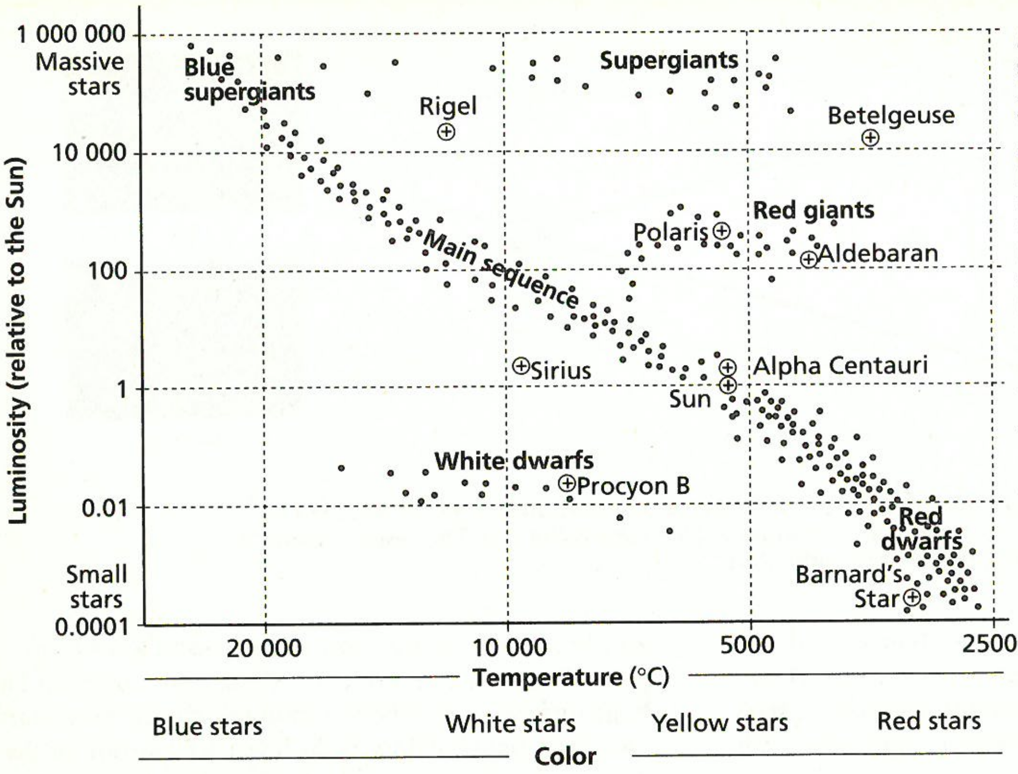


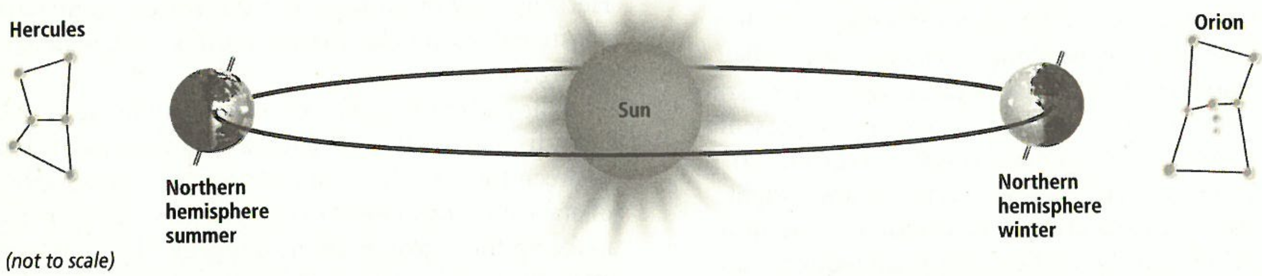
Figure 1-20 An H-R diagram shows the relationship between luminosity and temperature in stars. Most stars can be represented by points that lie along a diagonal band called the main sequence. Points representing the Sun and other specific stars are marked by ⊕. Note that massive stars are more luminous than small stars and that a star's color depends on its temperature. The Sun is a main sequence star and is average in temperature and luminosity.

The cluster M13, in the constellation Hercules, is a globular cluster. The cluster Pleiades, in the constellation Taurus, is an open cluster.

Two stars that are gravitationally bound to each other and orbit a common center of mass are called a **binary star.** Astronomers estimate that approximately one-half of all visible stars are members of binary-star systems or multiple-star systems, such as Aleor-Mizar in Ursa Major. Most binary stars appear to be single stars, even when they are viewed through a telescope. This is because the two stars are so close together and because one star in the pair is often much brighter than the other. However, astronomers can infer that a star is part of a binary-star pair by observing the star shift back and forth as it orbits the common center of mass. In addition, when the orbital plane of a binary-star system can be seen edge-on from Earth, the two stars will take turns eclipsing each other. Each time such an eclipse occurs, the total brightness of the binary star decreases. This type of binary star is called an eclipsing binary.

Equilibrium in Stars

Inside a star, conditions vary in much the same way as they do inside the Sun. Density and temperature increase toward the core, where energy is generated by nuclear fusion. Main-sequence stars produce energy by fusing hydrogen into helium, as the Sun does. Once a star's core has been converted into helium, the helium may fuse to form carbon if the temperature is high enough. At higher temperatures, carbon can fuse with helium to form oxygen,



(not to scale)

Figure 1-21 Constellations can be seen by an observer on Earth's surface only at night when they are not obscured by light from the Sun. Moreover, only those constellations that the dark side of Earth is facing are visible. As Earth moves along its orbit around the Sun, the dark side of Earth faces different regions and different constellations become visible.

then neon, then magnesium, and then silicon. Other types of reactions can produce even heavier elements, but few of these elements are heavier than iron.

The fusion reactions in a star's core produce energy, which is radiated toward the surface of the star. This energy exerts an outwardly directed pressure that tends to make the star expand. The outward pressure is opposed by gravity, which is directed inward and tends to make the star contract. In any stable star, there is an equilibrium, or balance, between the outward pressure of fusion and radiation and the inward pressure of gravity. This equilibrium is governed by the mass of the star. The more massive a star is, the greater is the gravity pressing inward and the hotter the star must be to drive the nuclear reactions needed to balance the gravity.

