Chapter 15

Stars, Galaxies, and the Universe

CALIFORNIA Standards Preview

S 8.2 Unbalanced forces cause changes in velocity. As a basis for understanding this concept:

- **g.** Students know the role of gravity in forming and maintaining the shapes of planets, stars, and the solar system.

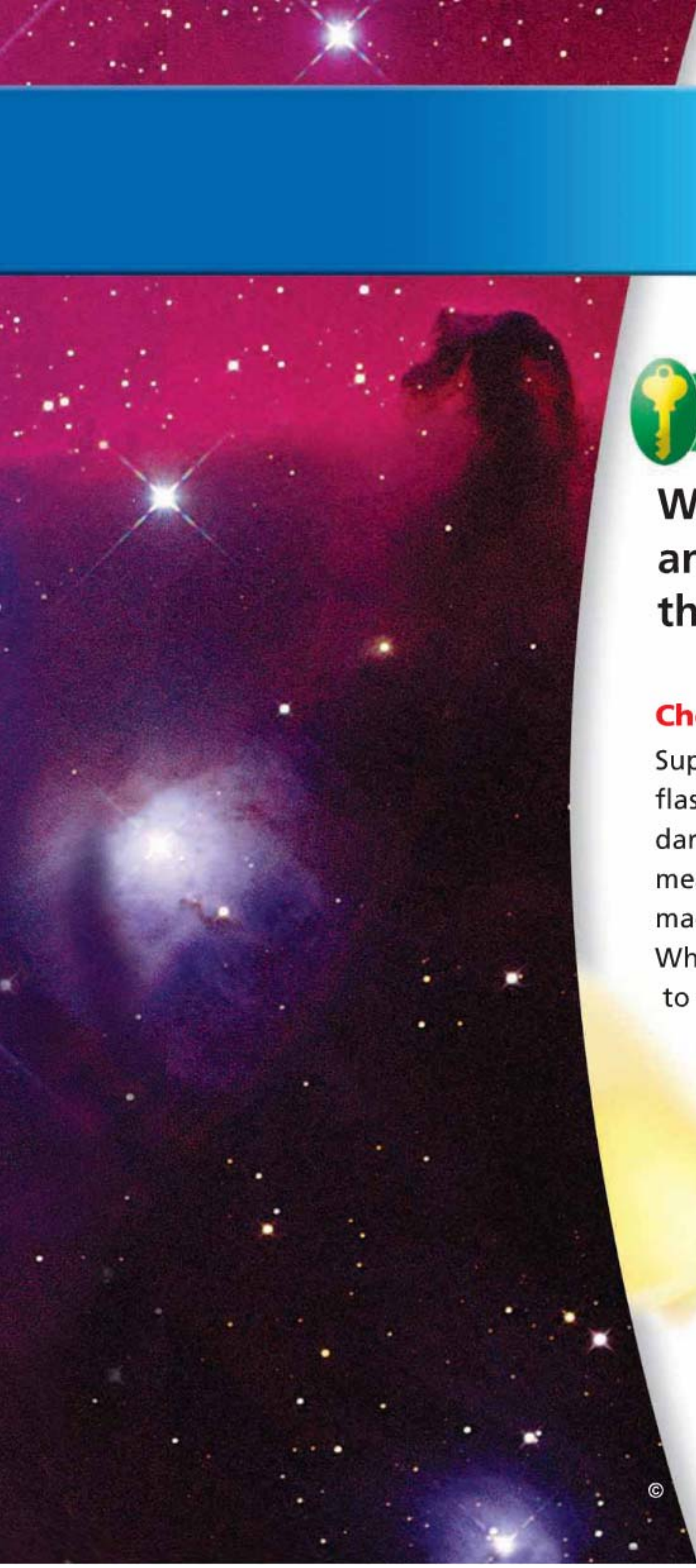
S 8.4 The structure and composition of the universe can be learned from studying stars and galaxies and their evolution. As a basis for understanding this concept:

- **a.** Students know galaxies are clusters of billions of stars and may have different shapes.
- **b.** Students know that the Sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.
- **c.** Students know how to use astronomical units and light years as measures of distance between the Sun, stars, and Earth.
- **d.** Students know that stars are the source of light for all bright objects in outer space and that the Moon and planets shine by reflected sunlight, not by their own light.

S 8.9 Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

- **b.** Evaluate the accuracy and reproducibility of data.

The dark Horsehead Nebula is visible against red-glowing hydrogen gas.



Video Preview

Discovery Channel School

Stars, Galaxies, and the Universe

Focus on the **BIG Idea** S 8.4.b

What is the structure and composition of the universe?

Check What You Know

Suppose you shine the beam of a flashlight against the wall of a darkened room. You then measure the size of the circle made by the beam on the room. What do you think would happen to the size and brightness of the circle if you moved closer to the wall? Farther from the wall? Explain your answer.

Build Science Vocabulary

The images shown here represent some of the key terms in this chapter. You can use this vocabulary skill to help you understand the meaning of some key terms in this chapter.

Vocabulary Skill

Suffixes

A suffix is a letter or group of letters added to the end of a word to change its meaning and often its part of speech. For example, the suffix *-ory* means "a place for." The suffix *-ory* added to the verb *observe* forms the noun *observatory*. An *observatory* is a place used to *observe* stars and planets through a telescope.

In this chapter, you will learn key terms that have the suffixes *-al*, *-ic*, *-ness*, and *-ory*.

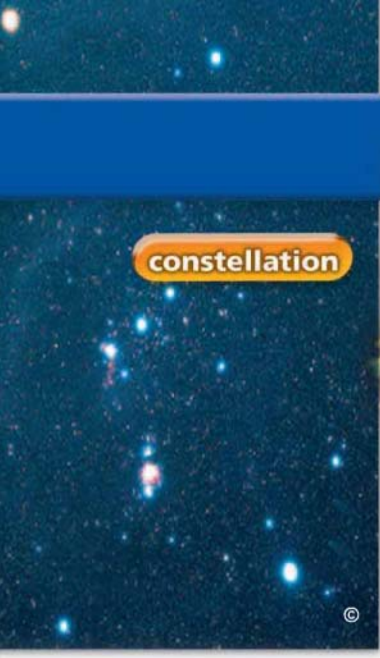
Suffix	Meaning	Part of Speech	Key Terms
-al	relating to	adjective	optical, elliptical
-ic	relating to	adjective	electromagnetic, scientific
-ness	state or quality of	noun	brightness
-ory	a place for	noun	observatory

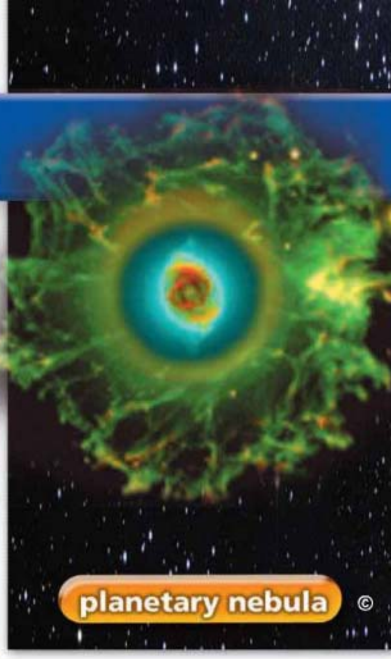
Apply It!

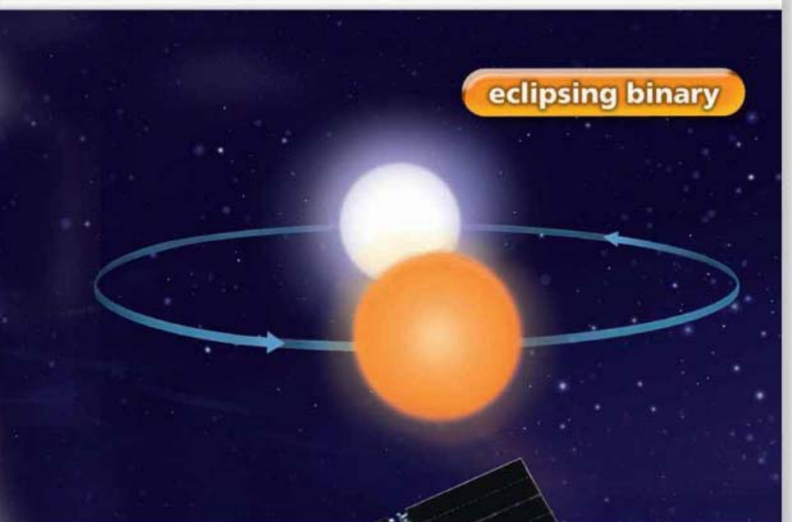
Complete the sentence below with the correct form of the word (*science/scientific*).

A theory in __________ is a well-tested concept that is based on ________ evidence.

When you come across an unfamiliar word, look at the suffix to help you determine its meaning. Then check the definition in the glossary or a dictionary.







Chapter 15 Vocabulary

Section 1 (page 590)

- electromagnetic radiation
- visible light
- wavelength
- spectrum
- optical telescope
- refracting telescope
- convex lens
- reflecting telescope
- radio telescope
- observatory

Section 2 (page 598)

- constellation
- spectograph
- apparent brightness
- absolute brightness
- light-year
- parallax
- Hertzsprung-Russell diagram
- main sequence

Section 3 (page 608)

- nebula
- protostar
- planetary nebula
- white dwarf
- supernova
- neutron star
- pulsar
- black hole

Section 4 (page 614)

- binary star
- eclipsing binary
- open cluster
- globular cluster
- galaxy
- quasar
- spiral galaxy
- elliptical galaxy
- irregular galaxy
- universe
- scientific notation

Section 5 (page 622)

- big bang
- Hubble's law
- cosmic background radiation
- solar nebula
- planetesimal
- dark matter
- dark energy

Interactive Textbook

Build Science Vocabulary
Online
Visit: PHSchool.com
Web Code: cxj-4150

How to Read Science

Reading Skill

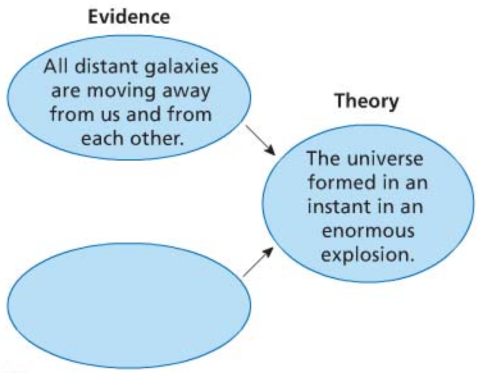
Identify Supporting Evidence

Science textbooks often describe the scientific evidence that supports a theory or hypothesis. Remember that scientific evidence includes data and facts that have been confirmed by observation or experiments.

You can use a graphic organizer like the one below to help you understand how supporting evidence is related to a theory. When you draw a graphic organizer, include

- a title
- supporting evidence on the left
- the hypothesis or theory on the right

This chapter discusses the theory of how the universe was formed.



Apply It!

1. What is a good title for this graphic organizer?

2. What kind of information would you include in the ovals on the left?

As you read Section 5, complete the graphic organizer explaining the big bang theory.

Lab zone

Standards Investigation

S 8.4.b, 8.4.d

Star Stories

Many years ago, people created stories to explain the patterns of stars they saw in the sky. In your investigation, you'll learn how the names of these constellations reflect the cultures of the people who named them.

Your Goal

To complete this investigation you will

- learn the star patterns of at least three constellations
- research the myths that gave one constellation its name
- create your own star myth

Plan It!

Begin by making a list of constellations that you have heard about. Then use the star charts in Appendix E on pages 656 and 657 to locate constellations in the night sky. The constellations that are visible change from season to season and over the course of a night. So read the instructions in the appendix carefully to learn how to use the star charts. Once you are familiar with the charts, find a safe, unobstructed area to view the stars. Make a sketch of the constellations that you locate.

Choose one constellation, and research the myths that gave it its name. Draw a new picture for the star pattern in your constellation, and choose a name for it. Finally, write a story about your constellation. At the end of the chapter, you will present your constellation and a story that explains its name.

Section 1

• Tech & Design •

Telescopes

CALIFORNIA Standards Focus

S 8.4.d Students know that stars are the source of light for all bright objects in outer space and that the Moon and planets shine by reflected sunlight, not by their own light.

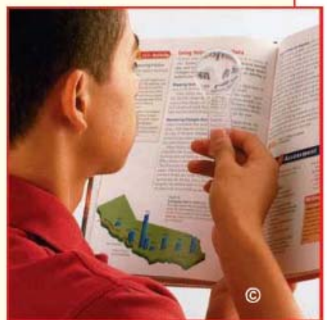
- What are the regions of the electromagnetic spectrum?
- What are telescopes and how do they work?
- Where are most large telescopes located?

Key Terms

- electromagnetic radiation
- visible light
- wavelength
- spectrum
- optical telescope
- refracting telescope
- convex lens
- reflecting telescope
- radio telescope
- observatory

Lab zone **Standards Warm-Up**

How Does Distance Affect an Image?



1. Hold a plastic hand lens about 7 cm away from your eye and about 5 cm away from a printed letter on a page. Move the lens slowly back and forth until the letter is in clear focus.
2. Keep the letter about 5 cm from the lens as you move your eye back to about 20 cm from the lens. Then, keeping the distance between your eye and the lens constant, slowly move the object away from the lens.

Think It Over

Observing What did the letter look like through the lens in Step 1 compared with how it looked without the lens? How did the image change in Step 2?

Ancient peoples often gazed up in wonder at the many points of light in the night sky. But they could see few details with their eyes alone. It was not until the invention of the telescope in 1608 that people could observe objects in the sky more closely. Recall that a telescope is a device that makes distant objects appear to be closer. The telescope revolutionized astronomy. Scientists now had a tool that allowed them to see many objects in space for the first time.

Although Galileo was not the first person to use a telescope, he soon made it famous as he turned his homemade instrument to the sky. With his telescope, Galileo saw things that no one had even dreamed of. He was the first to see sunspots, Saturn's rings, and the four large moons of Jupiter. Galileo could see fine details, such as mountains on the moon, which cannot be seen clearly by the unaided eye.

Since Galileo's time, astronomers have built ever larger and more powerful telescopes. These telescopes have opened up a whole universe of wonders that would have amazed even Galileo.

Galileo's ▶ telescope

Electromagnetic Radiation

To understand how telescopes work, it's useful to understand the nature of electromagnetic radiation. Light is a form of **electromagnetic radiation**, or energy that can travel through space in the form of waves. Stars produce such radiation during the process of nuclear fusion. You can see stars when the light that they produce reaches your eyes.

Forms of Radiation All the colors that you can see are **visible light**. Visible light is just one of many types of electromagnetic radiation. Many objects give off radiation that you can't see. For example, in addition to their reddish light, the glowing coils of an electric heater give off infrared radiation, which you feel as heat. Radio transmitters produce radio waves that carry signals to radios and televisions. Objects in space give off all types of electromagnetic radiation.

The Electromagnetic Spectrum As shown in Figure 1, the distance between the crest of one wave and the crest of the next wave is called a **wavelength**. Visible light has very short wavelengths, less than one millionth of a meter. Some electromagnetic waves have even shorter wavelengths. Other waves have much longer wavelengths, even several meters long.

If you shine white light through a prism, the light spreads out to make a range of different colors with different wavelengths, called a **spectrum**. The spectrum of visible light is made of the colors red, orange, yellow, green, blue, indigo, and violet. **The electromagnetic spectrum includes the entire range of radio waves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.**

Reading Checkpoint What is electromagnetic radiation?

Go Online SCI LINKS NSTA

For: Links on telescopes
Visit: www.SciLinks.org
Web Code: scn-0641

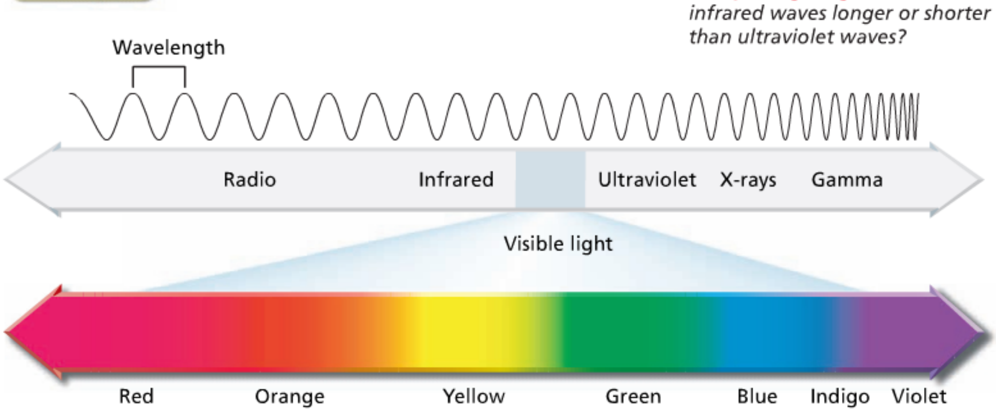


Figure 1
The Electromagnetic Spectrum
The electromagnetic spectrum ranges from long-wavelength radio waves through short-wavelength gamma rays.
Interpreting Diagrams *Are infrared waves longer or shorter than ultraviolet waves?*

Types of Telescopes

On a clear night, your eyes can see at most a few thousand stars. But with a telescope, you can see many millions. Why? The light from stars spreads out as it moves through space, and your eyes are too small to gather much light.

Telescopes are instruments that collect and focus light and other forms of electromagnetic radiation. Telescopes make distant objects appear larger and brighter. A telescope that uses lenses or mirrors to collect and focus visible light is called an **optical telescope.** The two major types of optical telescopes are refracting telescopes and reflecting telescopes.

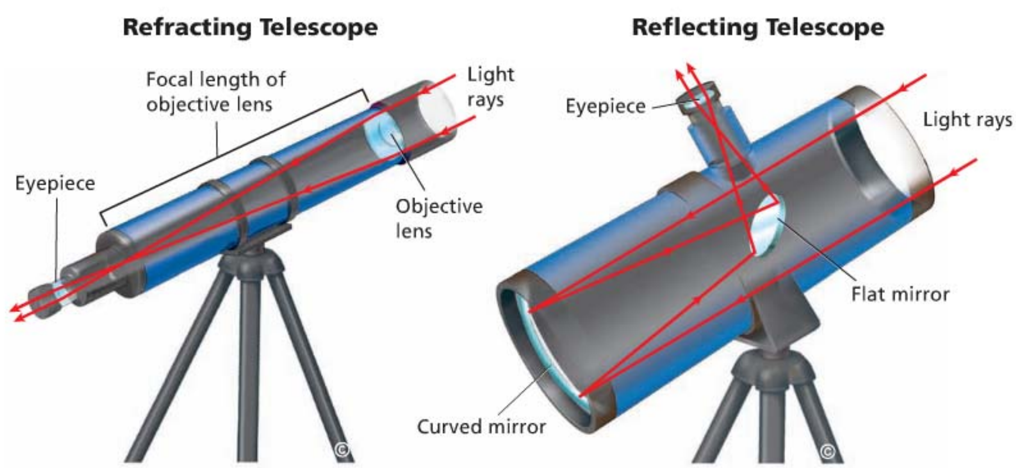
Modern astronomy is based on the detection of forms of electromagnetic radiation besides visible light. Non-optical telescopes collect and focus different types of electromagnetic radiation, just as optical telescopes collect visible light.

Refracting Telescopes A **refracting telescope** uses convex lenses to gather and focus light. A **convex lens** is a piece of transparent glass, curved so that the middle is thicker than the edges.

Figure 2 shows a simple refracting telescope. This telescope has two convex lenses, one at each end of a long tube. Light enters the telescope through the large objective lens at the top. The objective lens focuses the light at a certain distance from the lens. This distance is the focal length of the lens. The larger the objective lens, the more light the telescope can collect. This makes it easier for astronomers to see faint objects.

The smaller lens at the lower end of a refracting telescope is called the eyepiece. The eyepiece magnifies the image produced by the objective lens.

FIGURE 2
Refracting and Reflecting Telescopes
A refracting telescope uses convex lenses to focus light. A reflecting telescope has a curved mirror in place of an objective lens.



