Colliding Galaxies

These two spiral galaxies, known as “the mice,” have been colliding for about 160 million years. Eventually, they will merge into one giant, elliptical galaxy.

Science Journal
In your Science Journal, write a paragraph about what you know about the Sun as a star.
Launch LAB

Stars in the Sky
Have you ever looked up at the night sky and been amazed at the number of stars you could see? But if you live in a well lighted area, you may not have seen very many stars at all. In this lab, you will explore a quick way to estimate how many stars you can see in different parts of the sky.

1. Ask an adult to help you locate an area near your home suitable for star gazing where there are not very many lights.
2. Hold a cardboard tube up to one eye and look through it at one area of the sky.
3. Count the number of stars you can see easily through the tube.
4. Look at three other areas of the sky in the same way and count those stars. Try looking to the south, west, straight up, and in a random direction.
5. Compare your data with those of two or three other students.
6. **Think Critically** In your Science Journal, report whether a similar number of stars were easily visible no matter where you looked or whether the number of stars varied. Explain any similarities or differences noted by you or other students.

Foldables

**Cosmology** Make the following Foldable to help identify what you know, what you want to know, and what you learned about stars, galaxies, and cosmology.

**STEP 1** Fold a vertical sheet of paper from side to side. Make the front edge about \(\frac{1}{2}\) inch longer than the back edge.

**STEP 2** Turn lengthwise and fold into thirds.

**STEP 3** Unfold and cut only the top layer along both folds to make three tabs. Label each tab as shown.

Questioning Before you read the chapter, write what you know about cosmology under the left tab of your Foldable, and write questions about what you’d like to know under the center tab. After you read the chapter, list what you learned under the right tab.

Science Online

Preview this chapter’s content and activities at gpescience.com
Constellations

Have you ever watched clouds drift by on a summer day and tried to find shapes and patterns in them? One might look like a ship and another might resemble a rabbit or a bear. Long ago, people did much the same thing with stars. They named these patterns of stars after characters in stories, animals, or tools. Many of the names given to these star patterns by ancient cultures survive today and are called constellations. Astronomers use these constellations to locate and name stars.

From Earth, the stars in a constellation appear relatively close to one another. You can see that some of the stars are brighter than others, but you can’t see how far they are from you or from each other. Usually, they lie at greatly different distances and just happen to line up and form a pattern.

In Figure 1, three constellations are shown with some of their brighter stars. The constellations visible in the evening sky change throughout the year.

Mythology In many cultures, Orion was a great hunter who had two hunting dogs, Canis Major (big dog) and Canis Minor (little dog). In another myth, two bears traveled around Earth’s north pole. The constellations Ursa Major and Ursa Minor (big and little bears) were named for them. Indeed, they do swing around the north pole. In fact, Polaris, the polestar, is in Ursa Minor. If you have seen the Big Dipper you have seen most of Ursa Major, because the dipper is part of this constellation.
Telescopes Constellations and the stars that make them up are visible with the unaided eye. However, to see other objects in space, or to see some objects better, you need a telescope. Scientists and amateur astronomers use many different types of telescopes. Optical telescopes are used to study objects in visible light, and radio telescopes are used to study objects in the radio wavelengths. What do you think would be used to study X rays?

Optical Telescopes There are two basic types of optical telescopes. One type uses only lenses to study light and the other uses lenses and mirrors. Optical telescopes collect visible light and produce magnified images of objects. Light is collected by an objective lens or mirror. Because starlight is so distant, the light forms an image at the focus of the telescope. The focus is where light that is bent by the objective lens or reflected by the objective mirror comes together. A second lens, the eyepiece lens, then magnifies the image. The distance from the objective to the focus is the focal length of the telescope. You can find the magnifying power ($M_p$) of a telescope by dividing the focal length of the objective ($f_o$) by the focal length of the eyepiece ($f_e$).

$$M_p = \frac{f_o}{f_e}$$

Refracting Optical Telescopes A refracting telescope uses a convex lens, which is curved outward like the surface of a ball, as an objective, shown in Figure 2. When the lens curves outward on both sides, it is a double convex lens. Light passes through the objective lens. The eyepiece, which also can be a double convex lens, then magnifies the image. There is a limit to how large a refracting telescope can be. Since the objective lens can be supported only at its edges, it could sag in the middle if it is too large. When a larger telescope is needed, a reflecting telescope is used.

Modeling a Telescope

Procedure

1. Obtain two lenses of different focal length from your teacher.
2. Place double-sided tape around the edge of one lens.
3. Place the lens along the short side of a piece of construction paper and roll the paper around the lens to form a tube. Tape the tube securely.
4. Repeat steps 2 and 3 with the other lens.
5. Insert the small tube into the large tube with the lenses on opposite ends.
6. Look through the eyepiece lens (small tube) and slide it in and out until you see a clear image.