Star Formation

The formation of a star begins with a cloud of interstellar gas and dust called a **nebula** (*pl.* nebulae). This cloud collapses on itself as a result of its own gravity. As the cloud contracts, its rotation forces it into a disk with a hot, condensed object, called a **protostar,** at the center.

Protostars are brightest at infrared wavelengths. Continued contraction raises the temperature of the protostar. Eventually, the protostar becomes hot enough to support nuclear fusion reactions, the first of which is always the conversion of hydrogen into helium. Once nuclear fusion begins, equilibrium is attained and the protostar becomes a new, stable star. The new star takes its place on the main sequence according to its mass. What happens to the star after that depends on its mass.

Life Cycles of Stars Like the Sun

A star with a mass similar to that of the Sun gradually becomes more luminous because its core density and temperature slowly rise and increase the nuclear reaction rate. Such a star has a main-sequence lifetime of about 10 billion years, which is the amount of time it takes for all the hydrogen in its core to convert into helium. When the hydrogen in its core is gone, some hydrogen in a thin shell just outside the helium core continues to react. The energy produced in this shell forces the outer layers of the star to expand and cool. The star's luminosity increases while its surface temperature decreases due to the expansion. At this point, the star becomes a red giant.

A red giant is so large that its surface gravity is very low. Consequently, gas in the outer layers of the star can be driven off by small pulsations of the star caused by instability. Meanwhile, the core of the star becomes hotter, and when the temperature reaches 100 million K, helium begins to fuse into carbon. The star contracts and becomes stable for about a billion years until all the helium in the core has converted into carbon. A star of the Sun's mass never has a core hot enough for carbon to fuse, so the star's energy production ends at this stage. The outer layers expand once again and are driven off entirely by pulsations. The escaping gas forms a shell called a planetary nebula. (In spite of its name, it has nothing to do with planets.) At the center of the planetary nebula is the exposed carbon core, which is now a small, hot object about the size of Earth. This object is a white dwarf.

White dwarfs are stable despite the lack of nuclear reactions because the resistance of electrons being forced together exerts an outward pressure that opposes gravity. Equilibrium exists as long as the mass of the remaining core is less than about 1.4 times the mass of the Sun.

A star that is less massive than the Sun has a similar life cycle, except that helium may never form carbon in the core. As a result, the star ends as a white dwarf made of helium. The main-sequence lifetime of such a star is much longer than 10 billion years because low-mass stars are dim and do not use up their nuclear fuel very rapidly.

Life Cycles of Massive Stars

A star that is much more massive than the Sun begins its life cycle the same way, by converting hydrogen into helium. However, its main-sequence lifetime is short because the star is very luminous and uses up its fuel quickly. A massive star undergoes many more reaction phases and thus produces an assortment of elements in its interior. As more shells are formed by the fusion of different elements, the star expands. It becomes a red giant several times, with each red giant occurrence following the end of a reaction phase. Eventually the star becomes so large that it is classified as a supergiant. An example of a supergiant is Betelgeuse, in the constellation Orion.

A massive star loses much of its mass as gas drifts from its outer layers or is driven away by stellar wind. Even a star that begins with as much as 8 times the Sun's mass may end up as a white dwarf with a final mass less than 1.4 times the Sun's mass. The composition of a white dwarf formed from a massive star is determined by how many reaction phases the star went through before it stopped reacting altogether. Hence, there are white dwarfs made of oxygen, others made of neon, and so on.

Supernovae

A star that begins with a mass between about 8 and 20 times the Sun's mass will end up with a core that is too massive to exist as a stable white dwarf. Once reactions in the core of such a star have created iron, no further energy-producing reactions can occur, and the core violently collapses in on itself. As it does so, protons and electrons in the core merge to form neutrons. Like electrons, neutrons resist being forced together, and this resistance creates an outward pressure that halts the collapse of the core. At this point, the core becomes a **neutron star,** a star with a mass of 1.5 to 3 times the Sun's mass but a diameter of only about 10 to 20 km. The density of a neutron star is extremely high, up to 10^{14} g/cm^3, and is comparable to that of an atomic nucleus.

A neutron star forms quickly while the outer layers of the star are still falling inward. When the infalling material strikes the hard surface of the neutron star, the material rebounds. The entire outer portion of the star is blown off in a massive explosion called a **supernova** (*pl.* supernovae). The explosion creates elements that are heavier than iron and distributes these elements throughout the universe.

Black Holes

The pressure from the resistance of neutrons being forced together cannot support the core of a star if the star's mass is greater than about 3 times the mass of the Sun. A star that begins with a mass of more than about 20 times the Sun's mass will end up above this mass limit; therefore, it cannot form a neutron star. When the nuclear reactions cease in such a massive star, the remaining matter simply continues to collapse into an ever smaller volume. The tiny but exceedingly dense object that results is called a **black hole.** Its gravity is so strong that nothing—not even light—can escape it.

SUBTOPIC D
GALAXIES AND THE UNIVERSE

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; D.1, D.3, D.4

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Earth and Space Science

D.1	Energy in the Earth system
D.3	Origin and evolution of the Earth system
D.4	Origin and evolution of the universe

VOCABULARY

cosmology
steady-state theory
Big Bang theory
cosmic background radiation
inflationary model

The universe contains billions of galaxies, which have a wide variety of sizes and shapes. Studies of our own galaxy, the Milky Way, have revealed a great deal of information about its structure and formation. By combining this information with information from observations of remote galaxies, astronomers can understand how the universe looks as a whole. Clues from remote galaxies have also led to competing models of how the universe formed and what its fate will be.

The Milky Way

The Milky Way is a great disk made of stars that orbit a central point in the disk. Not all stars in the galaxy lie in the plane of the disk, however. Globular clusters of stars are located above and below the plane. Astronomers can estimate the distances to these clusters by identifying variable stars. Variable stars are red giants that pulsate in brightness because of the expansion and contraction of their outer layers. The pulsation period varies for different types of variable stars. For example, RR Lyrae variables have pulsation periods between 1.5 hours and 1 day, and have on average the same luminosity. Cepheid variables have pulsation periods between 1 and 100 days, and the longer a star's pulsation period is, the greater its luminosity is. Thus, by measuring a variable star's pulsation period, astronomers can calculate the star's luminosity. By comparing its luminosity to its apparent magnitude, astronomers can determine the distance to the cluster in which the star is located.