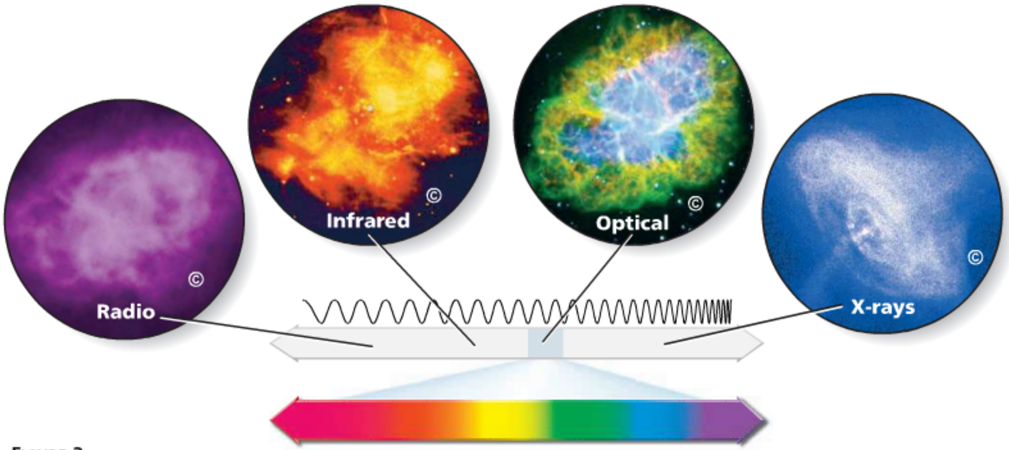


FIGURE 3
Four Views of the Crab Nebula
Different types of telescopes collect electromagnetic radiation at different wavelengths. Astronomers are able to learn a great deal about the Crab Nebula by examining these different images. The images are shown at different scales.

Reflecting Telescopes In 1668, Isaac Newton built the first reflecting telescope. A **reflecting telescope** uses a curved mirror to collect and focus light. Like the objective lens in a refracting telescope, the curved mirror in a reflecting telescope focuses a large amount of light onto a small area. The larger the mirror, the more light the telescope can collect. The largest optical telescopes today are all reflecting telescopes.

Radio Telescopes Devices used to detect radio waves from objects in space are called **radio telescopes.** Most radio telescopes have curved, reflecting surfaces—up to 305 meters in diameter. These surfaces focus radio waves the way the mirror in a reflecting telescope focuses light waves. The surfaces concentrate the faint radio waves from space onto small antennas like those on radios. As with optical telescopes, the larger a radio telescope is, the more radio waves it can collect.

Other Telescopes Some telescopes detect infrared radiation, which has longer wavelengths than visible light but shorter wavelengths than radio waves. There are also telescopes that detect the shortest wavelengths—ultraviolet radiation, X-rays, and gamma rays.

Reading Checkpoint **Who built the first reflecting telescope?**

Lab zone Try This Activity

Locating Radio Waves

You can use an umbrella to focus radio waves.

1. Line the inside of an open umbrella with aluminum foil.
2. Turn on a small radio and tune it to a station.
3. Move the radio up and down along the umbrella handle. Find the position where the station is clearest. Radio waves reflecting off the foil focus at this point. Tape the radio to the handle.
4. Hold the umbrella at different angles. At which angle is the station the clearest?

Inferring In which direction do you think the radio station's transmitter is located? Explain.

Observatories

In general, an **observatory** is a building that contains one or more telescopes. But some observatories are located in space. **Many large observatories are located on mountaintops or in space.** Why? Earth's atmosphere makes objects in space look blurry. The sky on some mountaintops is clearer than at sea level and is not brightened much by city lights. Unlike optical telescopes, radio telescopes don't need to be on mountaintops because many radio waves can pass through the atmosphere.

One of the best observatory sites on Earth is on the top of Mauna Kea, a dormant volcano in Hawaii. Mauna Kea is so tall that it is above 40 percent of Earth's atmosphere.

• Tech & Design in History •

Development of Modern Telescopes

During the last century, astronomers have built larger telescopes, which can collect more visible light and other types of radiation. Today's astronomers use tools that could not have been imagined 100 years ago.

1897 Yerkes Telescope
The 1-meter-diameter telescope at Yerkes Observatory in Wisconsin is the largest refracting telescope ever built. Because its main lens is so large, the Yerkes telescope can collect more light than any other refracting telescope.

1931 Beginning of Radio Astronomy
Karl Jansky, an American engineer, was trying to find the source of static that was interfering with radio communications. Using a large antenna, he discovered that the static was radio waves given off by objects in space. Jansky's accidental discovery led to the beginning of radio astronomy.

1963 Arecibo Radio Telescope
This radio telescope in Puerto Rico was built in a natural bowl in the ground. It is 305 meters in diameter, the largest radio telescope in existence.

1900 1940 1960

Advanced Telescopes Today, many large optical telescopes are equipped with systems that significantly improve the quality of their images. Optical telescopes on Earth equipped with such systems are able to produce images of small regions of the sky that rival those of optical telescopes based in space.

Some new telescopes are equipped with computer systems that correct images for problems such as telescope movement and changes in air temperature or mirror shape. Other advanced telescopes use lasers to monitor conditions in the atmosphere. The shape of the telescope's mirror is automatically adjusted thousands of times each second in response to changes in the atmosphere.

Writing in Science

Research and Write
Research one of these telescopes or another large telescope. Create a publicity brochure in which you describe the telescope's features, when and where it was built, and what types of research it is used for.

1980 Very Large Array
The Very Large Array is a set of 27 radio telescopes in New Mexico. The telescopes can be moved close together or far apart. The telescopes are linked, so they can be used as if they were one giant radio telescope 25 kilometers in diameter.

1990 Hubble Space Telescope
The Hubble Space Telescope views objects in space from high above the atmosphere. As a result, it can produce extremely sharp images.

2003 Spitzer Space Telescope
The Spitzer Space Telescope is a powerful 0.85-meter diameter telescope that surveys the sky in the infrared range of the spectrum.

1980 2000 2020

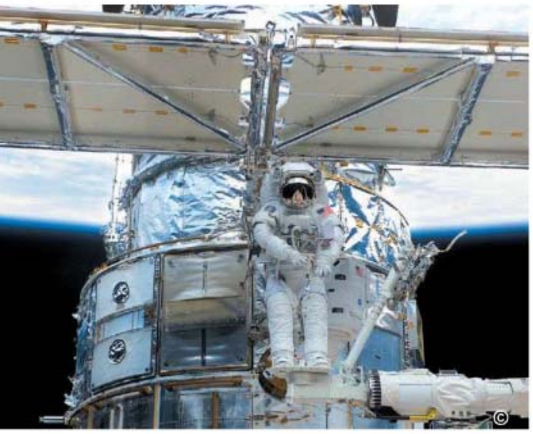


FIGURE 4
Repairing Hubble
Astronauts have repaired and upgraded the Hubble Space Telescope on several occasions.

Telescopes in Space X-rays, gamma rays, and most ultraviolet radiation are blocked by Earth's atmosphere. To detect these wavelengths, astronomers have placed telescopes in space. Some space telescopes are designed to detect visible light or infrared radiation, since Earth's atmosphere also interferes with the transmission of these forms of radiation.

The Hubble Space Telescope is a reflecting telescope with a mirror 2.4 meters in diameter. Because the Hubble telescope orbits Earth above the atmosphere, it can produce very detailed images in visible light. It also collects ultraviolet and infrared radiation. The spectacular Hubble telescope images have changed how astronomers view the universe.

The hottest objects in space give off X-rays. The Chandra X-ray Observatory produces images in the X-ray portion of the spectrum. Chandra's X-ray images are much more detailed than those of earlier X-ray telescopes.

The most recent addition to NASA's lineup of telescopes in space is the Spitzer Space Telescope. Launched in 2003, the Spitzer telescope produces images in the infrared portion of the spectrum.

Reading Checkpoint **What is an observatory?**

Section 1 Assessment

S 8.4.d, E-LA: Reading 8.1.0 Writing 8.2.6

Vocabulary Skill **Suffixes** What suffix do you see in the word *electromagnetic?* What part of speech does it indicate? Define *electromagnetic radiation.*

Reviewing Key Concepts

HINT
1. a. **Sequencing** List the main types of electromagnetic waves, from longest wavelength to shortest.

HINT
b. **Applying Concepts** Why are images from the Hubble Space Telescope clearer than images from telescopes on Earth?

HINT
2. a. **Identifying** What are the two major types of optical telescope?

HINT
b. **Explaining** How does a refracting telescope work?

HINT
c. **Comparing and Contrasting** Use Figure 2 to explain the major differences between reflecting and refracting telescopes.

3. a. **Summarizing** How does the atmosphere affect electromagnetic radiation? HINT

b. **Explaining** Why are many large optical telescopes located on mountaintops? HINT

c. **Applying Concepts** Would it make sense to place an X-ray or gamma ray telescope on a mountaintop? Explain why or why not. HINT

Writing in Science

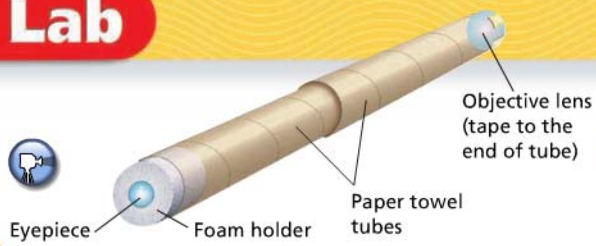
Writing Technical Instructions List the sequence of steps needed to build and operate a reflecting telescope for a booklet to be included in a model telescope kit. Be sure to describe the shape and position of each of the lenses or mirrors. You may include drawings.

Lab zone **Technology Lab**

• Tech & Design •

Design and Build a Telescope

S 8.4.d



Problem

Can you design and build a telescope?

Skills Focus

evaluating the design, redesigning

Materials

- 2 paper towel tubes of slightly different diameters
- several plastic objective lenses
- several plastic eyepiece lenses
- meter stick
- foam holder for eyepiece
- transparent tape

Procedure

1. Fit one of the paper towel tubes inside the other. Make sure you can move the tubes but that they will not slide on their own.
2. Place the large objective lens flat against the end of the outer tube. Tape the lens in place.
3. Insert the small eyepiece lens into the opening in the foam holder.
4. Place the foam eyepiece lens holder into the inner tube at the end of the telescope opposite to the objective lens.
5. Tape a meter stick to the wall. Look through the eyepiece at the meter stick from 5 m away. Slide the tubes in and out to focus your telescope so that you can clearly read the numbers on the meter stick. Draw your telescope. On the drawing, mark the tube position that allows you to read the numbers most clearly.
6. Use your telescope to look at other objects at different distances, both in your classroom and through the window. For each object you view, draw your telescope, marking the tube position at which you see the object most clearly. **CAUTION:** *Do not look at the sun. You will damage your eyes.*
7. Design and build a better telescope. Your new telescope should make objects appear larger than your first model from the same observing distance. It should have markings on the inner tube to enable you to pre-focus the telescope for a given observing distance.
8. Draw a design for your new telescope. List the materials you'll need. Obtain your teacher's approval. Then build your new model.

Analyze and Conclude

1. **Inferring** Why do you need two tubes?
2. **Observing** If you focus on a nearby object and then focus on something farther away, do you have to move the tubes together or apart?
3. **Evaluating the Design** How could you improve on the design of your new telescope? What effects would different lenses or tubes have on its performance?
4. **Redesigning** Describe the most important factors in redesigning your telescope.

Communicate

Write a product brochure for your new telescope. Be sure to describe in detail why your new telescope is better than the first telescope.

Section 2

Characteristics of Stars

CALIFORNIA
Standards Focus

S 8.4.b Students know that the Sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.

S 8.4.c Students know how to use astronomical units and light years as measures of distance between the Sun, stars, and Earth.

- How are stars classified?
- How do astronomers measure distances to the stars?
- What is an H-R diagram and how do astronomers use it?

Key Terms

- constellation
- spectrograph
- apparent brightness
- absolute brightness
- light-year
- parallax
- Hertzsprung-Russell diagram
- main sequence

Lab zone **Standards Warm-Up**

How Does Your Thumb Move?

1. Stand facing a wall, at least an arm's length away. Stretch your arm out with your thumb up and your fingers curled.
2. Close your right eye and look at your thumb with your left eye. Line your thumb up with something on the wall.
3. Now close your left eye and open your right eye. How does your thumb appear to move along the wall?
4. Bring your thumb closer to your eye, about half the distance as before. Repeat Steps 2 and 3.

Think It Over

Observing How does your thumb appear to move in Step 4 compared to Step 3? How are these observations related to how far away your thumb is at each step? How could you use this method to estimate distances?

When ancient observers around the world looked up at the night sky, they imagined that groups of stars formed pictures of people or animals. Today, we call these imaginary patterns of stars **constellations.**

Different cultures gave different names to the constellations. For example, a large constellation in the winter sky is named Orion, the Hunter, after a Greek myth. In this constellation, Orion is seen with a sword in his belt and an upraised arm. On the other hand, the ancient Sumerians thought that the stars in Orion formed the outline of a sheep. In ancient China, this group of stars was called "three," probably because of the three bright stars in Orion's belt.

Astronomers use the patterns of the constellations to locate objects in the night sky. But although the stars in a constellation look as if they are close to one another, they generally are not. They just happen to lie in the same part of the sky as seen from Earth.

Illustration of Orion ▶

Classifying Stars

Like the sun, all stars are huge spheres of glowing gas. They are made up mostly of hydrogen, and they produce energy through the process of nuclear fusion. This energy makes stars shine brightly. Astronomers classify stars according to their physical characteristics. **Characteristics used to classify stars include color, temperature, size, composition, and brightness.**

Color and Temperature If you look at the night sky, you can see slight differences in the colors of the stars. For example, Betelgeuse (BAY tul jooz), the bright star in Orion's shoulder, looks reddish. Rigel, the star in Orion's heel, is blue-white.

Like hot objects on Earth, a star's color reveals its surface temperature. If you watch a toaster heat up, you can see the wires glow red-hot. The wires inside a light bulb are even hotter and glow white. Similarly, the coolest stars—with a surface temperatures of about 3,200 degrees Celsius—appear reddish. With a surface temperature of about 5,500 degrees Celsius, the sun appears yellow. The hottest stars in the sky, with surface temperatures of over 20,000 degrees Celsius, appear bluish.

Size When you look at stars in the sky, they all appear to be points of light of the same size. Many stars are actually about the size of the sun, which is a medium-sized star. However, some stars are much larger than the sun. Very large stars are called giant stars or supergiant stars. If the supergiant star Betelgeuse were located where our sun is, it would be large enough to fill the solar system as far out as Jupiter.

Most stars are much smaller than the sun. White dwarf stars are about the size of Earth. Neutron stars are even smaller, only about 20 kilometers in diameter.

Go Online
PHSchool.com
For: More on types of stars
Visit: PHSchool.com
Web Code: cfd-5042

FIGURE 5
Star Size
Stars vary greatly in size. Giant stars are typically 10 to 100 times larger than the sun and more than 1,000 times the size of a white dwarf. **Calculating** *Betelgeuse has a diameter of 420 million kilometers. How many times larger is this than the sun, which has a diameter of 1.4 million kilometers?*

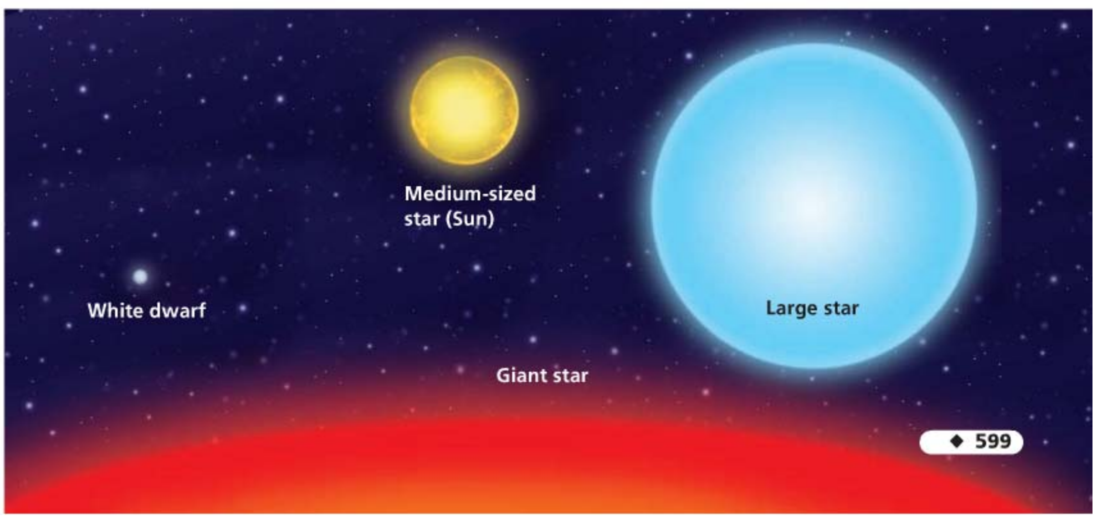
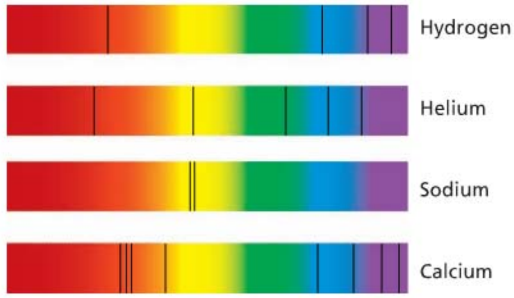


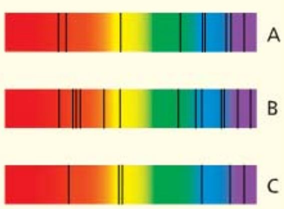
FIGURE 6
Spectrums of Four Stars
Astronomers can use line spectrums to identify the chemical elements in a star. Each element produces a characteristic pattern of spectral lines.



Lab zone Skills Activity

Inferring

The lines on the spectrums below are from three different stars. Each of these star spectrums is made up of an overlap of spectrums from the individual elements shown in Figure 6. In star A, which elements can you detect? Which can you find in star B? In star C?



Chemical Composition Stars vary in their chemical composition. The chemical composition of most stars is about 73 percent hydrogen, 25 percent helium, and 2 percent other elements by mass. This is similar to the composition of the sun.

Astronomers use spectrographs to determine the elements found in stars. A **spectrograph** (SPEK truh graf) is a device that breaks light into colors and produces an image of the resulting spectrum. Most large telescopes have spectrographs.

The gases in a star's atmosphere absorb some wavelengths of light produced within the star. When the star's light is seen through a spectrograph, each absorbed wavelength is shown as a dark line on a spectrum. Each chemical element absorbs light at particular wavelengths. Just as each person has a unique set of fingerprints, each element has a unique set of lines for a given temperature. Figure 6 shows the spectral lines of four elements. By comparing a star's spectrum with the spectrums of known elements, astronomers can infer how much of each element is found in the star.

Reading Checkpoint What is a spectrograph?

Brightness of Stars

Stars also differ in brightness, the amount of light they give off. **The brightness of a star depends upon both its size and temperature.** Recall that the photosphere is the visible surface of a star. Betelgeuse is fairly cool, so a square meter of its photosphere doesn't give off much light compared to hotter stars. But Betelgeuse is very large, so it shines brightly.

Rigel, on the other hand, is very hot, so each square meter of Rigel's photosphere gives off a lot of light. Even though it is smaller than Betelgeuse, Rigel shines more brightly.

How bright a star looks from Earth depends on both its distance from Earth and how bright the star truly is. Because of these two factors, the brightness of a star can be described in two ways: apparent brightness and absolute brightness.

Apparent Brightness A star's **apparent brightness** is its brightness as seen from Earth. Astronomers can measure apparent brightness fairly easily using electronic devices. However, astronomers can't tell how much light a star gives off just from the star's apparent brightness. Just as a flashlight looks brighter the closer it is to you, a star looks brighter the closer it is to Earth. For example, the sun looks very bright. This does not mean that the sun gives off more light than all other stars. The sun looks so bright simply because it is so close. In reality, the sun is a star of only average brightness.

Absolute Brightness A star's **absolute brightness,** or luminosity, is the brightness the star would have if it were at a standard distance from Earth. Finding a star's absolute brightness is more complex than finding its apparent brightness. An astronomer must first find out both the star's apparent brightness and its distance from Earth. The astronomer can then calculate the star's absolute brightness.

Astronomers have found that the absolute brightness of stars can vary tremendously. The brightest stars are more than a billion times brighter than the dimmest stars!