Analysis

1. Observe an object with and without your telescope. Estimate how many times larger it appears through the telescope.
2. Obtain the focal lengths of your lenses from your teacher. Calculate the magnifying power of your telescope using the equation on this page. Compare this value to your estimate.
Reflecting Optical Telescopes A **reflecting telescope** uses a mirror as an objective to reflect light to the focus. **Figure 3** shows how light passes through the open end of a reflecting telescope and strikes a concave mirror at the base of the telescope. Often, a smaller mirror is used to reflect light into the eyepiece where it is magnified for viewing. However, in very large reflecting telescopes, the astronomer sits inside the telescope and looks through the eyepiece at the focus. Because mirrors can be supported from underneath a much larger telescope can be built.

**Figure 3** Reflecting telescopes use concave mirrors to gather light.

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**Applying Math**

**Use Equations**

**THE MAGNIFYING POWER OF TELESCOPES** If the focal lengths of a telescope’s objective and eyepiece are known, the magnifying power can be calculated from the equation:

\[ M_p = \frac{f_o}{f_e} \]

In this equation, \( M_p \) is the magnifying power of the telescope, \( f_o \) is the focal length of the objective, and \( f_e \) is the focal length of the eyepiece. Find the magnifying power of a telescope with a focal length of 1200 mm using eyepieces of 20 mm and 6 mm.

**IDENTIFY** known values and unknown values.

**Identify the known values.**

- the focal length of the objective is 1,200 mm, this means \( f_o = 1,200 \text{ mm} \)
- the focal lengths of the eyepieces are 20 mm and 6 mm, this means \( f_e = 20 \text{ mm}; 6 \text{ mm} \)

**Identify the unknown value**

- what is the magnifying power of the telescope means \( M_p = ? \)

**SOLVE** the problem

Substitute the known values into the equation for magnifying power:

\[ M_p = \frac{1,200 \text{ mm}}{20 \text{ mm}} = 60 \]
\[ M_p = \frac{1,200 \text{ mm}}{6 \text{ mm}} = 200 \]

Notice that the units cancel, and that magnifying power has no unit.

**CHECK** the answer

Does your answer seem reasonable? Do images look 60 times larger than the object when using the 20 mm eyepiece and 200 times larger when using the 6 mm eyepiece?

**Practice Problems**

1. Find the magnifying power of a telescope with a focal length of 2,500 mm when using eyepieces with focal lengths of 50 mm and 10 mm.

2. Find the magnifying power for a telescope with a focal length of 900 mm when using an eyepiece with a focal length of 12 mm.

For more practice problems, go to page 879 and visit Math Practice at gpescience.com.
**New Telescope Design** The most recent innovations in optical telescopes involve active and adaptive optics. With active optics, a computer is used to correct changes in temperature, mirror distortions, and bad viewing conditions. Adaptive optics uses a laser to probe the atmosphere and relay information to a computer about air turbulence. The computer then adjusts the telescope's mirror thousands of times per second to lessen the effects of atmospheric turbulence. The European Southern Observatory’s *Very Large Telescope* in Chile, the largest optical telescope in use, uses adaptive optics.

**Radio Telescopes** Radio waves, like visible light, are a form of electromagnetic energy emitted by stars and other objects in space. Radio waves can be detected even during the day, when the Sun’s light makes it impossible to see the fainter visible light from other stars. Radio waves pass freely through Earth’s atmosphere, even on completely cloudy days.

A telescope that collects and amplifies radio waves is a *radio telescope*. Because radio waves have long wavelengths, a radio telescope must be built with a very large objective, usually some form of dish antenna. Astronomers often build several radio telescopes close together and connect them to form one large telescope. The VLA (very large array), shown in Figure 4, is an example of this.

*What type of telescope is used to study radio waves?*

**Hubble Space Telescope** Even using active and adaptive optics, the atmosphere limits what Earth-based telescopes can achieve. For this reason, astronomers use space telescopes, such as the *Hubble Space Telescope* shown in Figure 5.

The clear images provided by *Hubble* are changing scientists’ ideas about space. One object viewed by *Hubble* is the massive galaxy cluster Abell 2218, which is about 2 billion light-years away. This cluster acts as a gravity lens that magnifies the light of even more distant galaxies. Such large distances in space are measured in a unit called a *light-year*, the distance that light travels in one year—about 9.5 trillion km. Even though it may seem confusing, remember that a light-year measures distance, not time.

*Figure 4* 27 dish antennae of the VLA are mounted on railroad tracks for rapid repositioning. The 304-m dish antenna in Arecibo, Puerto Rico is shown in the inset.

*Figure 5* The *Hubble Space Telescope* orbits Earth at an altitude of 610 km.

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**ScienceOnline**

**Topic: New Telescope Design**

Visit gpescience.com for Web links to information about the development of new telescopes.