Nuclear Bulge and Halo

Measurements of variable stars indicate that the Milky Way is about 130 000 ly in diameter and that the globular clusters are orbiting a region of very high star density located about 28 000 ly from Earth. This region corresponds to the center of the Milky Way. From Earth, the direction of the galactic center is toward the constellation Sagittarius. Interstellar gas and dust in the galactic center scatter visible light, but radio waves penetrate the interstellar gas and dust. Therefore, astronomers use radio telescopes to map the galactic center. They have discovered that the center is surrounded by a nuclear bulge that protrudes above and below the galactic disk, as shown in Figure 1-22A. Outside the nuclear bulge is the halo, a spherical region where the globular clusters are located.

Spiral Arms

Winding around the galactic center are regions of stars and gas clouds called spiral arms, which lie within the galactic disk. Astronomers have mapped the locations of the spiral arms by monitoring radiation emitted by hydrogen atoms, which are concentrated in the arms. As Figure 1-22B shows, the Milky Way has four major spiral arms, named Centaurus, Sagittarius, Perseus, and Cygnus, and numerous minor arms. The Sun is located in a minor arm named Orion and is orbiting the galactic center at a speed of about 220 km/s. Given its orbital speed and its distance from the center (28 000 ly), astronomers calculate the Sun's orbital period to be about 240 million years. This means that during the 5 billion years since the Sun formed, it must have orbited the galactic center approximately 20 times.

Mass of the Milky Way

The mass that is located within the circle of the Sun's orbit through the Milky Way is about 100 billion times the mass of the Sun. However, the stars and gas clouds that orbit outside this circle are moving faster than they would if the galaxy's mass were concentrated near the galactic center.

This indicates that as much as 90 percent of the galaxy's mass is contained in the halo. The mass in the halo does not exist in the form of normal stars. Some of it probably consists of dim stellar remnants, such as white dwarfs, neutron stars, or black holes, but the remaining mass is a mystery. Astronomers refer to this unseen mass as dark matter.

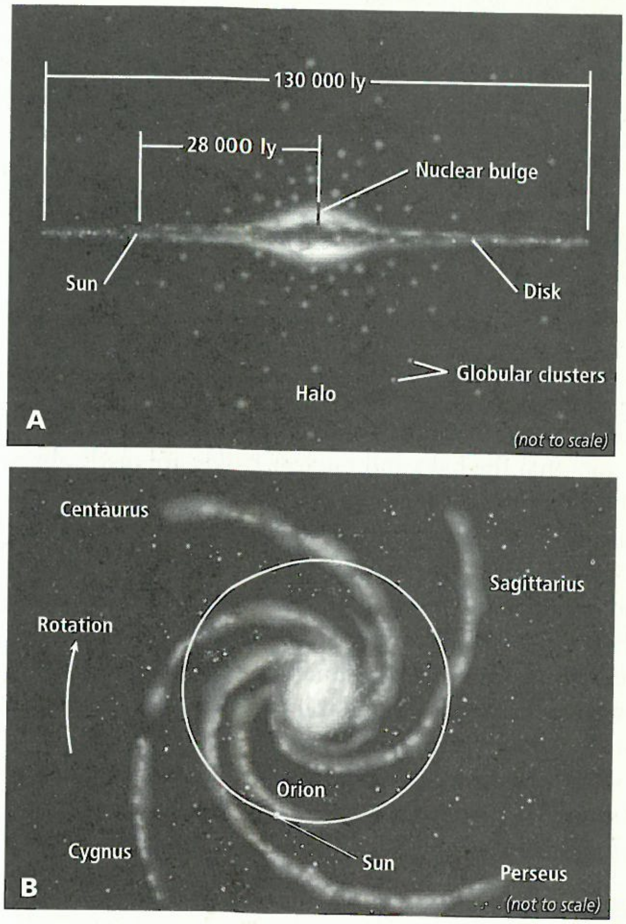


Figure 1-22 The Milky Way is a disk of stars, at the center of which is a region of high star density and interstellar gas and dust. An edge-on view of the galaxy shows the nuclear bulge around the center and the outlying halo of globular clusters (A). A view from above or below the galaxy shows the spiral arms that wind around the galactic center (B). The Sun lies in the minor arm Orion. The path of the Sun's orbit around the galactic center is marked by the circle.

Careful observations of the motions of stars orbiting close to the galactic center show that this area has about 2.6 million times the mass of the Sun, but is smaller than the solar system. Astronomers interpret these observations to mean that a supermassive black hole lies at the center, which glows brightly because of hot gas surrounding and spiraling into the black hole. This black hole probably formed early in the history of the galaxy, when the disk was still forming. Gas clouds and stars within the disk probably collided and merged into a massive object that collapsed to form the black hole.

Stars in the Milky Way

Astronomers calculate that about 100 billion stars are located in the galactic disk, which includes the spiral arms. Most star formation takes place in the disk. Consequently, stars here are relatively young, and about 2 percent of their mass consists of elements other than hydrogen and helium.

In contrast, nearly all stars in the halo and nuclear bulge are old. Their ages are estimated to be 12–14 billion years. Only about 0.1 percent of the mass of these stars is due to elements other than hydrogen and helium. There are very few stars currently forming in the halo or the nuclear bulge.

Formation and Evolution of the Milky Way

The fact that the halo and nuclear bulge are made almost exclusively of old stars suggests that these parts of the galaxy formed first. Astronomers therefore believe that the Milky Way began as a spherical cloud. The nuclear bulge represents the inner portion of the original cloud, and the oldest stars of the halo are those that formed in this early cloud stage. The cloud eventually collapsed under its own gravity, and rotation forced it into the shape of a disk. Stars that formed after this time have orbits lying in the plane of the disk. These younger stars contain a higher percentage of heavier elements because they formed from gas that had been enriched by previous generations of stars.

Other Galaxies

The existence of galaxies outside the Milky Way was confirmed in 1924, when Edwin Hubble showed that Cepheid variables in the Andromeda Nebula were much too far from Earth to be located in our own galaxy. The Andromeda Nebula then became known as the Andromeda Galaxy.