Reading Checkpoint **What is a star's absolute brightness?**

Lab zone Try This Activity

Star Bright

You can compare absolute and apparent brightness.

1. Dim the lights. Put two equally bright flashlights next to each other on a table. Turn them on.
2. Look at the flashlights from the other side of the room. Think of the flashlights as two stars. Then compare them in terms of absolute and apparent brightness.
3. Move one of the flashlights closer to you and repeat Step 2.
4. Replace one of the flashlights with a brighter one. Repeat Steps 1 and 2 with the unequally bright flashlights.

Making Models How could you place the flashlights in Step 4 so that they have the same apparent brightness? Try it.

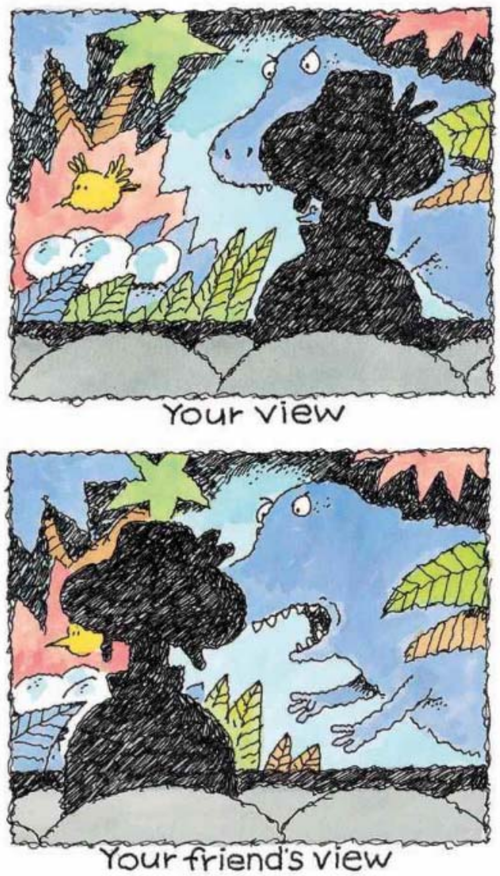
FIGURE 7
Absolute Brightness
The streetlights in this photo all give off about the same amount of light, and so have about the same absolute brightness.
Applying Concepts *Why do the closer streetlights appear brighter than the more distant lights?*

Measuring Distances to Stars

Imagine that you could travel to the stars at the speed of light. To travel from Earth to the sun would take about 8 minutes, not very much time for such a long trip. The next nearest star, Proxima Centauri, is much farther away. A trip to Proxima Centauri at the speed of light would take 4.2 years!

The Light-Year Distances on Earth's surface are often measured in kilometers. However, distances to the stars are so large that kilometers are not very practical units. **Astronomers typically use a unit called the light-year to measure distances between the stars.** In space, light travels at a speed of about 300,000 kilometers per second. A **light-year** is the distance that light travels in one year, about 9.5 million million kilometers.

FIGURE 8
Parallax at the Movies
You and your friend are sitting behind a woman with a large hat. **Applying Concepts** *Why is your view of the screen different from your friend's view?*

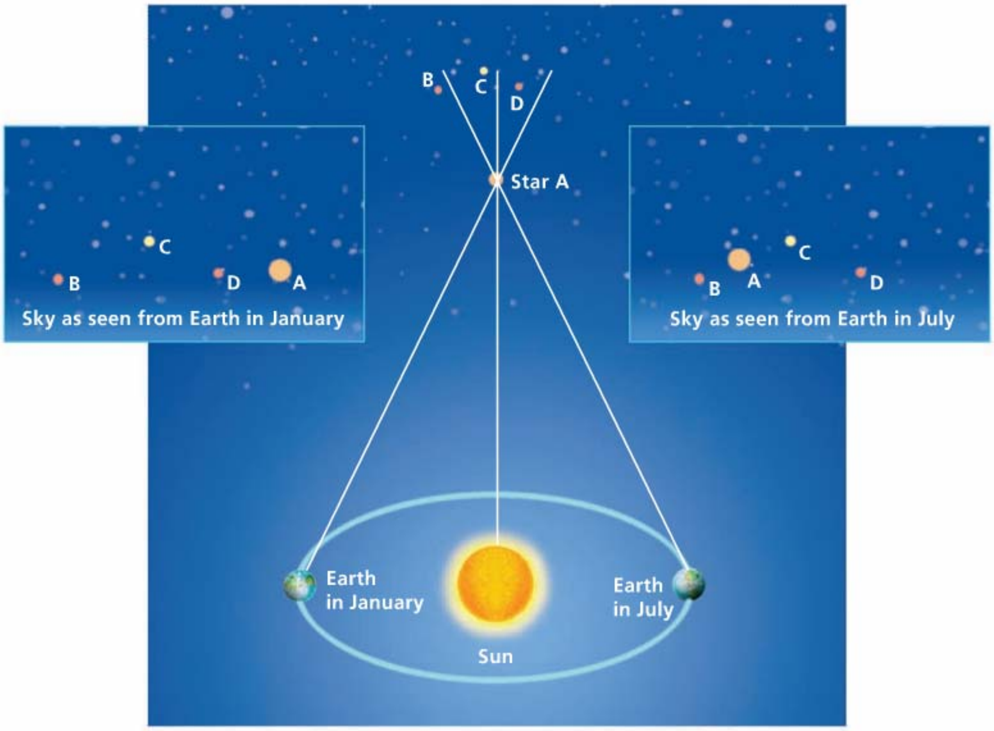


Note that the light-year is a unit of distance, not time. To help you understand this, consider an everyday example. If you bicycle at 10 kilometers per hour, it would take you 1 hour to go to a mall 10 kilometers away. You could say that the mall is "1 bicycle-hour" away.

Parallax Standing on Earth looking up at the sky, it may seem as if there is no way to tell how far away the stars are. However, astronomers have found ways to measure those distances. **Astronomers often use parallax to measure distances to nearby stars.**

Parallax is the apparent change in position of an object when you look at it from different places. For example, imagine that you and a friend have gone to a movie. A woman with a large hat sits down in front of you, as shown in Figure 8. Because you and your friend are sitting in different places, the woman's hat blocks different parts of the screen. If you are sitting on her left, the woman's hat appears to be in front of the large dinosaur. But to your friend on the right, she appears to be in front of the bird.

Have the woman and her hat moved? No. But because you are looking from different places, she appears to have moved. This apparent movement when you look from two different positions is parallax.



Parallax in Astronomy Astronomers are able to measure the parallax of nearby stars to determine their distances. As shown in Figure 9, astronomers look at a nearby star when Earth is on one side of the sun. Then they look at the same star again six months later, when Earth is on the opposite side of the sun. Astronomers measure how much the nearby star appears to move against a background of stars that are much farther away. They can then use this measurement to calculate the distance to the nearby star. The less the nearby star appears to move, the farther away it is.

Astronomers can use parallax to measure distances up to a few hundred light-years from Earth. The parallax of any star that is farther away is too small to measure accurately with existing technology.

Reading Checkpoint **How is parallax useful in astronomy?**

FIGURE 9
Parallax of Stars
The apparent movement of a star when seen from a different position is called parallax. Astronomers use parallax to calculate the distance to nearby stars. Note that the diagram is not to scale.
Interpreting Diagrams *Why do nearby stars appear to change position between January and July?*

The Hertzsprung-Russell Diagram

About 100 years ago, two scientists working independently made the same discovery. Both Ejnar Hertzsprung (EYE nahr HURT sprung) in Denmark and Henry Norris Russell in the United States made graphs to find out if the temperature and the absolute brightness of stars are related. They plotted the surface temperatures of stars on the *x*-axis and their absolute brightness on the *y*-axis. The points formed a pattern. The graph they made is still used by astronomers today. It is called the **Hertzsprung-Russell diagram,** or H-R diagram.

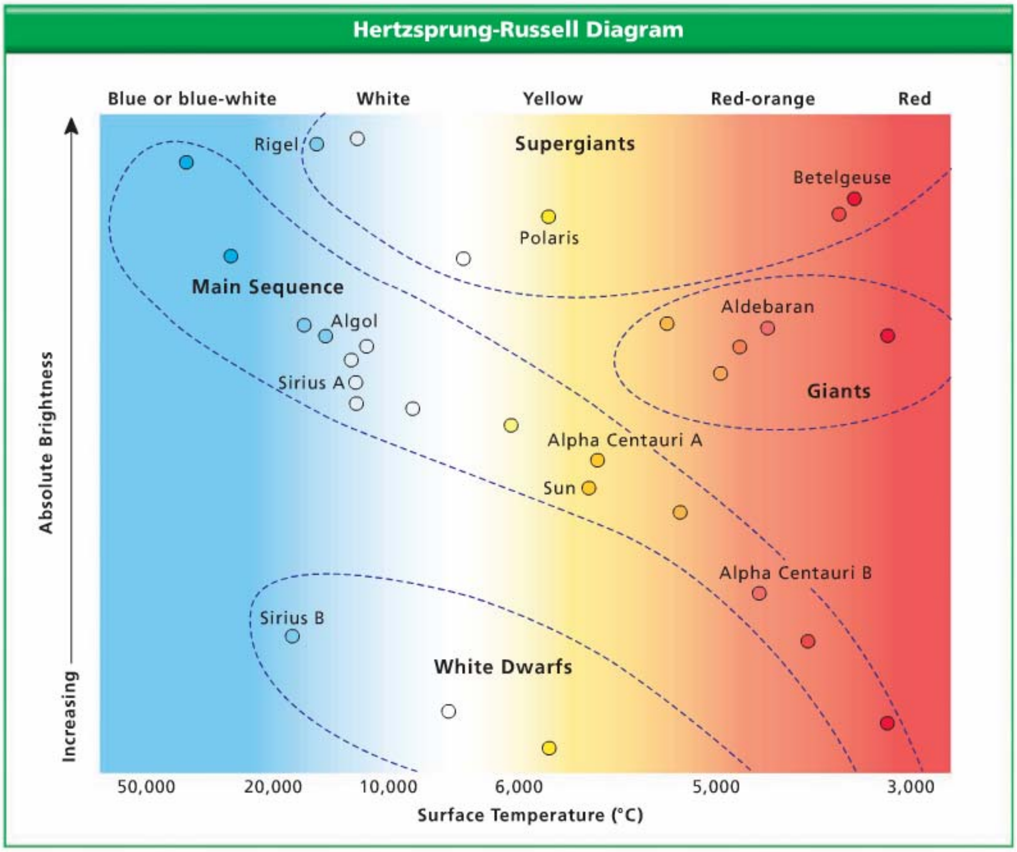


FIGURE 10
The Hertzsprung-Russell diagram shows the relationship between the surface temperature and absolute brightness of stars.
Interpreting Diagrams *Which star has a hotter surface: Rigel or Aldebaran?*

Astronomers use H-R diagrams to classify stars and to understand how stars change over time. As you can see in Figure 10, most of the stars in the H-R diagram form a diagonal area called the **main sequence.** More than 90 percent of all stars, including the sun, are main-sequence stars. Within the main sequence, surface temperature increases as absolute brightness increases. Thus, hot bluish stars are located at the left of an H-R diagram and cooler reddish stars are located at the right of the diagram.

The brightest stars are located near the top of an H-R diagram, while the dimmest stars are located at the bottom. Giant and supergiant stars are very bright. They can be found near the top center and right of the diagram. White dwarfs are hot, but not very bright, so they appear at the bottom left or bottom center of the diagram.

Reading Checkpoint **What is the main sequence?**

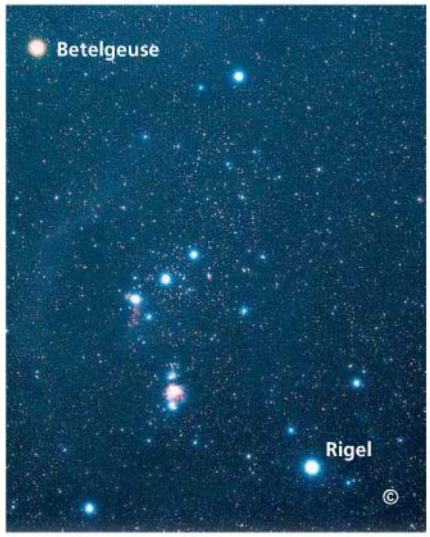


FIGURE 11
Orion
Orion includes the red supergiant Betelgeuse, the blue supergiant Rigel, and many other main-sequence and giant stars.

Section 2 Assessment

S 8.4.b, 8.4.c, E-LA: Reading 8.1.0

Vocabulary Skill **Suffixes** What suffix do you see in the word *constellation*? What part of speech does it indicate? (*Hint:* see Build Science Vocabulary, Chapter 3.) Define *constellation*.

Reviewing Key Concepts

HINT
1. a. Listing Name three characteristics used to classify stars.

HINT
b. Comparing and Contrasting What is the difference between apparent brightness and absolute brightness?

HINT
c. Applying Concepts Stars A and B have about the same apparent brightness, but Star A is about twice as far from Earth as Star B. Which star has the greater absolute brightness? Explain your answer.

HINT
HINT
HINT
2. a. Measuring What is a light-year?

b. Defining What is parallax?

c. Predicting Vega is 25.3 light-years from Earth and Arcturus is 36.7 light-years away. Which star would have a greater parallax? Explain.

HINT
3. a. Summarizing What two characteristics of stars are shown in an H-R diagram?

HINT
b. Identifying Identify two ways in which astronomers can use an H-R diagram.

HINT
c. Classifying The star Procyon B has a surface temperature of 6,600°C and an absolute brightness that is much less than the sun's. What type of star is Procyon B? (*Hint:* Refer to the H-R diagram.)

Lab zone At-Home Activity

Observing Orion With adult family members, go outside on a clear, dark night. Determine which way is south. Using the star charts in Appendix E, look for the constellation Orion, which is visible in the evening during winter and spring. Find the stars Betelgeuse and Rigel in Orion and explain to your family why they are different colors.

Lab zone **Skills Lab**

How Far Is That Star?

S 8.4.b, 8.9.b

Problem

How can parallax be used to determine distances?

Skills Focus

inferring, calculating, predicting

Materials

- masking tape • paper clips • pen
- black and red pencils • metric ruler • paper
- meter stick • calculator
- lamp without a shade, with 100-watt light bulb
- copier paper box (without the lid)
- flat rectangular table, about 1 m wide

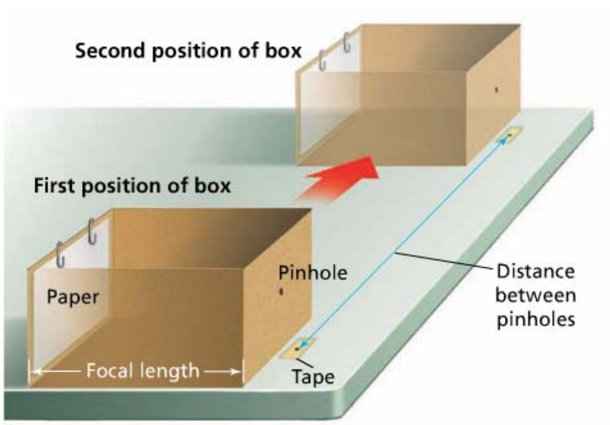
Procedure

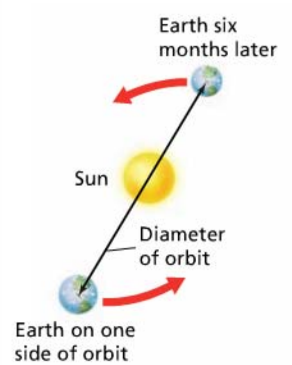
PART 1 Telescope Model

1. Place the lamp on a table in the middle of the classroom.
2. Carefully use the tip of the pen to make a small hole in the middle of one end of the box. The box represents a telescope.
3. At the front of the classroom, place the box on a flat table so the hole points toward the lamp. Line the left side of the box up with the left edge of the table.
4. Put a small piece of tape on the table below the hole. Use the pen to make a mark on the tape directly below the hole. The mark represents the position of the telescope when Earth is on one side of its orbit.

PART 2 Star 1

5. Label a sheet of paper Star 1 and place it inside the box as shown in the drawing. Hold the paper in place with two paper clips. The paper represents the film in a telescope.
6. Darken the room. Turn on the light to represent the star.
7. With the red pencil, mark the paper where you see a dot of light. Label this dot A. Dot A represents the image of the star on the film.
8. Move the box so the right edge of the box lines up with the right edge of the table. Repeat Step 4. The mark on the tape represents the position of the telescope six months later, when Earth is on the other side of its orbit.





Data Table						
Star	Parallax Shift (mm)	Focal Length (mm)	Diameter of Orbit (mm)	Calculated Distance to Star (mm)	Calculated Distance to Star (m)	Actual Distance to Star (m)

9. Repeat Step 7, using a black pencil to mark the second dot B. Dot B represents the image of the star as seen 6 months later from the other side of Earth's orbit.
10. Remove the paper. Before you continue, copy the data table into your notebook.
11. Measure and record the distance in millimeters between dots A and B. This distance represents the parallax shift for Star 1.
12. Measure and record the distance from the hole in the box to the lamp. This distance represents the actual distance to the star.
13. Measure and record the distance from the hole (lens) to the back of the box in millimeters. This distance represents the focal length of your telescope.
14. Measure and record the distance in millimeters between the marks on the two pieces of masking tape. This distance represents the diameter of Earth's orbit.

PART 3 Stars 2 and 3

15. Move the lamp away from the table—about half the distance to the back of the room. The bulb now represents Star 2. Predict what you think will happen to the light images on your paper.
16. Repeat Steps 6–12 with a new sheet of paper to find the parallax shift for Star 2.
17. Move the lamp to the back of the classroom. The bulb now represents Star 3. Repeat Steps 6–12 with a new sheet of paper to find the parallax shift for Star 3.

Analyze and Conclude

1. **Inferring** What caused the apparent change in position of the dots of light for each star? Explain.
2. **Calculating** Use the following formula to calculate the distance from the telescope to Star 1.

$$\text{Distance} = \frac{\text{Diameter} \times \text{Focal length}}{\text{Parallax shift}}$$

3. **Calculating** Divide your result from Question 2 by 1,000 to get the distance to the light bulb in meters.
4. **Calculating** Repeat Questions 2 and 3 for Stars 2 and 3.
5. **Predicting** Was your prediction in Step 15 correct? Why or why not?
6. **Interpreting Data** How did your calculation for Star 3 compare with the actual distance? What could you do to improve your results?
7. **Communicating** Write a paragraph that explains how parallax shift varies with distance. Relate each star's parallax shift to its distance from Earth.

Design an Experiment

What would happen if you kept moving the lamp away from the box? Is there a distance at which you can no longer find the distance to the star? Design an experiment to find out.

Section 3

Lives of Stars

CALIFORNIA Standards Focus

S 8.4.b Students know that the Sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.

S 8.4.d Students know that stars are the source of light for all bright objects in outer space and that the Moon and planets shine by reflected sunlight, not by their own light.

- How does a star form?
- What determines how long a star will exist?
- What happens to a star when it runs out of fuel?

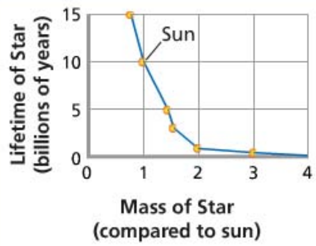
Key Terms

- nebula
- protostar
- planetary nebula
- white dwarf
- supernova
- neutron star
- pulsar
- black hole

Lab zone Standards Warm-Up

What Determines How Long Stars Live?

1. This graph shows how the mass of a star is related to its lifetime—how long the star lives before it runs out of fuel.



2. How long does a star with 0.75 times the mass of the sun live? How long does a star with 3 times the mass of the sun live?

Think It Over

Drawing Conclusions Describe the general relationship between a star's mass and its lifetime.

Imagine that you want to study how people age. You wish you could watch a few people for 50 years, but your project is due next week! You have to study a lot of people for a short time, and classify the people into different age groups. You may come up with groups like *babies, young adults,* and *elderly people.* You don't have time to see a single person go through all these stages, but you know the stages exist.

Astronomers have a similar problem in trying to understand how stars age. They can't watch a single star for billions of years. Instead, they study many stars and other objects in space. Over time, astronomers have figured out that these objects represent different stages in the lives of stars.

◀ Three generations

The Lives of Stars

Stars do not last forever. Each star is born, goes through its life cycle, and eventually dies. (Of course, stars are not really alive. The words *born*, *live*, and *die* are just helpful comparisons.)