**Activity** Write and illustrate a paragraph about one of the new designs being considered for Earth-based telescopes or Earth-orbital telescopes.
**Spectroscopes**

A **spectroscope** is a device that uses a prism or diffraction grating to disperse the light into its component wavelengths. When connected to a telescope, it disperses the light from the star or other celestial object collected by the telescope into its electromagnetic spectrum. This tells astronomers a great deal about a star. For example, they can determine its chemical composition, its surface temperature, and whether it is moving away from or toward Earth. Astronomers can even tell how fast the star is moving in relation to Earth.

**What does a spectroscope do?**

**Spectra** A spectroscope disperses light into its individual wavelengths, or its spectrum. Visible light yields a spectrum of colors, including red, orange, yellow, green, blue, indigo, and violet, the colors of a rainbow. In fact, a rainbow is actually a visible spectrum of sunlight that has been dispersed by droplets of water in Earth’s atmosphere. A spectrum displays all wavelengths in the light being studied, shown in **Figure 6**. You have learned that a star’s spectrum indicates its surface temperature. For example, if the blue section is brightest, the star has a relatively high surface temperature. If the red section is brightest, the temperature of the star is much lower.

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**Figure 6** The dark lines in stellar spectra tell astronomers what elements are present in the stars being studied.

**Explain how a spectroscope produces a spectrum of colors.**

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**Summary**

**Constellations**
- Constellations are patterns of stars that are used today to name and locate stars.

**Telescopes**
- Refracting telescopes use lenses to collect light and magnify the image.
- Reflecting telescopes use a mirror to collect light and a lens to magnify the image.
- A radio telescope collects and amplifies radio waves.

**Spectroscopes**
- A spectroscope disperses light into its spectrum.

**Self Check**

1. Define constellation.
2. Compare and contrast refractor telescopes and reflector telescopes.
3. Describe the objective of a radio telescope.
4. Explain how radio waves differ from visible light.
5. Think Critically Why do astronomers change eyepieces rather than objectives when they wish to increase the magnifying power of a telescope?

**Applying Math**

6. Use Numbers If the magnifying powers ($M_p$) of refracting and reflecting telescopes are 20 and 100, respectively, how much greater is the $M_p$ of the reflecting telescope?
Evolution of Stars

How do stars form?

Star formation begins with condensation of a large cloud of gas, ice, and dust called a nebula. These particles exert a gravitational force on each other, and the nebula contracts. Gravitational instability within the nebula causes it to break up into smaller cloud fragments. As a cloud fragment condenses its temperature increases. When the interior temperature reaches 1 million K, the center of the cloud is called a protostar. When the temperature reaches 10 million K, hydrogen fuses to form helium and a star is born.

**H-R Diagram** In the early 1900s, Ejnar Hertzsprung and Henry Russell studied the relationship between absolute magnitude and temperature of stars. They noticed that higher-temperature stars radiate more energy and have higher absolute magnitudes. As stars form, even while they are still protostars, they can be plotted on the Hertzsprung-Russell (H-R) diagram, like the one shown in Figure 7. About 90 percent of all stars fall on a line drawn from the upper left to the lower right of the H-R diagram, called the main sequence. The other 10 percent of stars fall elsewhere on the graph and will be discussed later.

Figure 7 The Sun is located in the center of the main sequence on this H-R diagram. It is cooler than young stars like Vega and Sirius, but warmer than the giant Betelgeuse.
**How do stars change?**

A star like our Sun probably had a diameter about 100 times its present size while a protostar. As a star continues to form, it shrinks and increases in density, raising its interior temperature. Once fusion begins and the star attains stellar equilibrium, it settles onto the main sequence. In general, stellar equilibrium is the balance between outward pressure due to energy released in fusion and inward pressure due to gravity. Once this state of equilibrium is lost, the star enters the next stage of its life.

**Main Sequence** As long as the star’s gravity balances outward pressures, the star remains on the main sequence. Stars are thought to spend most of their lives on the main sequence, which explains why this is the largest group on the H-R diagram. The Sun has been a main sequence star for about 5 billion years and will continue in this stage for about another 5 billion years.

The Sun is classified as which type of star?

When its hydrogen fuel is depleted, a star loses its equilibrium and its main sequence status. What it becomes next is determined by the total mass of the star. An average star like the Sun will become a giant, then a white dwarf, and finally a black dwarf. Stars more massive than the Sun can become supergiants and end up as neutron stars or black holes. Stars much lower in mass than the Sun, like the red dwarf star *Proxima Centauri*, could remain on the main sequence for 16 trillion years. Most stars on the main sequence are red dwarfs, and they probably make up about 80 percent of all stars in the universe.