Classification of Galaxies

Hubble went on to find other galaxies and to sort them into categories according to their shapes. Disklike galaxies with spiral arms, like the Milky Way, are called spiral galaxies. These galaxies are divided into two subcategories: barred spirals and normal spirals. As the right portion of Figure 1-23 illustrates, barred spirals are denoted by the letters *SB* and have an elongated central bar from which the spiral arms extend. Normal spirals, denoted by *S*, do not have bars. Normal and barred spirals are further subdivided based on how tightly the arms are wound and on the size and brightness of the galactic center. The letter *a* designates tightly wound arms and a large, bright nucleus; *c* designates loosely wound arms and a small, dim nucleus; and *b* designates characteristics between those of *a* and *c*.

Galaxies that consist of disks without spiral arms are denoted by *S0*. When an *S0* galaxy is observed edge-on, it appears to have a band of dark dust that crosses the nuclear bulge, as the middle portion of Figure 1-23 shows.

Galaxies that are spherical or ellipsoidal are called elliptical galaxies. They are divided into eight subcategories based on how elongated they are. As the left portion of Figure 1-23 shows, spherical ellipticals are denoted by *E0;* very elongated ellipticals are denoted by *E7;* and ellipticals with intermediate elongation are denoted by the letter *E* followed by a numeral from *1* to *6*.

Some galaxies do not have distinct shapes and do not fit into any of the above categories. Such galaxies are called irregular galaxies and are denoted by *Irr*. The Large and Small Magellanic Clouds are irregular galaxies close to the Milky Way.

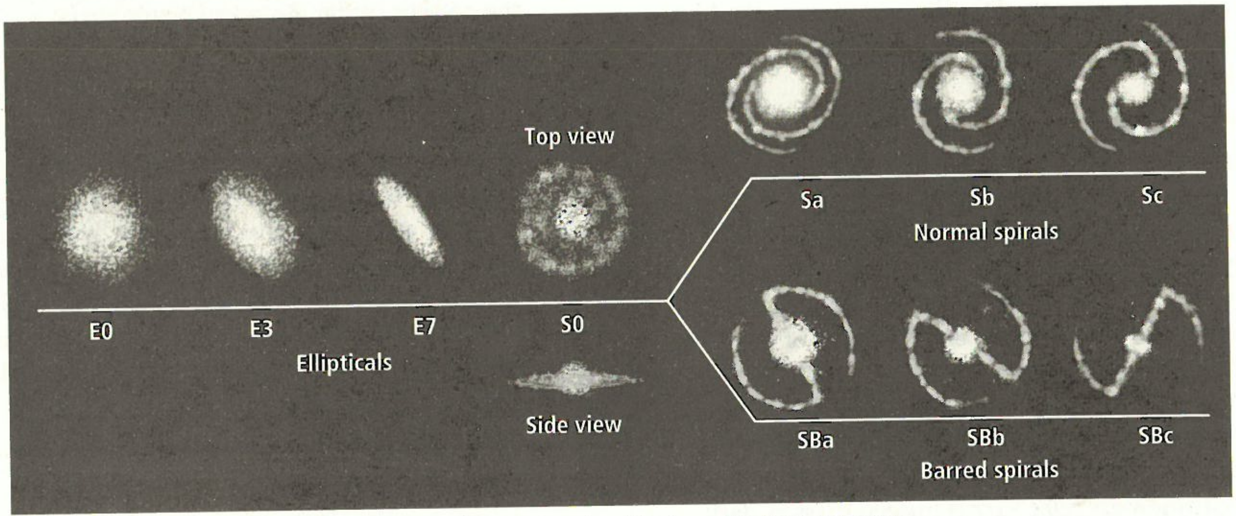


Figure 1-23 Galaxies that have distinct shapes are classified as elliptical galaxies, spiral galaxies, or S0 galaxies.

Clusters of Galaxies

Most galaxies are not spread uniformly throughout the universe but are located in clusters. The Milky Way belongs to a small cluster of galaxies called the Local Group, whose diameter is roughly 2 million ly. The Milky Way and Andromeda galaxies are the largest of the 35 known members of the Local Group. Most other galaxies in the cluster are dwarf ellipticals.

Large clusters may contain hundreds of galaxies and have diameters of about 5–30 million ly. The galaxies in the inner region of a large cluster are generally ellipticals, while a more even mix of ellipticals and spirals can be found in the outer region.

When galaxies are as close together as they are in large clusters, they may exert significant gravitational effects on one another. Collisions between galaxies can produce galaxies with strange shapes or more than one nucleus.

Clusters of galaxies are gathered into even larger groups called superclusters, which may span hundreds of millions of light-years. These gigantic formations can be observed only when astronomers map the locations of many galaxies. Superclusters have sheetlike and threadlike shapes in which the galaxies are surrounded by huge spaces devoid of galaxies.

Masses of Galaxies and Clusters

Estimates of the masses of galaxies range from about 1 million to 100 trillion times the mass of the Sun. Like the Milky Way, many galaxies have extensive halos that contain more mass than is visible. Similarly, the masses of galaxy clusters are always much larger than the sum of the visible masses of the component galaxies. These observations provide the strongest evidence that the universe contains a great amount of dark matter.

Movement of Galaxies

All galaxies are moving away from Earth, and the farther away a galaxy is, the faster it is moving away. This means that the universe is expanding, but it does not mean that Earth is at the center of the universe. In any medium that is uniformly expanding, all points are moving away from all other points.

Evidence that the universe is expanding comes from measurements of the absorption lines of galaxies. As Figure 1-24 illustrates, the absorption lines of a star or galaxy that is moving toward an observer are shifted toward shorter wavelengths, or blue-shifted. Conversely, if a star or galaxy is moving away from an observer, its absorption lines are shifted toward longer wavelengths, or red-shifted. These shifts are examples of the Doppler effect. All galaxies, except for a few that are close to Earth, have red-shifted absorption lines, indicating that they are all moving away from Earth.

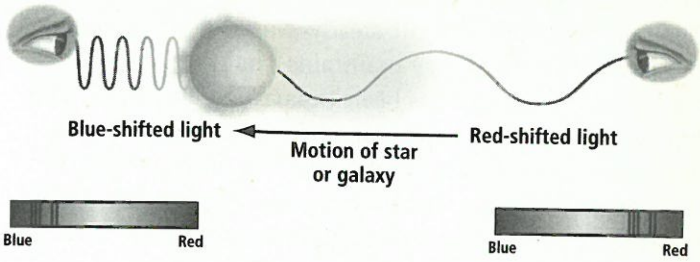


Figure 1-24 If a star or galaxy is moving toward an observer, its absorption lines are shifted toward shorter wavelengths (blue-shifted). If a star or galaxy is moving away from an observer, its absorption lines are shifted toward longer wavelengths (red-shifted).