A Star Is Born All stars begin their lives as parts of nebulas. A **nebula** is a large cloud of gas and dust spread out in an immense volume. A star, on the other hand, is made up of a large amount of gas in a relatively small volume.

In the densest part of a nebula, gravity pulls gas and dust together. As the cloud of gas and dust contracts, it starts to heat up. A contracting cloud of gas and dust with enough mass to form a star is called a **protostar.** *Proto* means "earliest" in Greek, so a protostar is the earliest stage of a star's life, before nuclear fusion has begun.

A star is born when the contracting gas and dust from a nebula become so dense and hot that nuclear fusion starts. Recall that nuclear fusion is the process by which atomic nuclei combine, releasing enormous amounts of energy. In the sun, for example, hydrogen atoms combine to form helium.

Lifetimes of Stars **How long a star lives depends on its mass.** You might think that stars with more mass would last longer than stars with less mass. But the reverse is true. You can think of stars as being like cars. A small car has a small gas tank, but it also has a small engine that burns gas slowly. A large car has a larger gas tank, but it also has a larger engine that burns gas rapidly. So the small car can travel farther on a tank of gas than the larger car. Small-mass stars use up their fuel more slowly than large-mass stars, so they have much longer lives.

Generally, stars that have less mass than the sun use their fuel slowly, and can live for up to 200 billion years. Medium-mass stars like the sun live for about 10 billion years. Astronomers think the sun is about 4.6 billion years old, so it is almost halfway through its lifetime.

Stars that have more mass than the sun have shorter lifetimes. A star that is 15 times as massive as the sun may live only about ten million years. That may seem like a long time, but it is only one tenth of one percent of the lifetime of the sun.

Reading Checkpoint How long will a star that is the mass of the sun live?

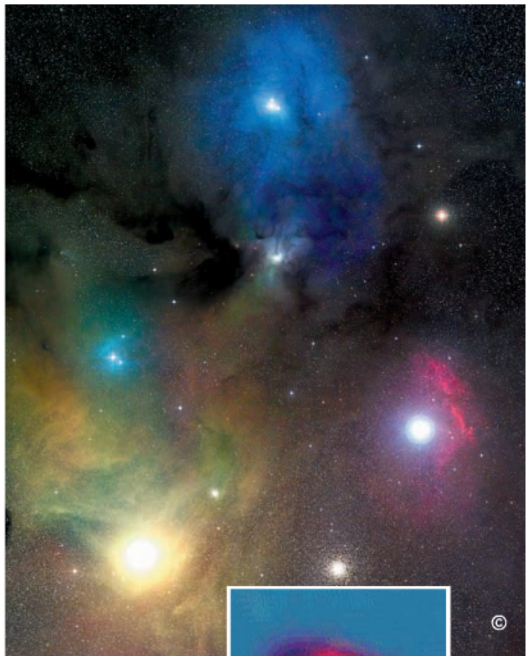


FIGURE 12
Young Stars
New stars are forming in the nebula on top. The bottom photo shows a protostar in the Orion Nebula. **Applying Concepts** *How do some of the gas and dust in a nebula become a protostar?*

Video Field Trip
Discovery Channel School
Stars, Galaxies, and the Universe

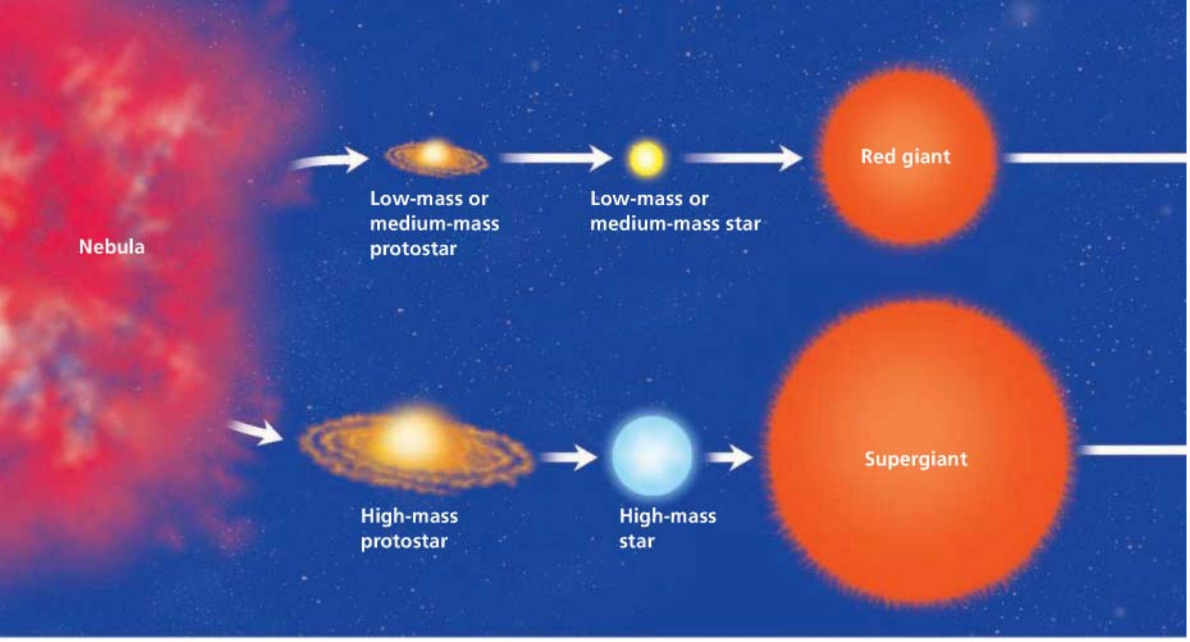


FIGURE 13
The Lives of Stars

A star's life history depends on its mass. A low-mass main-sequence star uses up its fuel slowly and eventually becomes a white dwarf. A high-mass star uses up its fuel quickly. After its supergiant stage, it will explode as a supernova, producing a neutron star or a black hole.
Interpreting Diagrams *What type of star produces a planetary nebula?*

Deaths of Stars

As long as a star produces energy through the fusion of hydrogen into helium in its core, the star stays on the main sequence. However, when the star begins to run out of hydrogen, its core shrinks and its outer portion expands. It moves off of the main sequence. Depending on its mass, the star becomes either a red giant or a supergiant.

At this stage, helium begins to fuse in the star's core. The fusion of helium creates heavier elements such as carbon and oxygen. In the most massive stars, elements as heavy as iron are created by nuclear fusion.

All main-sequence stars eventually become red giants or supergiants. As shown in Figure 13, red giants and supergiants evolve in very different ways. **After a star runs out of fuel, it becomes a white dwarf, a neutron star, or a black hole.**

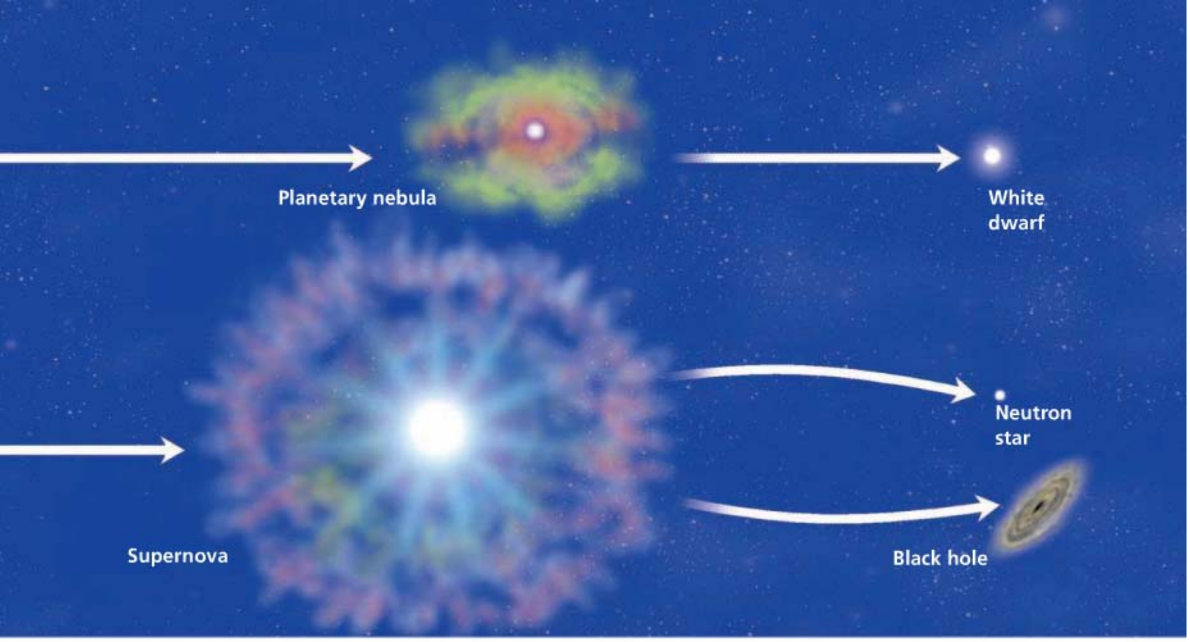
Planetary Nebulas Low-mass stars and medium-mass stars like the sun take billions of years to use up their nuclear fuel. As they start to run out of fuel, their outer layers expand, and they become red giants. Eventually, the outer parts grow larger still and drift out into space. There they form a glowing cloud of gas called a **planetary nebula.** Many planetary nebulas, such as the Cat's Eye Nebula shown on page 621, are spectacular in their beauty.

Reading Checkpoint What is a planetary nebula?

Lab zone Skills Activity

Predicting

Find Algol, Sirius B, and Polaris in Figure 10, the H-R diagram. What type of star is each of these now? Predict what the next stage in each star's life will be.



White Dwarfs A blue-white core of a star is left behind a planetary nebula. This core of the original star gradually cools and becomes a **white dwarf.** White dwarfs are only about the size of Earth, but they have about as much mass as the sun. Since a white dwarf has the same mass as the sun but only one millionth the volume, it is one million times as dense as the sun. A spoonful of material from a white dwarf has as much mass as a large truck. Nuclear fusion no longer takes place in white dwarfs. However, they continue to glow faintly for billions of years from leftover energy.

Supernovas The life cycle of a high-mass star is quite different from the life cycle of a low-mass or medium-mass star. High-mass stars quickly evolve into brilliant supergiants. When a supergiant runs out of fuel, it can explode suddenly. Within hours, the star blazes millions of times brighter. The explosion is called a **supernova.**

A supernova produces enough energy to create elements that are heavier than iron, such as lead and gold. These elements, along with other elements that form in massive stars from nuclear fusion, are flung into space by the supernova explosion. This material may eventually become part of a nebula. The nebula may eventually contract to form a new, partly recycled star. Astronomers think the sun began as a nebula that contained material from a supernova that exploded billions of years ago. This means that Earth, and even your body, are made largely of elements that formed inside a star.

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Neutron Stars After a supergiant explodes, some of the material from the star is left behind. This material may form a neutron star. **Neutron stars** are the remains of high-mass stars. They are even smaller and denser than white dwarfs. A neutron star may contain as much as three times the mass of the sun but be only about 25 kilometers in diameter, the size of a city.

In 1967, Jocelyn Bell, a British astronomy student, detected an object in space that appeared to give off regular pulses of radio waves. That is, the object seemed to rapidly turn on and then off in a regular pattern. Some astronomers hypothesized that the pulses might be a signal from an extraterrestrial civilization. At first, astronomers even named the source LGM, for the "Little Green Men" in early science-fiction stories. Soon, however, astronomers concluded that the source of the radio waves was really a rapidly spinning neutron star.

Pulsars Spinning neutron stars are called **pulsars,** short for pulsating radio sources. As shown in Figure 14, pulsars do not really give off pulses of radiation. Rather, they emit steady beams of radiation in narrow cones. As a pulsar rotates, these beams also turn, like the spinning beacon of a lighthouse. If the beam happens to sweep across Earth, astronomers can briefly detect a flash of radiation that disappears as the beam turns away from Earth. Thus, astronomers are able to detect a pulse each time a pulsar rotates.

Most pulsars rotate about once a second or so. However, some pulsars spin hundreds of times per second!

Reading Checkpoint **What is a pulsar?**

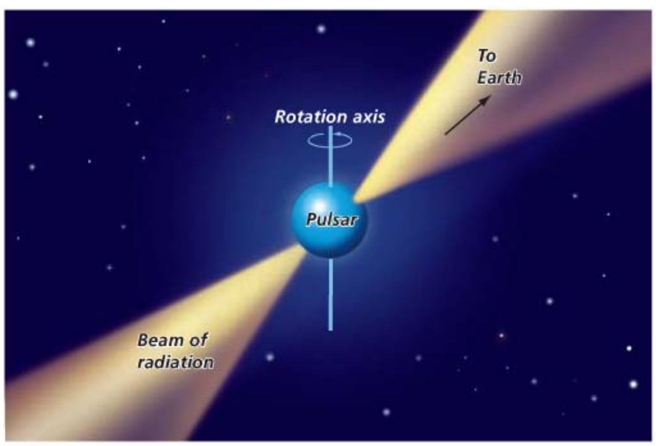

FIGURE 14
Pulsars
Pulsars emit steady beams of radiation. Like a lighthouse beacon, a pulsar appears to pulse when its spinning beam sweeps across Earth.

Black Holes The most massive stars—those having more than 40 times the mass of the sun—may become black holes when they die. A **black hole** is an object with gravity so strong that nothing, not even light, can escape. After a very massive star dies in a supernova explosion, more than five times the mass of the sun may be left. The gravity of this mass is so strong that the gas is pulled inward, packing the gas into a smaller and smaller space. The gas becomes so densely packed that its intense gravity will not allow even light to escape. The remains of the star have become a black hole.

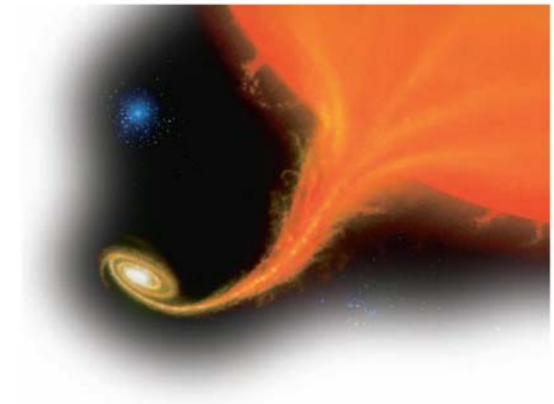

FIGURE 15
Black Holes
The remains of the most massive stars collapse into black holes. This artist's impression shows a black hole pulling matter from a companion star. The material glows as it is pulled into the black hole. **Applying Concepts** *If it is impossible to detect a black hole directly, how do astronomers find them?*

No light, radio waves, or any other form of radiation can ever get out of a black hole, so it is not possible to detect a black hole directly. But astronomers can detect black holes indirectly. For example, gas near a black hole is pulled so strongly that it revolves faster and faster around the black hole. Friction heats the gas up. Astronomers can detect X-rays coming from the hot gas and infer that a black hole is present. Similarly, if another star is near a black hole, astronomers can calculate the mass of the black hole from the effect of its gravity on the star. Scientists have detected dozens of star-size black holes with the Chandra X-ray Observatory. They have also detected huge black holes that are millions or billions of times the sun's mass.

Section 3 Assessment

S 8.4.b, 8.4.d E-LA: Reading 8.2.2; Writing 8.2.0

Target Reading Skill **Identify Supporting Evidence** Reread the text under the heading *Black Holes.* Create a graphic organizer showing supporting evidence for the hypothesis that black holes exist.

Reviewing Key Concepts

HINT
HINT
HINT
HINT
HINT

1. a. **Defining** What is a nebula?
   b. **Explaining** How does a star form from a nebula?
   c. **Comparing and Contrasting** How is a protostar different from a star?
2. a. **Identifying** What factor determines how long a star lives?
   b. **Applying Concepts** A star is twice as massive as the sun. Will its lifespan be longer, shorter, or the same as that of the sun? Explain.
3. a. **Comparing and Contrasting** What is a white dwarf? How is it different from a neutron star?
   b. **Relating Cause and Effect** Why do some stars become white dwarfs and others become neutron stars or black holes?
   c. **Predicting** What will happen to the sun when it runs out of fuel? Explain.

HINT
HINT
HINT

Writing in Science

Descriptive Paragraph Write a description of one of the stages in the life of a star, such as a nebula, red giant, supernova, or white dwarf. Include information on how it formed and what will happen next in the star's evolution.

Section 4

Star Systems and Galaxies

CALIFORNIA Standards Focus

S 8.4.a Students know galaxies are clusters of billions of stars and may have different shapes.

S 8.4.b Students know that the Sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.

- What is a star system?
- What are the major types of galaxies?
- How do astronomers describe the scale of the universe?

Key Terms

- binary star
- eclipsing binary
- open cluster
- globular cluster
- galaxy
- spiral galaxy
- elliptical galaxy
- irregular galaxy
- quasar
- universe
- scientific notation

Lab zone Standards Warm-Up

Why Does the Milky Way Look Hazy?

1. Using a pencil, carefully poke at least 20 holes close together in a sheet of white paper.
2. Tape the paper to a chalkboard or dark-colored wall.
3. Go to the other side of the room and look at the paper. From the far side of the room, what do the dots look like? Can you see individual dots?

Think It Over

Making Models How is looking at the paper from the far side of the room like trying to see many very distant stars that are close together? How does your model compare to the photograph of the Milky Way below?

On a clear, dark night in the country, you can see a hazy band of light stretched across the sky. This band of stars is called the Milky Way. It looks as if the Milky Way is very far away. Actually, though, Earth is inside the Milky Way! The Milky Way looks milky or hazy from Earth because the stars are too close together for your eyes to see them individually. The dark blotches in the Milky Way are clouds of dust that block light from the stars behind them.

The Milky Way

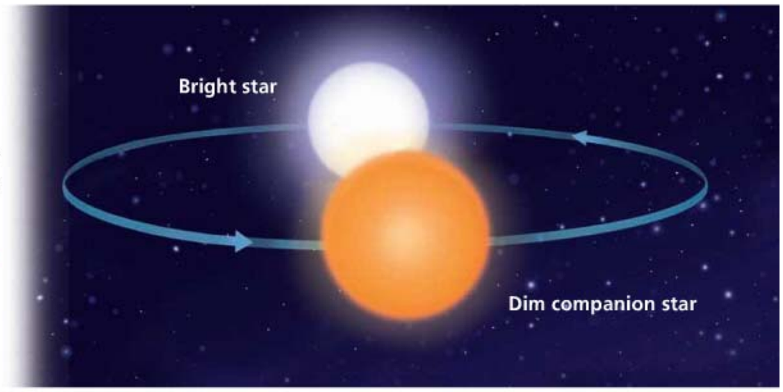

FIGURE 16
Eclipsing Binary
Algol is an eclipsing binary star system consisting of a bright star and a dim companion. Each time the dim star passes in front of the bright one, Algol appears dimmer. **Interpreting Diagrams** *When does Algol appear brighter?*

Star Systems and Clusters

Our solar system has only one star, the sun. But this is not the most common situation for stars. **Most stars are members of groups of two or more stars, called star systems.** If you were on a planet in one of these star systems, at times you might see two or more suns in the sky! At other times, one or more of these suns would be below the horizon.

Multiple Star Systems Star systems that have two stars are called double stars or **binary stars.** (The prefix *bi* means "two.") Those with three stars are called triple stars. The nearby star Proxima Centauri may be part of a triple star system. The other two stars in the system, Alpha Centauri A and Alpha Centauri B, form a double star. Scientists are not sure whether Proxima Centauri is really part of the system or is just passing close to the other two stars temporarily.

Often one star in a binary star is much brighter and more massive than the other. Astronomers can sometimes detect a binary star even if only one of the stars can be seen from Earth. Astronomers can often tell that there is a dim star in a binary system by observing the effects of its gravity. As the dim companion star revolves around a bright star, the dim star's gravity causes the bright star to wobble back and forth. Imagine watching a pair of dancers who are twirling each other around. Even if one dancer were invisible, you could tell that the invisible dancer was there from watching the motion of the visible dancer.

Eclipsing Binaries A wobble is not the only clue that a star has a dim companion. A dim star in a binary star may pass in front of a brighter star and eclipse it. From Earth, the binary star would look much dimmer. A system in which one star periodically blocks the light from another is called an **eclipsing binary.** As Figure 16 shows, the star Algol is actually an eclipsing binary star system.