The faster a galaxy moves, the more pronounced its red-shift is. Therefore, careful measurements of red-shifts can be used to determine the speed at which a galaxy is moving. When the speed of galaxies is plotted versus the distance from Earth, the result is a straight line. The line can be represented by the equation $v = Hd$, where v is the speed of the galaxy in kilometers per second, d is the distance to the galaxy in megaparsecs (Mpc; 1 Mpc = 10^6 pc), and H is a constant called the *Hubble constant*. H represents the slope of the line and has units of kilometers per second per megaparsec.

Years of observations of numerous galaxies with the Hubble Space Telescope indicate that the value of H is approximately 70 km/s·Mpc. Thus, galaxies located 1 Mpc from Earth are moving away from Earth at a speed of about 70 km/s, while galaxies at a distance of 10 Mpc are moving away at a speed of about 700 km/s. Astronomers can use the value of H to calculate the distances to galaxies that are so remote their distances cannot be measured accurately by other methods.

The Steady-State Theory of the Universe

The study of the universe, its current nature, its origin, and its evolution is called **cosmology.** Astronomers use a combination of observations and theoretical models in cosmology. One model that has been proposed to explain the nature of the universe is the **steady-state theory.** This theory maintains that the universe looks the same on a large scale to all observers and has always looked that way. According to the steady-state theory, the universe had no beginning and does not change with time. For this theory to make sense, new matter must be continually created and added to the universe, or else the overall density of the universe would decrease as the universe expands. This can be verified by using the equation for density, found in the *Earth Science Tables and Charts.* If mass is held constant while volume increases, the density decreases. The only way to keep density constant is to increase mass as well as volume.

The Big Bang Theory of the Universe

The main alternative to the steady-state theory is the **Big Bang theory.** This theory maintains that the universe started as a point and has been expanding ever since. The Big Bang was not an explosion into space, but rather an expansion of space that brought matter along with it. In contrast to the steady-state theory, the Big Bang theory holds that the universe had a beginning.

Cosmic Background Radiation

One testable prediction of the Big Bang theory relates to radiation in the universe. If the universe began in a highly compressed state, it would have been very hot and therefore would have been filled with radiation. That radiation should still fill the universe. When the radiation was first able to escape, it would have been in the form of visible light and ultraviolet radiation. As the universe expanded and cooled, the radiation would have shifted to longer wavelengths.

In 1965, scientists discovered a persistent, weak radio noise in the microwave portion of the electromagnetic spectrum that appeared to come from all directions in space. This noise, now known as **cosmic background radiation,** corresponds to an emitting object that has a temperature of 2.735 K (–270°C). This temperature is very close to that predicted by the Big Bang theory, suggesting that the radiation came from the Big Bang. Since the discovery of cosmic background radiation, extensive observations have confirmed that it matches other properties of the predicted leftover radiation from the early phase of the expansion of the universe. The steady-state theory does not predict such radiation, which is why most astronomers do not accept the steady-state theory.

The Possible Fate of the Universe

According to the Big Bang theory, the outward momentum of the expanding universe is opposed by the inward force of gravity due to the matter in the universe. The force of gravity acts to slow the expansion. What ultimately will happen depends on whether momentum or gravity is stronger.

There are three possible outcomes: an open universe, which will continue to expand forever; a closed universe, in which the expansion of the universe will turn into a contraction; and a flat universe, in which the expansion will slow to a halt in an infinite amount of time, but which will never turn into a contraction. All three outcomes are based on the premise that the rate of expansion has decreased since the beginning of the universe.

Testing the Predictions

One factor that will determine the outcome is the average density of matter in the universe. Astronomers have calculated that a critical density of about 10^{-26} kg/m^3 is the dividing point between an open and a closed universe. If the average density of the universe is less than the critical density, the universe is open. If the average density is greater than the critical density, the universe is closed. If the average density equals the critical density, the universe is flat. Observations of visible galaxies reveal an average density that is much less than the critical density. However, the evidence that a great amount of dark matter exists in the universe raises the possibility that the average density may be close to the critical density.

Another approach to determining the fate of the universe is to measure how much its expansion has slowed so far. This approach can be accomplished by comparing the expansion rate today with the rate long ago. The rate long ago can be estimated from the red-shifts of the most remote galaxies. These calculations indicate that the rate of expansion slowed for a while but is now increasing. Astronomers are not sure what is causing this increase in the rate of expansion.

The Inflationary Universe Model

A version of the Big Bang theory combines the increasing rate of expansion of the universe and the observed density of the universe, including an allowance for dark matter. This version, called the **inflationary model,** maintains that the universe began as a fluctuation in a vacuum and expanded very rapidly during a small fraction of a second after the Big Bang. It then settled into a more gradual expansion.

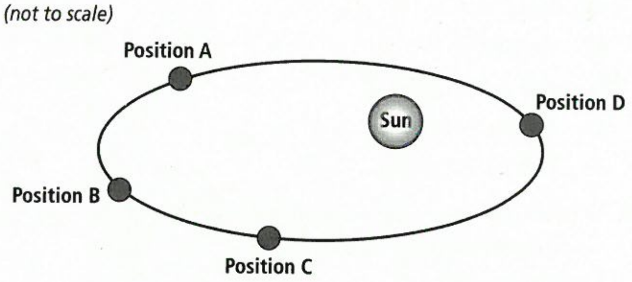
The Hubble constant, H, can be used to calculate the amount of time since the expansion started—in other words, the age of the universe. That time is simply $1/H$. Recall that the value of H is approximately 70 km/s·Mpc. Since 1 Mpc = 3.1×10^{19} km, $1/H = 4.4 \times 10^{17}$ s, or about 14 billion years. Corrections must be made for the more rapid expansion just after the Big Bang and for the increasing rate of expansion now. These corrections put the age of the universe at about 13 billon years. This value agrees well with the estimated age of the Milky Way—between 12 and 14 billion years—which is based on the ages of the oldest star clusters. Refinements to these measurements are still being made.