FIGURE 17
Invisible Partners
If you saw someone dancing but couldn't see a partner, you could infer that the partner was there by watching the dancer you could see. Astronomers use a similar method to detect faint stars in star systems.

Planets Around Other Stars In 1995, astronomers first discovered a planet revolving around another ordinary star. They used a method similar to the one used in studying binary stars. The astronomers observed that a star was moving slightly toward and away from us. They knew that the invisible object causing the movement didn't have enough mass to be a star. They inferred that it must be a planet.

Since then, astronomers have discovered more than 100 planets around other stars, and new ones are being discovered all of the time. Most of these new planets are very large, with at least half of the mass of Jupiter. A small planet would be hard to detect because it would have little gravitational effect on the star it orbited.

Could there be life on planets in other solar systems? Some scientists think it is possible. A few astronomers are using radio telescopes to search for signals that could not have come from natural sources. Such a signal might be evidence that an extraterrestrial civilization was sending out radio waves.

Star Clusters Many stars belong to larger groupings called star clusters. All of the stars in a particular cluster formed from the same nebula at about the same time and are about the same distance from Earth.

There are two major types of star clusters: open clusters and globular clusters. **Open clusters** have a loose, disorganized appearance and contain no more than a few thousand stars. They often contain many bright supergiants and much gas and dust. In contrast, **globular clusters** are large groupings of older stars. Globular clusters are round and densely packed with stars—some may contain more than a million stars.

Reading Checkpoint **What is a globular cluster?**

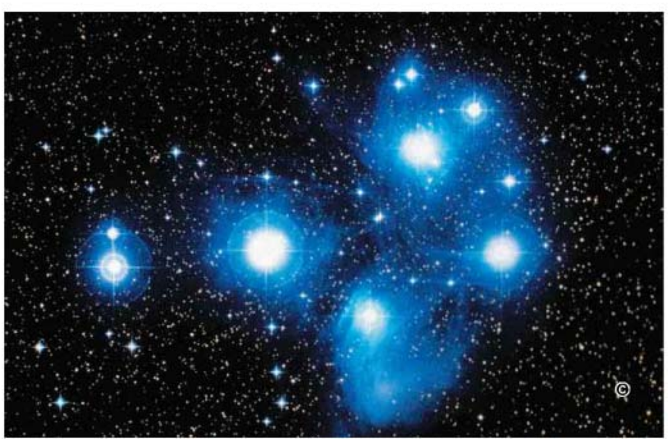

FIGURE 18
Star Clusters
The stars in a globular cluster (above) are all about the same age and the same distance from Earth. The Pleiades (right), also called the *Seven Sisters*, is an open cluster.

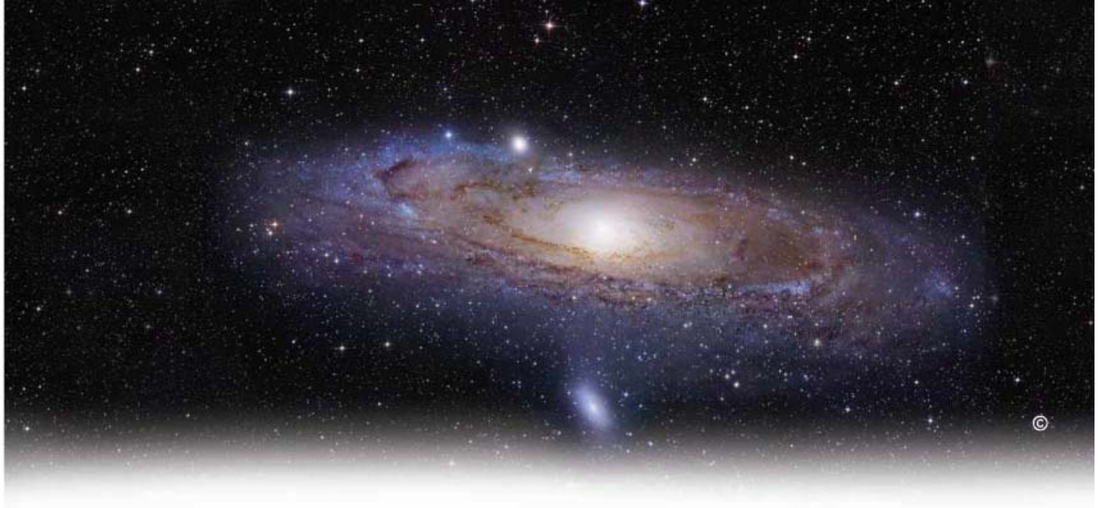

FIGURE 19
Andromeda Galaxy
The Andromeda Galaxy is the nearest large galaxy to our own Milky Way. Andromeda contains hundreds of billions of stars.

Galaxies

Stars are not distributed equally through space. As you have learned, most stars belong to star systems. On a larger scale, many stars belong to star clusters. On an even larger scale, stars are grouped into galaxies.

Galaxies in Space A **galaxy** is a huge group of single stars, star systems, star clusters, dust, and gas bound together by gravity. Many large galaxies, including our own, appear to have huge black holes at their center. There are billions of galaxies in the universe. Each galaxy typically has billions of stars, and the largest galaxies have more than a trillion stars.

Galaxies themselves appear to occur in clusters. For example, our galaxy, the Milky Way, is part of a cluster of 50 or so galaxies called the Local Group. The Local Group is part of the Virgo Supercluster, which contains hundreds of galaxies. Such clusters of galaxies are separated by vast regions of nearly empty space.

Quasars In the 1960s, astronomers discovered objects that are very bright, but also very far away. Many of these objects are 10 billion light-years or more away, making them among the most distant objects in the universe. These distant, enormously bright objects looked almost like stars. Since *quasi* means "something like" in Latin, these objects were given the name quasi-stellar objects, or **quasars.**

What could be so bright at such a great distance from Earth? Astronomers have concluded that quasars are active young galaxies with giant black holes at their centers. Many of these black holes have masses a billion times as great as the sun's mass. As enormous amounts of gas spiral towards the black hole, the gas heats up and shines brightly.

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FIGURE 20
Types of Galaxies
There are three major types of galaxies: spiral, elliptical, and irregular.

Types of Galaxies

Galaxies are classified according to size and shape. **Astronomers classify most galaxies into three main categories: spiral, elliptical, and irregular.** Figure 20 shows examples of each major type.

Spiral Galaxies Some galaxies appear to have a bulge in the middle and arms that spiral outward, like pinwheels. Such galaxies are called **spiral galaxies.** The spiral arms contain many bright, young stars as well as gas and dust. Most new stars in spiral galaxies form in these spiral arms. Relatively few new stars are forming in the central bulge.

Some spiral galaxies, called barred-spiral galaxies, have a huge bar-shaped region of stars and gas that passes through their center. Spiral arms extend outward from the bar in this type of galaxy.

Elliptical Galaxies Not all galaxies have spiral arms. **Elliptical galaxies** have shapes that are round, like balls, or oval, like eggs. These galaxies contain billions of stars but have little gas and dust between the stars. Because there is little gas or dust, stars are no longer forming. Most elliptical galaxies contain only old stars. Elliptical galaxies vary greatly in size.

Irregular Galaxies Some galaxies do not have regular shapes. These are known as **irregular galaxies.** Irregular galaxies are typically smaller than other types of galaxies. They generally have many bright, young stars and lots of gas and dust to form new stars. The Large Magellanic Cloud is an irregular galaxy about 180,000 light-years away from our galaxy. At this distance, it is one of the closest neighboring galaxies in the universe.

Irregular galaxies are often located close to larger galaxies. The gravitational pull of these larger galaxies may have distorted the shape of the smaller irregular galaxies.

Reading Checkpoint **In spiral galaxies, where are most new stars located?**

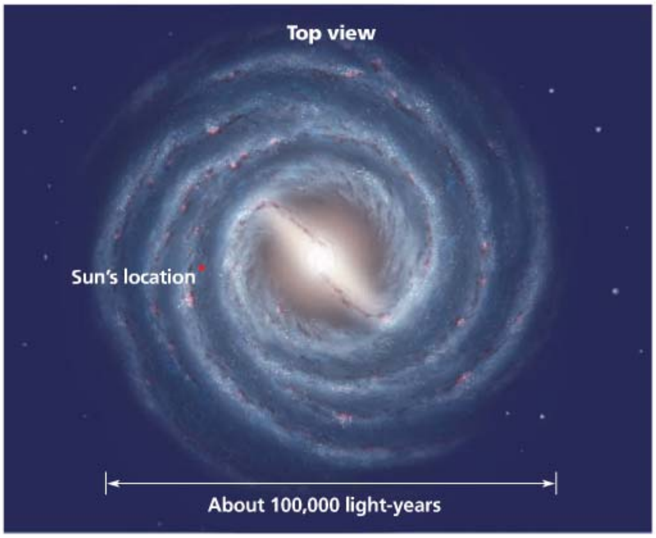


FIGURE 21
Structure of the Milky Way
From the side, the Milky Way appears to be a narrow disk with a bulge in the middle. The galaxy's spiral structure is visible only from above or below the galaxy.
Interpreting Diagrams *Where in the galaxy is the sun located?*

The Milky Way

Our solar system is located in a spiral galaxy called the Milky Way. As Figure 21 shows, the shape of the Milky Way varies depending on your vantage point. From the side, the Milky Way would look like a narrow disk with a large bulge in the middle. But from the top or bottom, the Milky Way would have a spiral, pinwheel shape. You can't see the spiral shape of the Milky Way from Earth because our solar system is inside the galaxy in one of the spiral arms. The solar system takes about 225 million years to orbit the galactic center.

The Milky Way is usually thought of as an ordinary spiral galaxy. However, recent evidence suggests that the Milky Way is a barred-spiral galaxy instead.

When you see the Milky Way at night during the summer, you are looking toward the center of our galaxy. The center of the galaxy is about 25,000 light-years away, but is hidden by large clouds of dust and gas. Astronomers can study the center using X-rays, infrared radiation, and radio waves.

Reading Checkpoint **How far away is the center of the galaxy?**

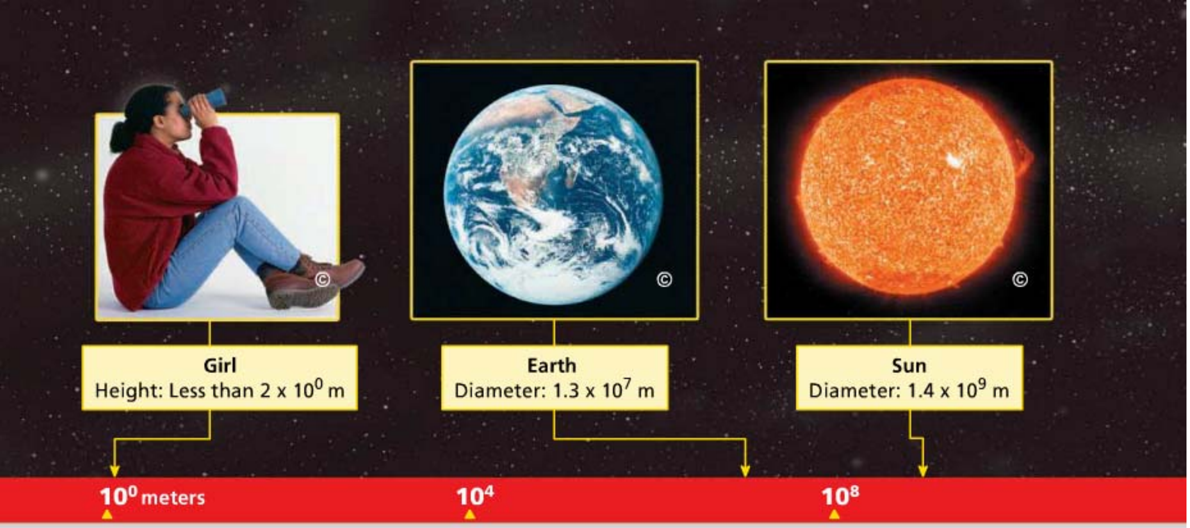
Lab zone Try This Activity

A Spiral Galaxy

You can make a model of our galaxy.

1. Using pipe cleaners, make a pinwheel with two spirals.
2. View the spirals along the surface of the table. Sketch what you see.
3. Next, view the spirals from above the table and sketch them.

Observing The sun is inside a flat spiral galaxy. From Earth's position on the flat surface, is it possible to get a good view of stars in the spiral arms? Why or why not?



The Scale of the Universe

Astronomers define the **universe** as all of space and everything in it. The universe is enormous, almost beyond imagination. Astronomers study objects as close as the moon and as far away as quasars. They study incredibly large objects, such as galaxies that are millions of light-years across. They may also study the behavior of tiny particles, such as the atoms within stars. **Since the numbers astronomers use are often very large or very small, they frequently use scientific notation to describe sizes and distances in the universe.**

Scientific Notation **Scientific notation** uses powers of ten to write very large or very small numbers in shorter form. Each number is written as the product of a number between 1 and 10 and a power of 10. For example: 1,200 is written as 1.2×10^3. One light-year is about 9,500,000,000,000,000 meters. Since there are 15 digits after the first digit, in scientific notation this number is written as 9.5×10^{15} meters.

The Immensity of Space The structures in the universe vary greatly in scale. To understand the scale of these structures, imagine that you are going on a journey through the universe. Refer to Figure 22 as you take your imaginary trip. Start at the left with something familiar—a girl looking through binoculars. She is about 1.5 meters tall. Now shift to the right and change the scale by 10,000,000 or 10^7. You're now close to the diameter of Earth, 1.28×10^7 meters. As you move from left to right across Figure 22, the scale increases. The diameter of the sun is about 100 times that of Earth.

Math Skills

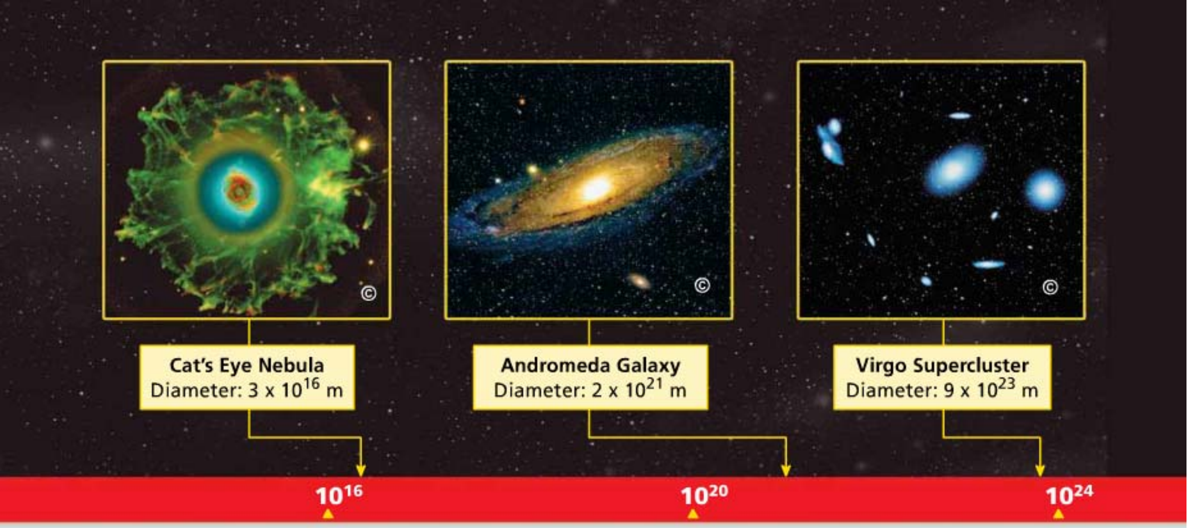
Scientific Notation

The bright star Deneb is about 3,230 light-years from Earth. To express this number in scientific notation, first insert a decimal point in the original number so that you have a number between one and ten. In this case, the number is 3.23.

To determine the power of 10, count the number of places that the decimal point moved. Here the decimal point moved three places.

3,230 light-years =
3.23×10^3 light-years

Practice Problem The sun takes about 220,000,000 years to revolve once around the center of the galaxy. Express this length of time in scientific notation.



Beyond the solar system, the sizes of observable objects become much larger. For example, within our galaxy, the beautiful Cat's Eye Nebula is about 3×10^{16} meters across.

Beyond our galaxy there are billions of other galaxies. For example, the nearby spiral galaxy Andromeda is about 2×10^{21} meters across. The Virgo Supercluster of galaxies, which includes Andromeda as well as the Milky Way, is about 9×10^{23} meters in diameter. The size of the observable universe is about 10^{10} light-years, or 10^{26} meters.

FIGURE 22
Scientific Notation
Scientists often use scientific notation to help describe the vast sizes and distances in space.
Calculating *About how many times larger is the Cat's Eye Nebula than Earth?*

Reading Checkpoint **How large is the observable universe?**

Section 4 Assessment

S 8.4.a, 8.4.b, Reviewing Math: 7NS1.1, E-LA: Reading 8.1.0

Vocabulary Skill **Suffixes** What suffixes do you see in the words *elliptical* and *scientific*? What parts of speech do they indicate? Use the term *elliptical galaxy* in a sentence.

Reviewing Key Concepts

HINT **1. a. Defining** What is a binary star?
HINT **b. Classifying** Are all binary stars part of star systems? Explain.
HINT **c. Applying Concepts** Some binary stars are called eclipsing binaries. Explain why this term is appropriate. (*Hint:* Think about Algol as you write your answer.)
HINT **2. a. Listing** Name the main types of galaxies.
HINT **b. Classifying** What type of galaxy is the Milky Way?
c. Classifying Suppose astronomers discover a galaxy that contains only old stars. What type of galaxy is it likely to be? HINT
3. a. Reviewing What is scientific notation? HINT
b. Explaining How is scientific notation useful to astronomers? HINT
c. Calculating How large is the Cat's Eye Nebula in light-years? (*Hint:* Refer to Figure 22.) HINT

Math Practice

4. Scientific Notation The star Betelgeuse has a diameter of 940,000,000 km. Betelgeuse is 427 light-years from Earth. Write each of these figures in scientific notation.

Section 5

The Expanding Universe

CALIFORNIA Standards Focus

S 8.2.g Students know the role of gravity in forming and maintaining the shapes of planets, stars, and the solar system.

S 8.4.a Students know galaxies are clusters of billions of stars and may have different shapes.

- What is the big bang theory?
- How did the solar system form?
- What do astronomers predict about the future of the universe?

Key Terms

- big bang
- Hubble's law
- cosmic background radiation
- solar nebula
- planetesimal
- dark matter
- dark energy

Lab zone **Standards Warm-Up**

How Does the Universe Expand?

1. Use a marker to put 10 dots on an empty balloon. The dots represent galaxies.
2. Blow up the balloon. What happens to the distances between galaxies that are close together? Galaxies that are far apart?

Think It Over

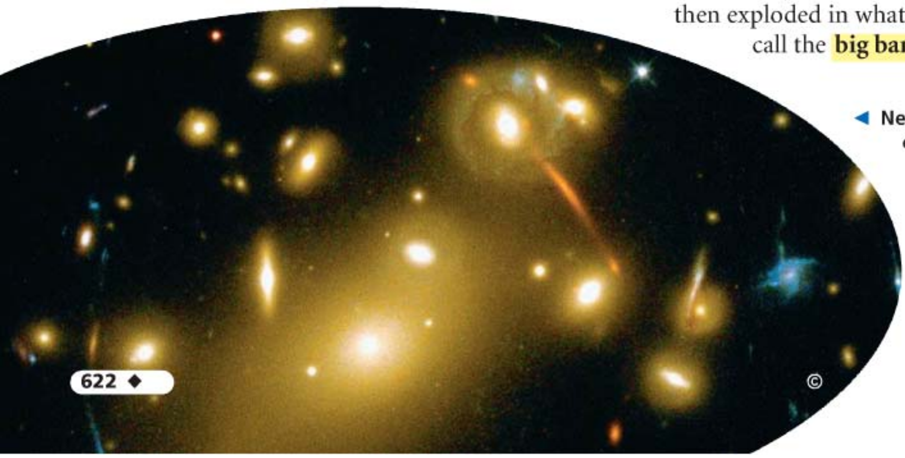
Inferring If the universe is expanding, do galaxies that are close together move apart faster or slower than galaxies that are far apart? Explain.

The Andromeda Galaxy is the most distant object that the human eye can see. Light from this galaxy has traveled for about 3 million years before reaching Earth. When that light finally reaches your eye, you are seeing how the galaxy looked 3 million years ago. It is as though you are looking back in time.

Astronomers have photographed galaxies that are billions of light-years away. Light from these galaxies traveled for billions of years before it reached Earth. From these observations, astronomers are able to infer the age of the universe.

How the Universe Formed

Astronomers theorize that the universe began billions of years ago. At that time, the part of the universe we can now see was no larger than the period at the end of this sentence. This tiny universe was incredibly hot and dense. The universe then exploded in what astronomers call the **big bang.**



◄ Nearly every visible object in this image is a distant galaxy.

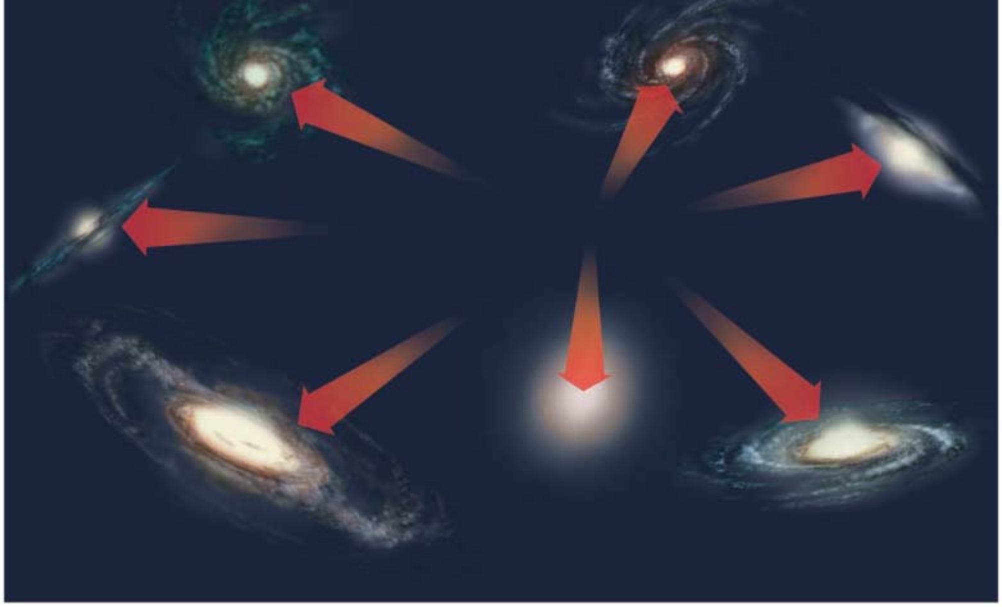


FIGURE 23
Retreating Galaxies
All of the distant galaxies astronomers have observed are moving rapidly away from our galaxy and from each other.

According to the big bang theory, the universe formed in an instant, billions of years ago, in an enormous explosion. Since the big bang, the size of the universe has been increasing rapidly. The universe is billions of times larger now than it was early in its history.

As the universe expanded, it gradually cooled. After a few hundred thousand years, atoms formed. After about 200 million years, gravity caused the first stars and galaxies to form.

If the big bang theory is accurate, what evidence might you expect to find in today's universe? You might expect that the matter that had been hurled apart by the big bang would still be moving apart. You might also expect to find evidence of energy left over from the explosion.

Moving Galaxies An American astronomer, Edwin Hubble, discovered important evidence that later helped astronomers to develop the big bang theory. In the 1920s, Hubble studied the spectrums of many galaxies at various distances from Earth. By examining a galaxy's spectrum, Hubble could tell how fast the galaxy is moving and whether it is moving toward our galaxy or away from it.

Hubble discovered that, with the exception of a few nearby galaxies, all galaxies are moving away from us and from each other. Hubble found that there is a relationship between the distance to a galaxy and its speed. **Hubble's law** states that the farther away a galaxy is, the faster it is moving away from us. Hubble's law strongly supports the big bang theory.

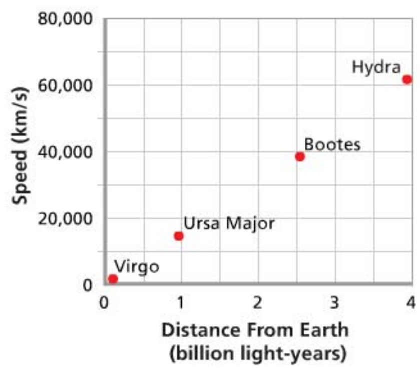
Math Analyzing Data

Speeding Galaxies

Use the graph to answer the questions below about moving clusters of galaxies.

1. **Reading Graphs** How far away is the Bootes cluster? How fast is it moving?
2. **Reading Graphs** Which galaxy is moving away the fastest? Which galaxy is closest to Earth?
3. **Drawing Conclusions** How are the distance and speed of a galaxy related?
4. **Predicting** Predict the speed of a galaxy that is 5 billion light-years from Earth.

Galaxy Movement



To understand how the galaxies are moving, think of raisin bread dough that is rising. If you could shrink yourself to sit on a raisin, you would see all the other raisins moving away from you. The farther a raisin was from you, the faster it would move away, because there would be more bread dough to expand between you and the raisin. No matter which raisin you sat on, all the other raisins would seem to be moving away from you. You could tell that the bread dough was expanding by watching the other raisins.

The universe is like the bread dough. Like the raisins in the dough, the galaxies in the universe are moving away from each other. In the universe, it is space that is expanding, like the dough between the raisins.

FIGURE 24
Rising Dough
The galaxies in the universe are like the raisins in rising bread dough. **Making Models** *How does rising raisin bread dough resemble the expanding universe?*

Cosmic Background Radiation In 1965, two American physicists, Arno Penzias and Robert Wilson, accidentally detected faint radiation on their radio telescope. This mysterious glow was coming from all directions in space. Scientists later concluded that this glow, now called **cosmic background radiation,** is the leftover thermal energy from the big bang. This energy was distributed in every direction as the universe expanded.

Age of the Universe Since astronomers can measure approximately how fast the universe is expanding now, they can infer how long it has been expanding. Based on careful measurements of how fast distant galaxies are moving away from us and the cosmic background radiation, astronomers estimate that the universe is about 13.7 billion years old.

Formation of the Solar System

After the big bang, matter in the universe separated into galaxies. Gas and dust spread throughout space. Where the solar system is now, there was only cold, dark gas and dust. How did the solar system form? The leading hypothesis is explained below.

The Solar Nebula **About five billion years ago, a giant cloud of gas and dust collapsed to form our solar system.** A large cloud of gas and dust such as the one that formed our solar system is called a **solar nebula.** Slowly, gravity began to pull the solar nebula together. As the solar nebula shrank, it spun faster and faster. The solar nebula flattened, forming a rotating disk. Gravity pulled most of the gas into the center of the disk, where the gas eventually became hot and dense enough for nuclear fusion to begin. The sun was born.

Planetesimals In the outer parts of the disk, gas and dust formed small asteroid-like and comet-like bodies called **planetesimals.** These formed the building blocks of the planets. Planetesimals collided and grew larger by sticking together, eventually combining to form the planets.

The Planets When the solar system formed, temperatures were very high. It was so hot close to the sun that most water and other ice-forming materials simply vaporized. Most gases escaped the gravity of the planets that were forming in this region. As a result, the inner planets are relatively small and rocky.

Farther from the sun it was much cooler. As the planets in this region grew, their gravity increased and they were able to capture much of the hydrogen and helium gas in the surrounding space. As a result, the gas giants became very large. Most comets formed near Jupiter and Saturn. They were later flunt out to the outer solar system. Beyond the gas giants, a huge disk of ice and other substances formed. Pluto also formed in this region.

Evidence The composition of the inner and outer planets provides strong evidence for the solar nebula theory. Other evidence includes the position of the sun at the center of the solar system and the fact that all of the planets revolve around the sun in the same direction.

Reading Checkpoint **What is a solar nebula?**

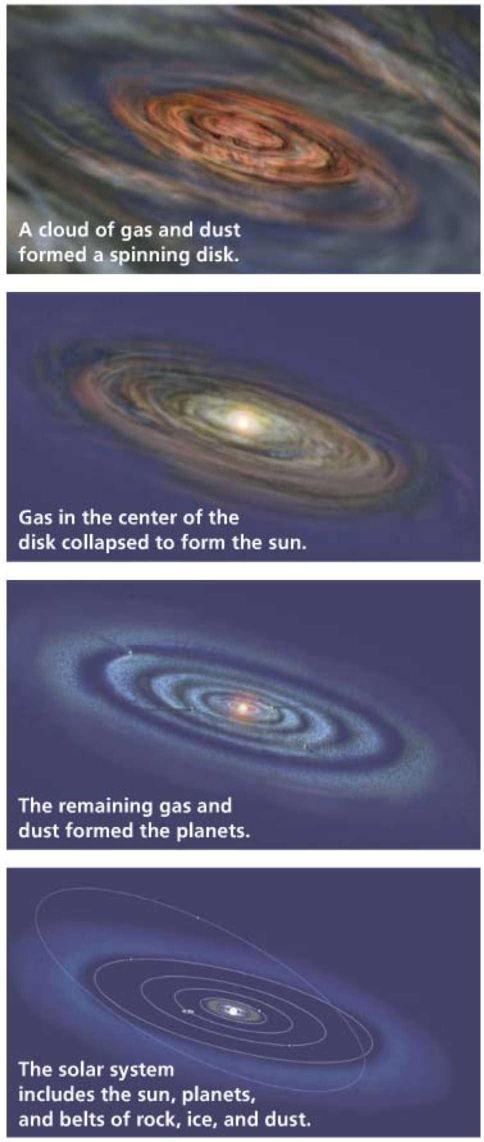


FIGURE 25
How the Solar System Formed
The solar system formed from a collapsing cloud of gas and dust.

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The Future of the Universe

What will happen to the universe in the future? One possibility is that the universe will continue to expand, as it is doing now. All of the stars will eventually run out of fuel and burn out, and the universe will be cold and dark. Another possibility is that the force of gravity will begin to pull the galaxies back together. The result would be a reverse big bang, or "big crunch." All of the matter in the universe would be crushed into an enormous black hole.

Which of these possibilities is more likely? Recent discoveries have led to a surprising new view of the universe that is still not well understood. **New observations lead many astronomers to conclude that the universe will likely expand forever.**

Dark Matter Until fairly recently, astronomers assumed that the universe consisted solely of the matter they could observe directly. But this idea was disproved by the American astronomer Vera Rubin. Rubin made detailed observations of the rotation of spiral galaxies. She discovered that the matter that astronomers can see, such as stars and nebulas, makes up as little as ten percent of the mass in galaxies. The remaining mass exists in the form of dark matter.

Dark matter is matter that does not give off electromagnetic radiation. Dark matter cannot be seen directly. However, its presence can be inferred by observing the effect of its gravity on visible objects, such as stars, or on light. Astronomers still don't know much about dark matter—what it is made of or all of the places where it is found.

FIGURE 26
Vera Rubin
Astronomer Vera Rubin's observations helped prove the existence of dark matter.

An Accelerating Expansion In the late 1990s, astronomers observed that the expansion of the universe appears be accelerating. That is, galaxies seem to be moving apart at a faster rate now than in the past. This observation was puzzling, as no known force could account for it. Astronomers infer that a mysterious new force, which they call **dark energy,** is causing the expansion of the universe to accelerate. Current estimates indicate that most of the universe is made of dark energy and dark matter. Astronomers think that only a small fraction of the universe—less than 5 percent—is composed of "normal matter" that they can see.

Astronomy is one of the oldest sciences, but there are still many discoveries to be made and puzzles to be solved about this universe of ours!

Reading Checkpoint **What is the effect of dark energy?**

FIGURE 27
Dark Matter
Astronomers measured the effect of gravity on light to produce this computer image of how dark matter (in blue) is distributed across a cluster of galaxies.

Section 5 Assessment

S 8.2.g, 8.4.a,
E-LA: Reading 8.2.2

Target Reading Skill **Identify Supporting Evidence** Create a graphic organizer showing the scientific evidence for the hypothesis that the universe will likely expand forever.

Reviewing Key Concepts

HINT
HINT
HINT
HINT
HINT
HINT

1. a. **Defining** What was the big bang?
   b. **Summarizing** When did the big bang occur?
   c. **Describing** Describe two pieces of evidence that support the big bang theory.
2. a. **Summarizing** How old is the solar system?
   b. **Relating Cause and Effect** What force caused the solar system to form?
   c. **Sequencing** Place the following events in the proper order: planets form; planetesimals form; solar nebula shrinks; nuclear fusion begins in the sun.
3. a. **Defining** What is dark matter?
   b. **Explaining** How do scientists know that dark matter exists?
   c. **Predicting** What evidence has led scientists to predict that the universe will continue to expand forever?

HINT
HINT
HINT

Lab zone At-Home Activity

Stargazing Plan an evening of stargazing with adult family members. Choose a dark, clear night. Use binoculars if available and the star charts in Appendix E to locate the Milky Way and some interesting stars that you have learned about. Explain to your family what you know about the Milky Way and each constellation that you observe.

Chapter 15

Study Guide

The BIG Idea Astronomers learn about the structure and evolution of the universe by studying stars, galaxies, and other objects in space.

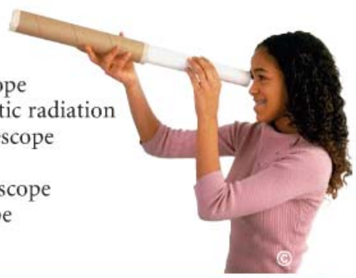
1 Telescopes

Key Concepts S 8.4.d

- The electromagnetic spectrum includes radio waves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.
- Telescopes are instruments that collect and focus light and other forms of electromagnetic radiation.
- Many large observatories are located on mountaintops or in space.

Key Terms

visible light
wavelength
spectrum
optical telescope
electromagnetic radiation
refracting telescope
convex lens
reflecting telescope
radio telescope
observatory



2 Characteristics of Stars

Key Concepts S 8.4.b, 8.4.c

- Characteristics used to classify stars include color, temperature, size, composition, and brightness.
- The brightness of a star depends upon both its size and temperature.
- Astronomers use a unit called the light-year to measure distances between the stars.
- Astronomers often use parallax to measure distances to nearby stars.
- Astronomers use H-R diagrams to classify stars and to understand how stars change over time.

Key Terms

• constellation • spectrograph
• apparent brightness • absolute brightness
• light-year • parallax
• Hertzsprung-Russell diagram
• main sequence

3 Lives of Stars

Key Concepts S 8.4.b, 8.4.d

- A star is born when gas and dust a become so dense and hot that nuclear fusion starts.
- How long a star lives depends on its mass.
- After a star runs out of fuel, it becomes a white dwarf, a neutron star, or a black hole.

Key Terms

• nebula • protostar • planetary nebula
• white dwarf • supernova • neutron star
• pulsar • black hole

4 Star Systems and Galaxies

Key Concepts S 8.4.a, 8.4.b

- Most stars are members of star systems.
- Astronomers classify most galaxies into the following types: spiral, elliptical, and irregular.
- Our solar system is located in a spiral galaxy called the Milky Way.
- Astronomers often use scientific notation to describe sizes and distances in the universe.

Key Terms

• binary star • eclipsing binary • open cluster
• globular cluster • galaxy • quasar
• spiral galaxy • elliptical galaxy
• irregular galaxy • universe
• scientific notation

5 The Expanding Universe

Key Concepts S 8.2.g, 8.4.a

- According to the big bang theory, the universe formed in an explosion billions of years ago.
- About five billion years ago, a giant cloud of gas and dust collapsed to form our solar system.
- New observations lead astronomers to conclude that the universe will likely expand forever.

Key Terms

• big bang • Hubble's law
• cosmic background radiation • solar nebula
• planetesimal • dark matter • dark energy

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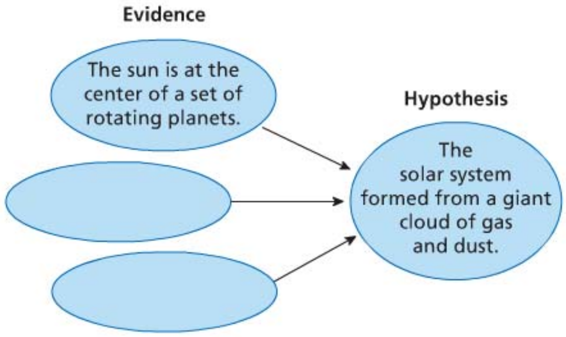
Target Reading Skill

Identify Supporting Evidence

Create a graphic organizer that shows the evidence supporting the solar nebula theory.



Reviewing Key Terms

Choose the letter of the best answer.

HINT **1.** Visible light is a form of
- **a.** spectrum.
- **b.** electromagnetic radiation.
- **c.** wavelength.
- **d.** cosmic background radiation.

HINT **2.** An H-R diagram is a graph of stars' temperature and
- **a.** apparent brightness.
- **b.** main sequence.
- **c.** absolute brightness.
- **d.** parallax.

HINT **3.** A low-mass main sequence star will eventually evolve into a
- **a.** white dwarf.
- **b.** protostar.
- **c.** black hole.
- **d.** nebula.

HINT **4.** A star system in which one star blocks the light from another is called a(n)
- **a.** open cluster.
- **b.** quasar.
- **c.** binary star.
- **d.** eclipsing binary.

HINT **5.** Astronomers theorize that the universe began in an enormous explosion called the
- **a.** solar nebula.
- **b.** supernova.
- **c.** big bang.
- **d.** big crunch.

Complete the following sentences so that your answers clearly explain the key terms.

6. Astronomy was revolutionized by the invention of the **telescope,** which is _______ . HINT

7. More than 90 percent of stars are found on the **main sequence,** which is _________ . HINT

8. Stars are formed in **nebulas,** which are _________ . HINT

9. The Milky Way is an example of a **galaxy,** which is _________ . HINT

10. Evidence for the big bang includes **cosmic background radiation,** which is _________ . HINT

Writing in Science

News Article Imagine that you are a journalist covering current research in astronomy. Write an article explaining what black holes are, how they form, and how they can be detected.

Video Assessment
Discovery Channel School
Stars, Galaxies, and the Universe

Review and Assessment

Checking Concepts

11. Is a light-year a unit of distance or a unit of time? Explain.

12. Why can't astronomers measure the parallax of a star that is a million light-years away?

13. At what point in the evolution of a star is the star actually born?

14. Where in our galaxy does most star formation take place?

15. What is Hubble's law?

16. How can astronomers detect dark matter if they cannot observe it directly?

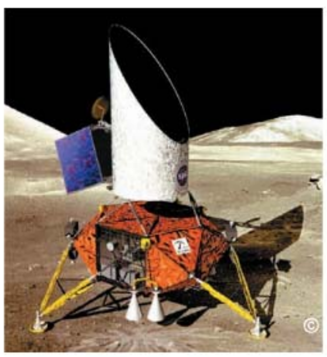
Math Practice

17. **Calculating** The bright star Spica is about 262 light-years from our solar system. How many kilometers is this?

18. **Scientific Notation** The star Antares is approximately 604 light-years from Earth. Write this distance in scientific notation.

Thinking Critically

19. **Inferring** What advantage might there be to locating a telescope, such as the one shown below, on the moon?



20. **Applying Concepts** Describe a real-world situation involving absolute and apparent brightness. (*Hint:* Think about riding in a car at night.)

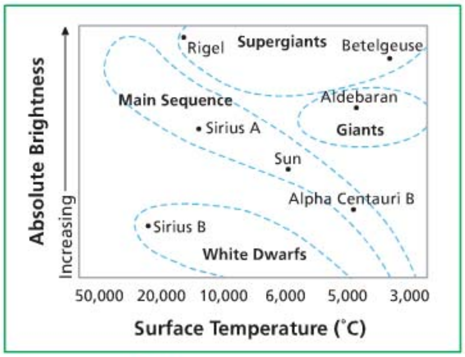
21. **Relating Cause and Effect** How does a star's mass affect its lifetime?

22. **Comparing and Contrasting** Compare the conditions that led to the formation of the terrestrial planets with those that led to the formation of the gas giants.

Applying Skills

Use the data in the H-R diagram below to answer Questions 23–26.

Hertzsprung-Russell Diagram



23. **Interpreting Diagrams** Which star has a greater absolute brightness, Aldebaran or Sirius B?