QUESTIONS FOR SUBTOPIC A

Type A

1. Which statement provides the best evidence that Earth revolves around the Sun?
   - **a.** The Sun follows an apparent daily path, rising in the east and setting in the west.
   - **b.** A Foucault pendulum appears to shift its direction of swing in a predictable manner.
   - **c.** The stars appear to follow circular paths around the north Star (Polaris).
   - **d.** The seasons of spring, summer, fall, and winter repeat in a pattern.

2. The diagram below shows the elliptical orbit of a hypothetical planet. At which point in this planet's orbit is the planet moving the fastest?



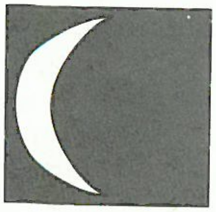
   - **a.** Position A
   - **b.** Position B
   - **c.** Position C
   - **d.** Position D

3. Which of the following is caused by Earth's rotation?
   - **a.** the year
   - **b.** day and night
   - **c.** the seasons
   - **d.** Earth's tilt

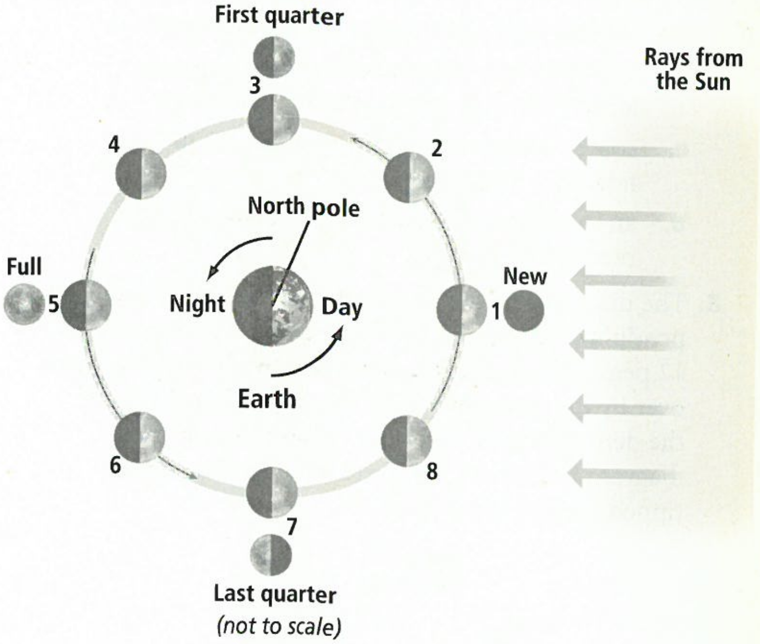
4. What causes tides?
   - **a.** gravitational attraction of the Moon and the Sun
   - **b.** rotation of the Moon on its axis
   - **c.** movement of Earth's tectonic plates
   - **d.** Coriolis effect

Type B

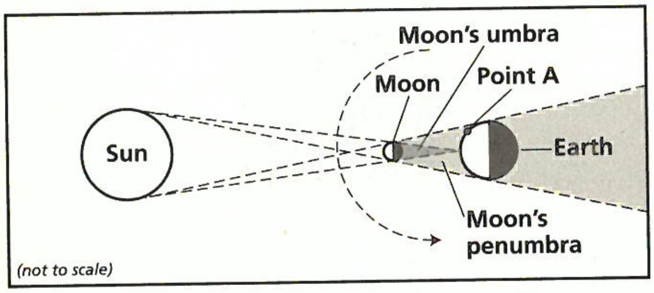
5. An observer on Earth sees the crescent phase of the Moon, as shown below.



The diagram below shows positions 1–8 of the phases of the Moon. Which position number shows the observed crescent phase?
   - **a.** Position 6
   - **b.** Position 3
   - **c.** Position 8
   - **d.** Position 4



6. The diagram below shows the positions of the Sun, Earth, and the Moon during a solar eclipse. What would someone standing at Point A on Earth see in the sky?



- **a.** total lunar eclipse
- **b.** waning gibbous moon
- **c.** partial solar eclipse
- **d.** total solar eclipse

7. If Earth's tilt increased from 23.5°to 33.5°, the result would be

- **a.** shorter days and longer nights at the equator.
- **b.** less difference between winter and summer temperatures in the northern hemisphere.
- **c.** colder winters and warmer summers in the northern hemisphere.
- **d.** an increase in the amount of solar radiation received by Earth.

8. The diagrams below represent two views of a Foucault pendulum in the northern hemisphere with a ring of 12 pegs at the base. Diagram II shows two pegs tipped over by the swinging pendulum at the beginning of the demonstration. On your answer paper, draw a diagram that shows the next two pegs that will be tipped over by the pendulum.

Diagram I
(side view)

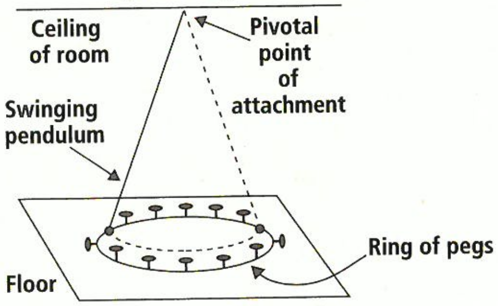
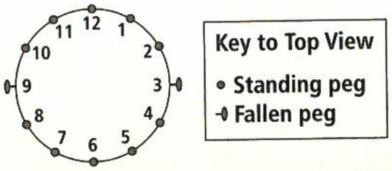
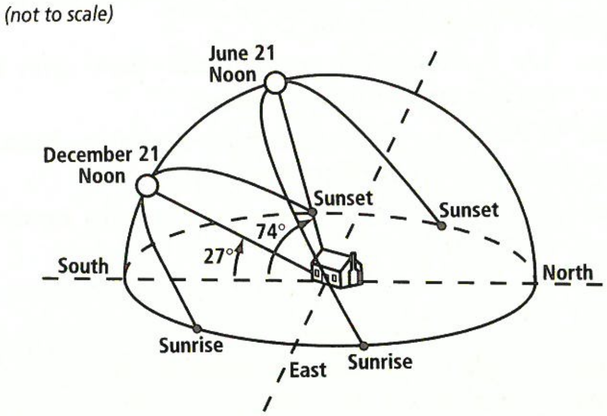


Diagram II
(top view)



Type C

Base your answers to questions 9 through 11 on the diagram below.