24. **Interpreting Diagrams** Which stars have higher surface temperatures than Sirius A?

25. **Applying Concepts** Which star is most likely to be red: Rigel, Sirius B, or Betelgeuse?

26. **Comparing and Contrasting** Compare Aldebaran and the sun in terms of size, temperature, and absolute brightness.

Lab zone Standards Investigation

Performance Assessment Check the final draft of your constellation story for correct spelling, grammar, punctuation, and usage. Then decide how you will present your story. For example, you could make a poster, read your story aloud, or perform it as a skit or a play.

CALIFORNIA

Standards Practice

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Choose the letter of the best answer.

1. You can often see stars at night because
A they produce light from nuclear fusion.
B they reflect light from the planets.
C they reflect light from the sun.
D they have exploded as supernovas. **S 8.4.d**

2. The most common chemical element in most stars is
A oxygen.
B hydrogen.
C helium.
D nitrogen. **S 8.4.b**

3. The main factor that affects the evolution of a star is its
A color.
B apparent brightness.
C mass.
D parallax. **S 8.4.b**

4. An astronomer would likely measure the distance between stars in
A light-years.
B kilometers.
C astronomical units.
D millimeters. **S 8.4.c**

The table below gives an estimate of the distribution of stars in the Milky Way galaxy. Use the table and your knowledge of science to answer Question 5.

Type of Star	Percentage of Total
Main sequence	90.75%
Red Giant	0.50%
Supergiant	$<$ 0.0001%
White Dwarf	8.75%

5. According to the table, the most common type of stars in the Milky Way are
A main-sequence stars.
B red giants.
C supergiants.
D white dwarfs. **S 8.4.b**

6. The image above shows a galaxy with few or no new stars. It is most likely a(n)
A spiral galaxy.
B barred spiral galaxy.
C irregular galaxy.
D elliptical galaxy. **S 8.4.a**

7. Which of the following correctly describes the evolution of a sun-like star from young to old?
A white dwarf, red giant, main-sequence star, protostar
B red giant, main-sequence star, white dwarf, protostar
C protostar, main-sequence star, white dwarf, red giant
D protostar, main-sequence star, red giant, white dwarf **S 8.4.b**

8. What force pulled matter together in the solar nebula to form the solar system?
A inertia
B nuclear fusion
C dark energy
D gravity **S 8.2.g**

Apply the BIG Idea

9. Describe the appearance of the Milky Way as you would see it both from Earth and from a point directly above or below the galaxy. Why does the galaxy look different from different vantage points? **S 8.4.a**

Astronomy

Unit 4 Review

Chapter 12

Earth, Moon, and Sun

The BIG Idea

The motions of Earth and the moon and their position relative to the sun result in day and night, the seasons, phases of the moon, eclipses, and tides.

- How does Earth move in space?
- What two factors combine to keep the moon and Earth in orbit?
- What causes the phases of the moon, eclipses, and tides?
- What are some characteristics of the moon?

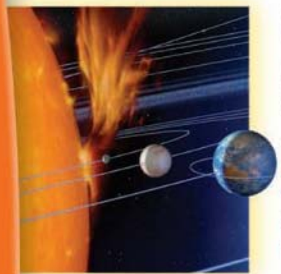
Chapter 13

Exploring Space

The BIG Idea

Scientists have learned much about the solar system through various types of space missions.

- How does a rocket work?
- What were the major events in human exploration of the moon?
- What are the roles of space shuttles, space stations, and space probes?
- How has space technology benefited modern society?



Chapter 14

The Solar System

The BIG Idea

The solar system includes the sun, the planets and their moons, and smaller objects such as comets, asteroids, and meteoroids.

- What are the layers of the sun's interior and its atmosphere?
- What characteristics do the inner planets have in common?
- What characteristics distinguish each of the outer planets?
- What are the characteristics of comets, asteroids, and meteoroids?

Chapter 15

Stars, Galaxies, and the Universe

The BIG Idea

Astronomers learn about the structure and evolution of the universe by studying stars, galaxies, and other objects in space.

- How are stars classified?
- How does a star form?
- What are the major types of galaxies?
- What is the big-bang theory?

Unit 4 Assessment

Connecting the BIG Ideas

Imagine an adventurous group of astronauts in the far future going on a grand tour of our solar system. They might time their trip to start just after a big event, such as a solar eclipse. They would need a powerful rocket to get them off Earth's surface and beyond Earth's gravitational pull.

The astronauts would visit Mars, pass through the asteroid belt, and then delight at the gas giants Jupiter, Saturn, Uranus, and Neptune. They might spend a lot of time studying Jupiter and its four large moons. And no grand solar system tour would be complete without enjoying a close-up view of Saturn's lovely rings.

After a stop at tiny, cold Pluto, the astronauts would head back toward the center of the solar system, passing Venus and Mercury until finally they would get as close to the sun as they possibly could. They might take note of how well the sun supports life on Earth. Not every star in the galaxy has a system of planets, and of those that do, many may not support life as we know it.

1. For a solar eclipse to occur, what must be the moon's phase? *(Chapter 12)*
a. new moon **b.** first quarter
c. full moon **d.** third quarter

2. To leave Earth's gravitational pull, the astronauts' rocket had to reach which of the following? *(Chapter 13)*
a. terminal velocity
b. orbit
c. orbital velocity
d. escape velocity

3. Which of Jupiter's largest moons is thought to have the conditions necessary for life to develop? *(Chapter 14)*
a. Io **b.** Callisto
c. Europa **d.** Ganymede

4. What kind of star is the sun? *(Chapter 15)*
a. white dwarf **b.** main-sequence
c. giant **d.** supergiant

5. **Summary** Write a paragraph that summarizes the conditions necessary for a planet to support life. Give examples of places in our solar system where each of these conditions exist.

Think Like a Scientist

Scientists have a particular way of looking at the world, or scientific habits of mind. Whenever you ask a question and explore possible answers, you use many of the same skills that scientists do. Some of these skills are described on this page.

Observing

When you use one or more of your five senses to gather information about the world, you are **observing.** Hearing a dog bark, counting twelve green seeds, and smelling smoke are all observations. To increase the power of their senses, scientists sometimes use microscopes, telescopes, or other instruments that help them make more detailed observations.

An observation must be an accurate report of what your senses detect. It is important to keep careful records of your observations in science class by writing or drawing in a notebook. The information collected through observations is called evidence, or data.

Inferring

When you interpret an observation, you are **inferring,** or making an inference. For example, if you hear your dog barking, you may infer that someone is at your front door. To make this inference, you combine the evidence—the barking dog—and your experience or knowledge—you know that your dog barks when strangers approach—to reach a logical conclusion.

Notice that an inference is not a fact; it is only one of many possible interpretations for an observation. For example, your dog may be barking because it wants to go for a walk. An inference may turn out to be incorrect even if it is based on accurate observations and logical reasoning. The only way to find out if an inference is correct is to investigate further.

Predicting

When you listen to the weather forecast, you hear many predictions about the next day's weather—what the temperature will be, whether it will rain, and how windy it will be. Weather forecasters use observations and knowledge of weather patterns to predict the weather. The skill of **predicting** involves making an inference about a future event based on current evidence or past experience.

Because a prediction is an inference, it may prove to be false. In science class, you can test some of your predictions by doing experiments. For example, suppose you predict that larger paper airplanes can fly farther than smaller airplanes. How could you test your prediction?

Activity

Use the photograph to answer the questions below.

Observing Look closely at the photograph. List at least three observations.

Inferring Use your observations to make an inference about what has happened. What experience or knowledge did you use to make the inference?

Predicting Predict what will happen next. On what evidence or experience do you base your prediction?

Classifying

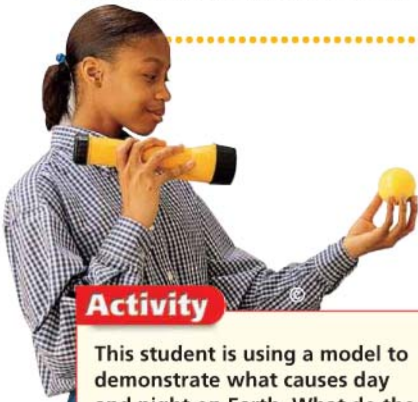
Could you imagine searching for a book in the library if the books were shelved in no particular order? Your trip to the library would be an all-day event! Luckily, librarians group together books on similar topics or by the same author. Grouping together items that are alike in some way is called **classifying.** You can classify items in many ways: by size, by shape, by use, and by other important characteristics.

Like librarians, scientists use the skill of classifying to organize information and objects. When things are sorted into groups, the relationships among them become easier to understand.

Activity

Classify the objects in the photograph into two groups based on any characteristic you choose. Then use another characteristic to classify the objects into three groups.

Making Models



Activity

This student is using a model to demonstrate what causes day and night on Earth. What do the flashlight and the tennis ball in the model represent?

Have you ever drawn a picture to help someone understand what you were saying? Such a drawing is one type of model. A model is a picture, diagram, computer image, or other representation of a complex object or process. **Making models** helps people understand things that they cannot observe directly.

Scientists often use models to represent things that are either very large or very small, such as the planets in the solar system, or the parts of a cell. Such models are physical models—drawings or three-dimensional structures that look like the real thing. Other models are mental models—mathematical equations or words that describe how something works.

Communicating

Whenever you talk on the phone, write a report, or listen to your teacher at school, you are communicating. **Communicating** is the process of sharing ideas and information with other people. Communicating effectively requires many skills, including writing, reading, speaking, listening, and making models.

Scientists communicate to share results, information, and opinions. Scientists often communicate about their work in journals, over the telephone, in letters, and on the Internet. They also attend scientific meetings where they share their ideas with one another in person.

Activity

On a sheet of paper, write out clear, detailed directions for tying your shoe. Then exchange directions with a partner. Follow your partner's directions exactly. How successful were you at tying your shoe? How could your partner have communicated more clearly?

Making Measurements

By measuring, scientists can express their observations more precisely and communicate more information about what they observe.

Measuring in SI

The standard system of measurement used by scientists around the world is known as the International System of Units, which is abbreviated as SI (**Système International d'Unités,** in French). SI units are easy to use because they are based on multiples of 10. Each unit is ten times larger than the next smallest unit and one tenth the size of the next largest unit. The table lists the prefixes used to name the most common SI units.

Common SI Prefixes

Prefix	Symbol	Meaning
kilo-	k	1,000
hecto-	h	100
deka-	da	10
deci-	d	0.1 (one tenth)
centi-	c	0.01 (one hundredth)
milli-	m	0.001 (one thousandth)

Length To measure length, or the distance between two points, the unit of measure is the **meter (m).** The distance from the floor to a doorknob is approximately one meter. Long distances, such as the distance between two cities, are measured in kilometers (km). Small lengths are measured in centimeters (cm) or millimeters (mm). Scientists use metric rulers and meter sticks to measure length.

Common Conversions

1 km	=	1,000 m
1 m	=	100 cm
1 m	=	1,000 mm
1 cm	=	10 mm

Activity

The larger lines on the metric ruler in the picture show centimeter divisions, while the smaller, unnumbered lines show millimeter divisions. How many centimeters long is the shell? How many millimeters long is it?

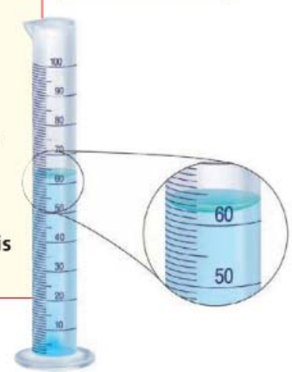
Liquid Volume To measure the volume of a liquid, or the amount of space it takes up, you will use a unit of measure known as the **liter (L).** One liter is the approximate volume of a medium-size carton of milk. Smaller volumes are measured in milliliters (mL). Scientists use graduated cylinders to measure liquid volume.

Activity

The graduated cylinder in the picture is marked in milliliter divisions. Notice that the water in the cylinder has a curved surface. This curved surface is called the *meniscus*. To measure the volume, you must read the level at the lowest point of the meniscus. What is the volume of water in this graduated cylinder?

Common Conversion

1 L	=	1,000 mL



Mass To measure mass, or the amount of matter in an object, you will use a unit of measure known as the **gram (g).** One gram is approximately the mass of a paper clip. Larger masses are measured in kilograms (kg). Scientists use a balance to find the mass of an object.

Common Conversion
1 kg = 1,000 g

Activity

The mass of the potato in the picture is measured in kilograms. What is the mass of the potato? Suppose a recipe for potato salad called for one kilogram of potatoes. About how many potatoes would you need?

Temperature To measure the temperature of a substance, you will use the **Celsius scale.** Temperature is measured in degrees Celsius (°C) using a Celsius thermometer. Water freezes at 0°C and boils at 100°C.

Time The unit scientists use to measure time is the **second (s).**

Activity

What is the temperature of the liquid in degrees Celsius?

Converting SI Units

To use the SI system, you must know how to convert between units. Converting from one unit to another involves the skill of **calculating,** or using mathematical operations. Converting between SI units is similar to converting between dollars and dimes because both systems are based on multiples of ten.

Suppose you want to convert a length of 80 centimeters to meters. Follow these steps to convert between units.

1. Begin by writing down the measurement you want to convert—in this example, 80 centimeters.
2. Write a conversion factor that represents the relationship between the two units you are converting. In this example, the relationship is 1 meter = 100 centimeters. Write this conversion factor as a fraction, making sure to place the units you are converting from (centimeters, in this example) in the denominator.
3. Multiply the measurement you want to convert by the fraction. When you do this, the units in the first measurement will cancel out with the units in the denominator. Your answer will be in the units you are converting to (meters, in this example).

Example

80 centimeters = ■ meters

$$80 \text{ centimeters} \times \frac{1 \text{ meter}}{100 \text{ centimeters}} = \frac{80 \text{ meters}}{100}$$

$$= 0.8 \text{ meters}$$

Activity

Convert between the following units.

1. 600 millimeters = ■ meters
2. 0.35 liters = ■ milliliters
3. 1,050 grams = ■ kilograms

Conducting a Scientific Investigation

In some ways, scientists are like detectives, piecing together clues to learn about a process or event. One way that scientists gather clues is by carrying out experiments. An experiment tests an idea in a careful, orderly manner. Although experiments do not all follow the same steps in the same order, many follow a pattern similar to the one described here.

Posing Questions

Experiments begin by asking a scientific question. A scientific question is one that can be answered by gathering evidence. For example, the question "Which freezes faster—fresh water or salt water?" is a scientific question because you can carry out an investigation and gather information to answer the question.

Developing a Hypothesis

The next step is to form a hypothesis. A **hypothesis** is a possible explanation for a set of observations or answer to a scientific question. A hypothesis may incorporate observations, concepts, principles, and theories about the natural world. Hypotheses lead to predictions that can be tested. A prediction can be worded as an *If . . . then . . .* statement. For example, a prediction might be *"If I add salt to fresh water, then the water will take longer to freeze."* A prediction worded this way serves as a rough outline of the experiment you should perform.

Designing an Experiment

Next you need to plan a way to test your hypothesis. Your plan should be written out as a step-by-step procedure and should describe the observations or measurements you will make.

Two important steps involved in designing an experiment are controlling variables and forming operational definitions.

Controlling Variables In a well-designed experiment, you need to keep all variables the same except for one. A **variable** is any factor that can change in an experiment. The factor that you change is called the **manipulated variable**. In this experiment, the manipulated variable is the amount of salt added to the water. Other factors, such as the amount of water or the starting temperature, are kept constant.

The factor that changes as a result of the manipulated variable is called the **responding variable.** The responding variable is what you measure or observe to obtain your results. In this experiment, the responding variable is how long the water takes to freeze.

An experiment in which all factors except one are kept constant is called a **controlled experiment.** Most controlled experiments include a test called the control. In this experiment, Container 3 is the control. Because no salt is added to Container 3, you can compare the results from the other containers to it. Any difference in results must be due to the addition of salt alone.

Forming Operational Definitions Another important aspect of a well-designed experiment is having clear operational definitions. An **operational definition** is a statement that describes how a particular variable is to be measured or how a term is to be defined. For example, in this experiment, how will you determine if the water has frozen? You might decide to insert a stick in each container at the start of the experiment. Your operational definition of "frozen" would be the time at which the stick can no longer move.

Experimental Procedure

1. Fill 3 containers with 300 milliliters of cold tap water.
2. Add 10 grams of salt to Container 1; stir. Add 20 grams of salt to Container 2; stir. Add no salt to Container 3.
3. Place the 3 containers in a freezer.
4. Check the containers every 15 minutes. Record your observations.

Interpreting Data

The observations and measurements you make in an experiment are called **data.** At the end of an experiment, you need to analyze the data to look for any patterns or trends. Patterns often become clear if you organize your data in a data table or graph. Then think through what the data reveal. Do they support your hypothesis? Do they point out a flaw in your experiment? Do you need to collect more data?

Drawing Conclusions

A **conclusion** is a statement that sums up what you have learned from an experiment. When you draw a conclusion, you need to decide whether the data you collected support your hypothesis or not. You may need to repeat an experiment several times before you can draw any conclusions from it. Conclusions often lead you to pose new questions and plan new experiments to answer them.

Activity

Is a ball's bounce affected by the height from which it is dropped? Using the steps just described, plan a controlled experiment to investigate this problem.

Technology Design Skills

Engineers are people who use scientific and technological knowledge to solve practical problems. To design new products, engineers usually follow the process described here, even though they may not follow these steps in the exact order. As you read the steps, think about how you might apply them in technology labs.

Identify a Need

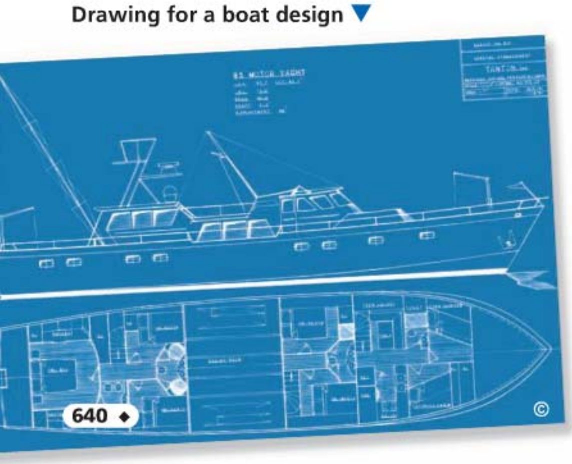
Before engineers begin designing a new product, they must first identify the need they are trying to meet. For example, suppose you are a member of a design team in a company that makes toys. Your team has identified a need: a toy boat that is inexpensive and easy to assemble.

Research the Problem

Engineers often begin by gathering information that will help them with their new design. This research may include finding articles in books, magazines, or on the Internet. It may also include talking to other engineers who have solved similar problems. Engineers often perform experiments related to the product they want to design.

For your toy boat, you could look at toys that are similar to the one you want to design. You might do research on the Internet. You could also test some materials to see whether they will work well in a toy boat.

Drawing for a boat design ▼



Design a Solution

Research gives engineers information that helps them design a product. When engineers design new products, they usually work in teams.

Generating Ideas Often design teams hold brainstorming meetings in which any team member can contribute ideas. **Brainstorming** is a creative process in which one team member's suggestions often spark ideas in other group members. Brainstorming can lead to new approaches to solving a design problem.

Evaluating Constraints During brainstorming, a design team will often come up with several possible designs. The team must then evaluate each one.

As part of their evaluation, engineers consider constraints. **Constraints** are factors that limit or restrict a product design. Physical characteristics, such as the properties of materials used to make your toy boat, are constraints. Money and time are also constraints. If the materials in a product cost a lot, or if the product takes a long time to make, the design may be impractical.

Making Trade-offs Design teams usually need to make trade-offs. In a **trade-off,** engineers give up one benefit of a proposed design in order to obtain another. In designing your toy boat, you will have to make trade-offs. For example, suppose one material is sturdy but not fully waterproof. Another material is more waterproof, but breakable. You may decide to give up the benefit of sturdiness in order to obtain the benefit of waterproofing.

Build and Evaluate a Prototype

Once the team has chosen a design plan, the engineers build a prototype of the product. A **prototype** is a working model used to test a design. Engineers evaluate the prototype to see whether it works well, is easy to operate, is safe to use, and holds up to repeated use.

Think of your toy boat. What would the prototype be like? Of what materials would it be made? How would you test it?

Troubleshoot and Redesign

Few prototypes work perfectly, which is why they need to be tested. Once a design team has tested a prototype, the members analyze the results and identify any problems. The team then tries to **troubleshoot,** or fix the design problems. For example, if your toy boat leaks or wobbles, the boat should be redesigned to eliminate those problems.

Communicate the Solution

A team needs to communicate the final design to the people who will manufacture and use the product. To do this, teams may use sketches, detailed drawings, computer simulations, and word descriptions.

Activity

You can use the technology design process to design and build a toy boat.

Research and Investigate

1. Visit the library or go online to research toy boats.
2. Investigate how a toy boat can be powered, including wind, rubber bands, or baking soda and vinegar.
3. Brainstorm materials, shapes, and steering for your boat.

Design and Build

4. Based on your research, design a toy boat that
   - is made of readily available materials
   - is no larger than 15 cm long and 10 cm wide
   - includes a power system, a rudder, and an area for cargo
   - travels 2 meters in a straight line carrying a load of 20 pennies
5. Sketch your design and write a step-by-step plan for building your boat. After your teacher approves your plan, build your boat.

Evaluate and Redesign

6. Test your boat, evaluate the results, and troubleshoot any problems.
7. Based on your evaluation, redesign your toy boat so it performs better.

Creating Data Tables and Graphs

How can you make sense of the data in a science experiment? The first step is to organize the data to help you understand them. Data tables and graphs are helpful tools for organizing data.

Data Tables

You have gathered your materials and set up your experiment. But before you start, you need to plan a way to record what happens during the experiment. By creating a data table, you can record your observations and measurements in an orderly way.

Suppose, for example, that a scientist conducted an experiment to find out how many Calories people of different body masses burn while doing various activities. The data table shows the results.

Notice in this data table that the manipulated variable (body mass) is the heading of one column. The responding variable (for Experiment 1, the number of Calories burned while bicycling) is the heading of the next column. Additional columns were added for related experiments.

Calories Burned in 30 Minutes

Body Mass	Experiment 1: Bicycling	Experiment 2: Playing Basketball	Experiment 3: Watching Television
30 kg	60 Calories	120 Calories	21 Calories
40 kg	77 Calories	164 Calories	27 Calories
50 kg	95 Calories	206 Calories	33 Calories
60 kg	114 Calories	248 Calories	38 Calories

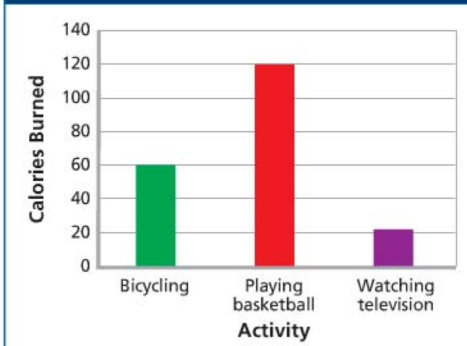
Bar Graphs

To compare how many Calories a person burns doing various activities, you could create a bar graph. A bar graph is used to display data in a number of separate, or distinct, categories. In this example, bicycling, playing basketball, and watching television are the three categories.

To create a bar graph, follow these steps.

1. On graph paper, draw a horizontal, or x-, axis and a vertical, or y-, axis.
2. Write the names of the categories to be graphed along the horizontal axis. Include an overall label for the axis as well.
3. Label the vertical axis with the name of the responding variable. Include units of measurement. Then create a scale along the axis by marking off equally spaced numbers that cover the range of the data collected.
4. For each category, draw a solid bar using the scale on the vertical axis to determine the height. Make all the bars the same width.
5. Add a title that describes the graph.

Calories Burned by a 30-Kilogram Person in 30 Minutes



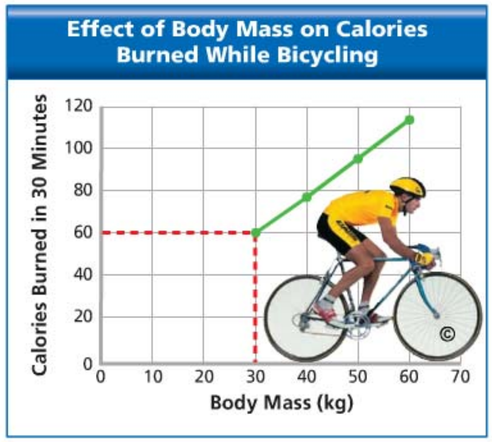
Line Graphs

To see whether a relationship exists between body mass and the number of Calories burned while bicycling, you could create a line graph. A line graph is used to display data that show how one variable (the responding variable) changes in response to another variable (the manipulated variable). You can use a line graph when your manipulated variable is **continuous,** that is, when there are other points between the ones that you tested. In this example, body mass is a continuous variable because there are other body masses between 30 and 40 kilograms (for example, 31 kilograms). Time is another example of a continuous variable.

Line graphs are powerful tools because they allow you to estimate values for conditions that you did not test in the experiment. For example, you can use the line graph to estimate that a 35-kilogram person would burn 68 Calories while bicycling.

To create a line graph, follow these steps.

1. On graph paper, draw a horizontal, or *x*-, axis and a vertical, or *y*-, axis.
2. Label the horizontal axis with the name of the manipulated variable. Label the vertical axis with the name of the responding variable. Include units of measurement.
3. Create a scale on each axis by marking off equally spaced numbers that cover the range of the data collected.
4. Plot a point on the graph for each piece of data. In the line graph above, the dotted lines show how to plot the first data point (30 kilograms and 60 Calories). Follow an imaginary vertical line extending up from the horizontal axis at the 30-kilogram mark. Then follow an imaginary horizontal line extending across from the vertical axis at the 60-Calorie mark. Plot the point where the two lines intersect.



5. Connect the plotted points with a solid line. (In some cases, it may be more appropriate to draw a line that shows the general trend of the plotted points. In those cases, some of the points may fall above or below the line. Also, not all graphs are linear. It may be more appropriate to draw a curve to connect the points.)
6. Add a title that identifies the variables or relationship in the graph.

Activity

Create line graphs to display the data from Experiment 2 and Experiment 3 in the data table.

Activity

You read in the newspaper that a total of 4 centimeters of rain fell in your area in June, 2.5 centimeters fell in July, and 1.5 centimeters fell in August. What type of graph would you use to display these data? Use graph paper to create the graph.

Circle Graphs

Like bar graphs, circle graphs can be used to display data in a number of separate categories. Unlike bar graphs, however, circle graphs can only be used when you have data for *all* the categories that make up a given topic. A circle graph is sometimes called a pie chart. The pie represents the entire topic, while the slices represent the individual categories. The size of a slice indicates what percentage of the whole a particular category makes up.

The data table below shows the results of a survey in which 24 teenagers were asked to identify their favorite sport. The data were then used to create the circle graph at the right.

Favorite Sports

Sport	Students
Soccer	8
Basketball	6
Bicycling	6
Swimming	4

To create a circle graph, follow these steps.

1. Use a compass to draw a circle. Mark the center with a point. Then draw a line from the center point to the top of the circle.
2. Determine the size of each "slice" by setting up a proportion where x equals the number of degrees in a slice. (*Note:* A circle contains 360 degrees.) For example, to find the number of degrees in the "soccer" slice, set up the following proportion:

$$\frac{\text{Students who prefer soccer}}{\text{Total number of students}} = \frac{x}{\text{Total number of degrees in a circle}}$$

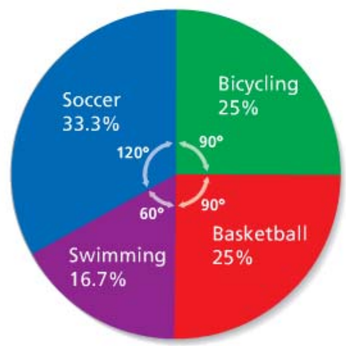
$$\frac{8}{24} = \frac{x}{360}$$

Cross-multiply and solve for x.

$$24x = 8 \times 360$$
$$x = 120$$

The "soccer" slice should contain 120 degrees.

Sports That Teens Prefer



3. Use a protractor to measure the angle of the first slice, using the line you drew to the top of the circle as the 0° line. Draw a line from the center of the circle to the edge for the angle you measured.
4. Continue around the circle by measuring the size of each slice with the protractor. Start measuring from the edge of the previous slice so the wedges do not overlap. When you are done, the entire circle should be filled in.
5. Determine the percentage of the whole circle that each slice represents. To do this, divide the number of degrees in a slice by the total number of degrees in a circle (360), and multiply by 100%. For the "soccer" slice, you can find the percentage as follows:

$$\frac{120}{360} \times 100\% = 33.3\%$$

6. Use a different color for each slice. Label each slice with the category and with the percentage of the whole it represents.
7. Add a title to the circle graph.

Activity

In a class of 28 students, 12 students take the bus to school, 10 students walk, and 6 students ride their bicycles. Create a circle graph to display these data.

Math Review

Scientists use math to organize, analyze, and present data. This appendix will help you review some basic math skills.

Mean, Median, and Mode

The **mean** is the average, or the sum of the data divided by the number of data items. The middle number in a set of ordered data is called the **median.** The **mode** is the number that appears most often in a set of data.

Example

A scientist counted the number of distinct songs sung by seven different male birds and collected the data shown below.

Male Bird Songs

Bird	A	B	C	D	E	F	G
Number of Songs	36	29	40	35	28	36	27

To determine the mean number of songs, add the total number of songs and divide by the number of data items—in this case, the number of male birds.

$$\text{Mean} = \frac{231}{7} = 33 \text{ songs}$$

To find the median number of songs, arrange the data in numerical order and find the number in the middle of the series.

27 28 29 35 36 36 40

The number in the middle is 35, so the median number of songs is 35.

The mode is the value that appears most frequently. In the data, 36 appears twice, while each other item appears only once. Therefore, 36 songs is the mode.

Practice

Find out how many minutes it takes each student in your class to get to school. Then find the mean, median, and mode for the data.

Probability

Probability is the chance that an event will occur. Probability can be expressed as a ratio, a fraction, or a percentage. For example, when you flip a coin, the probability that the coin will land heads up is 1 in 2, or $\frac{1}{2}$, or 50 percent.

The probability that an event will happen can be expressed in the following formula.

$$P(\text{event}) = \frac{\text{Number of times the event can occur}}{\text{Total number of possible events}}$$

Example

A paper bag contains 25 blue marbles, 5 green marbles, 5 orange marbles, and 15 yellow marbles. If you close your eyes and pick a marble from the bag, what is the probability that it will be yellow?

$$P(\text{yellow marbles}) = \frac{\text{15 yellow marbles}}{\text{50 marbles total}}$$

$$P = \frac{15}{50}, \text{ or } \frac{3}{10}, \text{ or } 30\%$$

Practice

Each side of a cube has a letter on it. Two sides have *A*, three sides have *B*, and one side has *C*. If you roll the cube, what is the probability that *A* will land on top?

Area

The **area** of a surface is the number of square units that cover it. The front cover of your textbook has an area of about 600 cm^2.

Area of a Rectangle and a Square To find the area of a rectangle, multiply its length times its width. The formula for the area of a rectangle is

$$A = \ell \times w, \text{ or } A = \ell w$$

Since all four sides of a square have the same length, the area of a square is the length of one side multiplied by itself, or squared.

$$A = s \times s, \text{ or } A = s^2$$

Example

A scientist is studying the plants in a field that measures 75 m × 45 m. What is the area of the field?

$$A = \ell \times w$$
$$A = 75 \text{ m} \times 45 \text{ m}$$
$$A = 3{,}375 \text{ m}^2$$

Area of a Circle The formula for the area of a circle is

$$A = \pi \times r \times r, \text{ or } A = \pi r^2$$

The length of the radius is represented by r, and the value of π is approximately $\frac{22}{7}$.

Example

Find the area of a circle with a radius of 14 cm.

$$A = \pi r^2$$
$$A = \frac{22}{7} \times 14 \text{ cm} \times 14 \text{ cm}$$
$$A = 616 \text{ cm}^2$$

Practice

Find the area of a circle that has a radius of 21 m.

Circumference

The distance around a circle is called the circumference. The formula for finding the circumference of a circle is

$$C = 2 \times \pi \times r, \text{ or } C = 2\pi r$$

Example

The radius of a circle is 35 cm. What is its circumference?

$$C = 2\pi r$$
$$C = 2 \times \frac{22}{7} \times 35 \text{ cm}$$
$$C = 220 \text{ cm}$$

Practice

What is the circumference of a circle with a radius of 28 m?

Volume

The volume of an object is the number of cubic units it contains. The volume of a wastebasket, for example, might be about 26,000 cm^3.

Volume of a Rectangular Object To find the volume of a rectangular object, multiply the object's length times its width times its height.

$$V = \ell \times w \times h, \text{ or } V = \ell wh$$

Example

Find the volume of a box with length 24 cm, width 12 cm, and height 9 cm.

$$V = \ell wh$$
$$V = 24 \text{ cm} \times 12 \text{ cm} \times 9 \text{ cm}$$
$$V = 2{,}592 \text{ cm}^3$$

Practice

What is the volume of a rectangular object with length 17 cm, width 11 cm, and height 6 cm?

Fractions

A **fraction** is a way to express a part of a whole. In the fraction $\frac{4}{7}$, 4 is the numerator and 7 is the denominator.

Adding and Subtracting Fractions To add or subtract two or more fractions that have a common denominator, first add or subtract the numerators. Then write the sum or difference over the common denominator.

To find the sum or difference of fractions with different denominators, first find the least common multiple of the denominators. This is known as the least common denominator. Then convert each fraction to equivalent fractions with the least common denominator. Add or subtract the numerators. Then write the sum or difference over the common denominator.

Example

$$\frac{5}{6} - \frac{3}{4} = \frac{10}{12} - \frac{9}{12} = \frac{10 - 9}{12} = \frac{1}{12}$$

Multiplying Fractions To multiply two fractions, first multiply the two numerators, then multiply the two denominators.

Example

$$\frac{5}{6} \times \frac{2}{3} = \frac{5 \times 2}{6 \times 3} = \frac{10}{18} = \frac{5}{9}$$

Dividing Fractions Dividing by a fraction is the same as multiplying by its reciprocal. Reciprocals are numbers whose numerators and denominators have been switched. To divide one fraction by another, first invert the fraction you are dividing by—in other words, turn it upside down. Then multiply the two fractions.

Example

$$\frac{2}{5} \div \frac{7}{8} = \frac{2}{5} \times \frac{8}{7} = \frac{2 \times 8}{5 \times 7} = \frac{16}{35}$$

Practice

Solve the following: $\frac{3}{7} \div \frac{4}{5}$.

Decimals

Fractions whose denominators are 10, 100, or some other power of 10 are often expressed as decimals. For example, the fraction $\frac{9}{10}$ can be expressed as the decimal 0.9, and the fraction $\frac{7}{100}$ can be written as 0.07.

Adding and Subtracting With Decimals To add or subtract decimals, line up the decimal points before you carry out the operation.

Example

$$\begin{array}{r} 27.4 \\ +\ 6.19 \\ \hline 33.59 \end{array} \qquad \begin{array}{r} 278.635 \\ -\ 191.4 \\ \hline 87.235 \end{array}$$

Multiplying With Decimals When you multiply two numbers with decimals, the number of decimal places in the product is equal to the total number of decimal places in each number being multiplied.

Example

$$\begin{array}{rl} 46.2 & \text{(one decimal place)} \\ \times\ 2.37 & \text{(two decimal places)} \\ \hline 109.494 & \text{(three decimal places)} \end{array}$$

Dividing With Decimals To divide a decimal by a whole number, put the decimal point in the quotient above the decimal point in the dividend.

Example

$$15.5 \div 5$$

$$5\overline{)15.5} = 3.1$$

To divide a decimal by a decimal, you need to rewrite the divisor as a whole number. Do this by multiplying both the divisor and dividend by the same multiple of 10.

Example

$$1.68 \div 4.2 = 1.68 \div 4.2$$

$$42\overline{)16.8} = 0.4$$

Practice

Multiply 6.21 by 8.5.

Ratio and Proportion

A **ratio** compares two numbers by division. For example, suppose a scientist counts 800 wolves and 1,200 moose on an island. The ratio of wolves to moose can be written as a fraction, $\frac{800}{1,200}$, which can be reduced to $\frac{2}{3}$. The same ratio can also be expressed as 2 to 3 or 2 : 3.

A **proportion** is a mathematical sentence saying that two ratios are equivalent. For example, a proportion could state that $\frac{800 \text{ wolves}}{1,200 \text{ moose}} = \frac{2 \text{ wolves}}{3 \text{ moose}}$. You can sometimes set up a proportion to determine or estimate an unknown quantity. For example, suppose a scientist counts 25 beetles in an area of 10 square meters. The scientist wants to estimate the number of beetles in 100 square meters.

Example

1. Express the relationship between beetles and area as a ratio: $\frac{25}{10}$, simplified to $\frac{5}{2}$.
2. Set up a proportion, with x representing the number of beetles. The proportion can be stated as $\frac{5}{2} = \frac{x}{100}$.
3. Begin by cross-multiplying. In other words, multiply each fraction's numerator by the other fraction's denominator.

   $5 \times 100 = 2 \times x$, or $500 = 2x$
4. To find the value of x, divide both sides by 2. The result is 250, or 250 beetles in 100 square meters.

Practice

Find the value of x in the following proportion: $\frac{6}{7} = \frac{x}{49}$.

Percentage

A **percentage** is a ratio that compares a number to 100. For example, there are 37 granite rocks in a collection that consists of 100 rocks. The ratio $\frac{37}{100}$ can be written as 37%. Granite rocks make up 37% of the rock collection.

You can calculate percentages of numbers other than 100 by setting up a proportion.

Example

Rain falls on 9 days out of 30 in June. What percentage of the days in June were rainy?

$$\frac{9 \text{ days}}{30 \text{ days}} = \frac{d\%}{100\%}$$

To find the value of d, begin by cross-multiplying, as for any proportion:

$9 \times 100 = 30 \times d \qquad d = \frac{900}{30} \qquad d = 30$

Practice

There are 300 marbles in a jar, and 42 of those marbles are blue. What percentage of the marbles are blue?

Significant Figures

The **precision** of a measurement depends on the instrument you use to take the measurement. For example, if the smallest unit on the ruler is millimeters, then the most precise measurement you can make will be in millimeters.

The sum or difference of measurements can only be as precise as the least precise measurement being added or subtracted. Round your answer so that it has the same number of digits after the decimal as the least precise measurement. Round up if the last digit is 5 or more, and round down if the last digit is 4 or less.

Example

Subtract a temperature of 5.2°C from the temperature 75.46°C.

$$75.46 - 5.2 = 70.26$$

5.2 has the fewest digits after the decimal, so it is the least precise measurement. Since the last digit of the answer is 6, round up to 3. The most precise difference between the measurements is 70.3°C.

Practice

Add 26.4 m to 8.37 m. Round your answer according to the precision of the measurements.

Significant figures are the number of nonzero digits in a measurement. Zeros between nonzero digits are also significant. For example, the measurements 12,500 L, 0.125 cm, and 2.05 kg all have three significant figures. When you multiply and divide measurements, the one with the fewest significant figures determines the number of significant figures in your answer.

Example

Multiply 110 g by 5.75 g.

$$110 \times 5.75 = 632.5$$

Because 110 has only two significant figures, round the answer to 630 g.

Scientific Notation

A **factor** is a number that divides into another number with no remainder. In the example, the number 3 is used as a factor four times.

An **exponent** tells how many times a number is used as a factor. For example, $3 \times 3 \times 3 \times 3$ can be written as 3^4. The exponent "4" indicates that the number 3 is used as a factor four times. Another way of expressing this is to say that 81 is equal to 3 to the fourth power.

Example

$$3^4 = 3 \times 3 \times 3 \times 3 = 81$$

Scientific notation uses exponents and powers of ten to write very large or very small numbers in shorter form. When you write a number in scientific notation, you write the number as two factors. The first factor is any number between 1 and 10. The second factor is a power of 10, such as 10^3 or 10^6.

Example

The average distance between the planet Mercury and the sun is 58,000,000 km. To write the first factor in scientific notation, insert a decimal point in the original number so that you have a number between 1 and 10. In the case of 58,000,000, the number is 5.8.

To determine the power of 10, count the number of places that the decimal point moved. In this case, it moved 7 places.

$$58{,}000{,}000 \text{ km} = 5.8 \times 10^7 \text{ km}$$

Practice

Express 6,590,000 in scientific notation.