9. What is the most likely location of the house shown in the diagram?

- **a.** Australia
- **b.** the north pole
- **c.** South America
- **d.** North America

10. Which factor is one cause of the difference in noontime altitude of the Sun on June 21 and December 21?

- **a.** the tilt of Earth's axis
- **b.** the Sun's apparent diameter
- **c.** Earth's changing distance from the Sun
- **d.** the Sun's period of rotation

11. On which side of the house should a solar collector be installed to absorb the greatest amount of solar energy?

- **a.** north
- **b.** south
- **c.** east
- **d.** west

QUESTIONS FOR SUBTOPIC B

Type A

12. Our solar system formed about 5 billion years ago when

- **a.** a large planet broke into many pieces.
- **b.** a cloud of interstellar gas began to condense.
- **c.** stars collided with one another.
- **d.** Jupiter formed as the largest planet.

13. What began to occur when the newly formed Sun became a star?

a. The Sun cooled.

b. Several older planets in the solar system were swallowed up.

c. Nuclear fusion began in the Sun's core.

d. The Sun began to convert helium into oxygen.

14. Which of these planets is the densest?

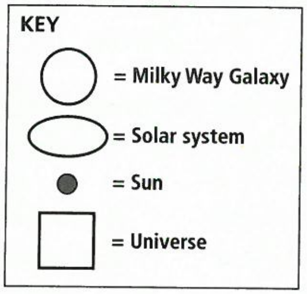
a. Earth

b. Jupiter

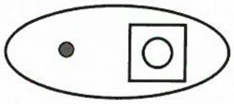
c. Saturn

d. Uranus

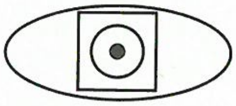
15. The symbols below represent the Milky Way Galaxy, the solar system, the Sun, and the universe.



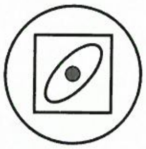
Which arrangement of these symbols is an accurate representation?



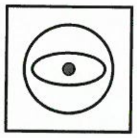
a.



c.



b.



d.

Type B

Some questions may require the use of the *Earth Science Tables and Charts.*

16. An object falls to Earth, making a large impact crater. The object left after the impact is probably a

a. meter.

b. meteor.

c. meteoroid.

d. meteorite.

17. The circle below represents Earth.

The four circles below represent the sizes of four planets.

a.

b.

c.

d.

Which lettered circle best represents the size of Mars?

Base your answers to questions 18 through 20 on the tables below. Table 1 shows the average distance from the Sun in astronomical units (AU) and the average orbital speed in kilometers per second (km/s) of the nine planets in our solar system. Table 2 lists five large asteroids and their average distances from the Sun.

Table 1

Planet	Average distance from Sun (AU)	Average orbital speed (km/s)
Mercury	0.4	48.0
Venus	0.7	35.0
Earth	1.0	30.0
Mars	1.5	24.0
Jupiter	5.2	13.0
Saturn	9.6	10.0
Uranus	19.0	7.0
Neptune	30.0	5.1
Pluto	39.0	4.7

Table 2

Asteroid	Average distance from Sun (AU)
Ceres	2.8
Pallas	2.8
Vesta	2.4
Hygiea	3.2
Juno	2.7

18. On the grid provided on your answer paper, plot the average orbital speed versus the average distance from the Sun for each of the nine planets listed in Table 1.

19. State the relationship between a planet's average distance from the Sun and the planet's average orbital speed.

20. The orbits of the asteroids listed in Table 2 are located between two adjacent planetary orbits. State the names of the two planets.

Type C

Base your answers to questions 21–23 on the article below.

> **Two Probes Hit Their Targets**
>
> Scientists at NASA's Jet Propulsion Laboratory (JPL) announced today that the second of two probes launched to study planets in our solar system has reached its destination. The Kuiper probe, which has been on its journey for several years, survived the trip through the asteroid belt and went into orbit around Planet A early this morning. Part of the probe will remain in orbit just above the top of the planet's thick hydrogen and helium atmosphere. It will send back close-up images of the planet's atmosphere and rings. A second part of the probe is expected to detach and descend toward the planet, passing through its atmosphere and into its fluid layers. The probe will send back data on temperature, wind speed, and density as it descends.
>
> Six months ago, scientists celebrated the successful arrival of the Oort probe at Planet B. Oort, which is similar in design to Kuiper, was launched much later than Kuiper and traveled a shorter distance to reach its destination. Like the Kuiper probe, the Oort probe split, leaving an orbiter circling above the thick carbon dioxide atmosphere of Planet B. The second part of the probe made a soft landing on the planet's solid surface, sending back photographs and data on heat and pressure before JPL scientists lost contact with it several weeks later.

21. Was the Kuiper probe heading toward or away from the Sun? What evidence supports your answer?

22. Did the Kuiper probe go to a terrestrial or a gas giant planet? Name all planets that meet the conditions listed for Planet A and tell how you decided on these planets.

23. Did the Oort probe reach a terrestrial planet or a gas giant planet? Which planet did the Oort probe reach? Use evidence from the article to name Planet B.

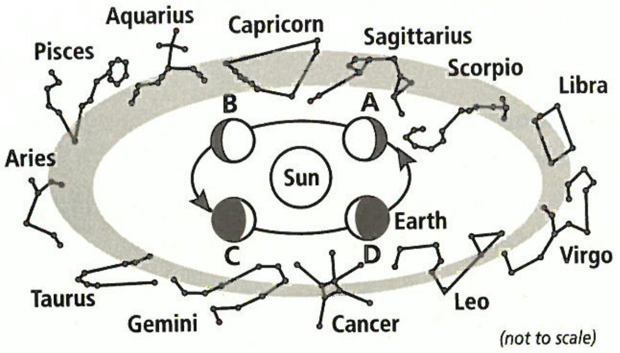
QUESTIONS FOR SUBTOPIC C

Type A

24. Which elements make up most of the mass of the Sun?

- **a.** oxygen and carbon
- **b.** hydrogen and helium
- **c.** carbon and hydrogen
- **d.** helium and oxygen

Base your answers to questions 25 and 26 on the diagram below. The diagram shows 12 constellations visible in the night sky. An observer in the northeastern United States could view these constellations over the course of one year. Different positions of Earth are represented by the letters A through D. The arrows represent the direction of Earth's motion around the Sun.



(not to scale)

25. Which constellations are visible at midnight to an observer in the northeastern United States when Earth is at position D?

- **a.** Aries and Taurus
- **b.** Pisces and Libra
- **c.** Leo and Virgo
- **d.** Aquarius and Scorpio

26. The constellations observed from the northeastern United States when Earth is at position A are different from the constellations observed when Earth is at position C because

- **a.** Earth moves in its orbit.
- **b.** Earth is tilted on its axis.
- **c.** the lengths of day and night are different.
- **d.** the stars move around Earth as shown by star trails.

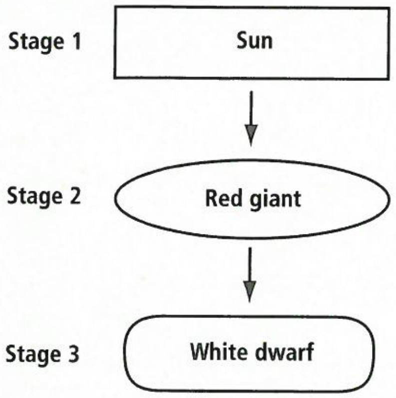
Type B

Base your answers to questions 27 and 28 on the *Luminosity and Temperature of Stars* graph in the *Earth Science Tables and Charts.* The graph shows the temperature and relative brightness of many stars observed from Earth.

27. The Sun is classified as a

- **a.** main sequence star with a temperature of approximately 4000°C and a luminosity of 100.
- **b.** main sequence star with a temperature of approximately 6000°C and a luminosity of 1.
- **c.** white dwarf star with a temperature of approximately 10 000°C and a luminosity of 0.01.
- **d.** blue supergiant star with a temperature of approximately 20 000°C and a luminosity of 700 000.

28. Stars are believed to undergo evolutionary changes over millions of years. The flowchart below shows stages of predicted changes in the Sun.



According to the flowchart above, the Sun will become

- **a.** hotter and brighter in stage 2, then cooler and dimmer in stage 3.
- **b.** cooler and dimmer in stage 2, then hotter and brighter in stage 3.
- **c.** hotter and dimmer in stage 2, then cooler and brighter in stage 3.
- **d.** cooler and brighter in stage 2, then hotter and dimmer in stage 3.

29. Two stars, X and Y, are both visible from Earth with the unaided eye. X has an apparent magnitude of +1.3, and Y has an apparent magnitude of +4.3. Which star appears brighter from Earth, and how much brighter does it appear than the other star?

Type C

Some questions may require the use of the *Earth Science Tables and Charts.*

30. Contrast the temperature and luminosity of blue supergiants and red dwarfs.

31. Star A and star B are main-sequence stars. If star A has a mass equal to five times the mass of the Sun and star B has a mass equal to ten times the mass of the Sun, what is each star's ultimate fate?

QUESTIONS FOR SUBTOPIC C

Type A

32. In which list are celestial features correctly shown in order of increasing size?

- **a.** galaxy → solar system → universe → planet
- **b.** solar system → galaxy → planet → universe
- **c.** planet → solar system → galaxy → universe
- **d.** universe → galaxy → solar system → planet

33. The oldest stars in the Milky Way are located in the

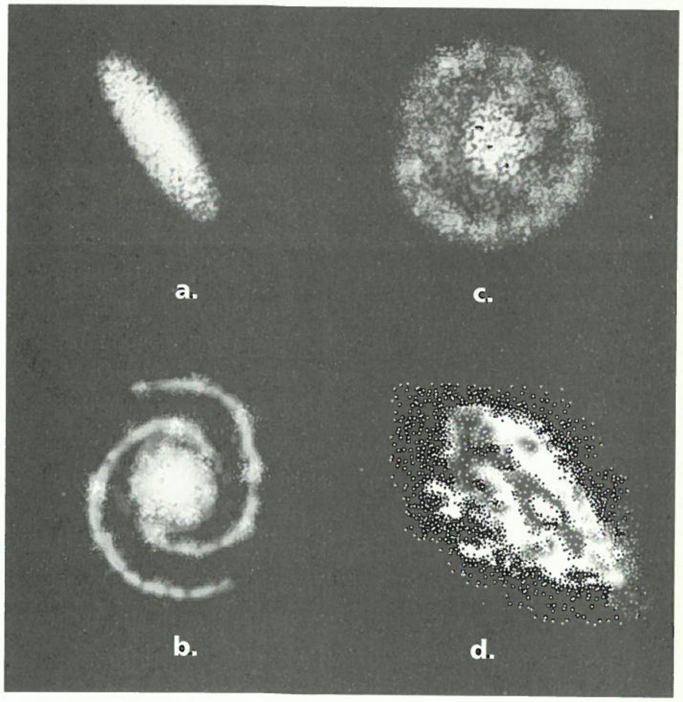
- **a.** nuclear bulge and halo.
- **b.** galactic disk.
- **c.** major spiral arms.
- **d.** minor spiral arms.

34. The Big Bang theory is supported by the detection of weak radiation, called cosmic background radiation, in the form of

- **a.** visible light.
- **b.** ultraviolet radiation.
- **c.** infrared radiation.
- **d.** microwaves.

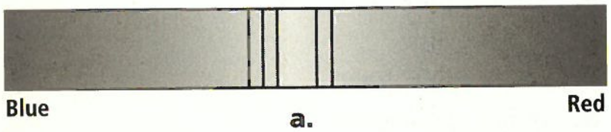
Type B

35. Which of the following drawings most accurately represents the shape of the Milky Way?

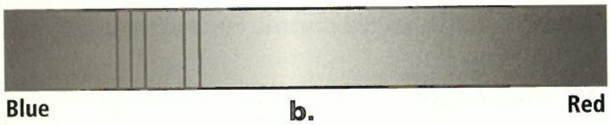


36. The diagram below shows the absorption spectrum of galaxy X as detected by an observer on Earth. Galaxy X is 1 billion ly from Earth.

Which spectrum below could be detected by an observer of galaxy X if the observer is on a planet that is 5 billion ly from galaxy X? Galaxy X is moving away from Earth and the other planet.

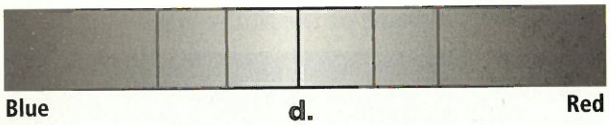


a.



b.

c.



d.

Type C

37. How do red-shift measurements of the absorption lines of galaxies support the Big Bang theory?