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**Figure 8** Only part of the giant star Antares is shown here. Super giant stars, such as Betelgeuse, are too large to be shown at all.
**Giants and Dwarfs** When hydrogen in a star’s core is used up, its outward pressure is overcome by gravity. Its core contracts and increases in temperature. The outer layers expand and cool. In this late stage of its life cycle, an average star like our Sun is called a giant. In about five billion years, our Sun will become a giant like the one shown in Figure 8.

The giant’s core continues to contract and become hotter. Eventually, the core uses up its helium and contracts even more. When temperature reaches 100 million K, helium fuses, forming carbon. Now the star is enormous and its surface is much cooler. Its outer layers escape into space leaving behind the hot, dense core that continues to contract. At this final stage in an average star’s evolution, it is a white dwarf. A white dwarf, also shown in Figure 8, is about the size of Earth.

**Supergiants, Neutron Stars, and Black Holes** Stars that are over eight times more massive than our Sun take a different course. Their cores reach temperatures high enough to cause fusion that produces heavier and heavier elements. The star expands into a supergiant, such as Betelgeuse shown in Figure 9. Eventually, iron accumulates in the core. Since iron does not fuse readily, there is no outward radiation of energy to counteract the inward pull of gravity. The core collapses violently, and the outer portion of the star explodes, producing a supernova.

A supernova is a gigantic explosion in which the temperature in the collapsing core reaches 10 billion K and atomic nuclei are split into neutrons and protons. Protons merge with electrons to form neutrons, and the collapsing core becomes a neutron star. A typical neutron star is the size of a major city on Earth, but has a mass greater than the Sun’s.

Very massive stars, with masses greater than 25 times that of the Sun, face a different end. In this case, the final collapse of the core continues past the neutron-star stage, forming a black hole—an object so dense that nothing can escape its gravity if it gets too close.

**Supernovas** The heavy elements you are made of formed during supernova explosions. Type I supernovas form from hydrogen-poor, low mass stars that have pulled in matter from a nearby red giant star. This process, called carbon detonation, causes carbon fusion almost everywhere inside the star and is thought to destroy the star completely. In contrast, Type II supernovas form from hydrogen-rich, high mass stars. They leave behind a collapsed core that can then condense further to form a neutron star or black hole.
The Pleiades star cluster blazed into existence a mere 100 million years ago, when dinosaurs reigned on Earth and mammals were just gaining a foothold. The Pleiades, located in the back of the constellation Taurus, is among the earliest of celestial objects to be known and recorded by humans. Many myths sprang up to explain their origin. Today, astronomers study star clusters like the Pleiades because they offer valuable insights into how the universe is evolving.

Because star clusters are believed to have formed from the same nebula, they are assumed to be about the same distance away. For this reason they are plotted using apparent magnitude instead of absolute magnitude or luminosity. Note that a lower magnitude number represents a brighter star. The H-R diagram for the Pleiades shows a well-defined main sequence. Stars in the upper left are hot, blue, and massive. As stars age, they burn all available hydrogen and eventually become red giants. The presence of hot, blue stars and the lack of red giants indicate that the Pleiades is a relatively young star cluster.

M5 is a globular cluster, located roughly 24,500 light-years from Earth. It has a compact appearance and vastly more stars than are found in open clusters like the Pleiades. Astronomers believe M5 is one of the oldest star clusters in our galaxy, with an estimated age of 13 billion years.

M5 is a globular cluster, located roughly 24,500 light-years from Earth. It has a compact appearance and vastly more stars than are found in open clusters like the Pleiades. Astronomers believe M5 is one of the oldest star clusters in our galaxy, with an estimated age of 13 billion years.

Compare the H-R diagram for M5 to the H-R diagram for the Pleiades. The stars in cluster M5, which were once hot and blue, have evolved into cooler, highly luminous red giants that appear in the upper right of the diagram. Sun-sized stars evolve from main sequence to red giants over billions of years, indicating that M5 is an ancient star cluster.
The Sun—A Main Sequence Star

The Sun is a middle-aged star and is plotted just about in the middle of the main sequence on the H-R diagram. It is average in size, temperature, and absolute magnitude. A solar mass is simply the mass of the Sun. For most stars, the relationship between mass and luminosity can be approximated by

$$\frac{L}{L_\odot} = \left( \frac{M}{M_\odot} \right)^{3.5}$$

where $L_\odot$ and $M_\odot$ are the luminosity and mass of the Sun. The H-R diagrams, shown in Figure 10, are used to compare very young stars to very old stars.

Structure of the Sun Although scientists cannot see inside the Sun, they have developed some theories about its interior. Much of what they know comes from studying its outer layers and its surface. The solar interior is composed of the core, the radiation layer, and the convection layer. The surface of the Sun is called the photosphere. This is the layer of the Sun that gives us light. The atmosphere above the photosphere is composed of the chromosphere and the corona. The Sun’s structure is shown in Figure 11.

Solar Interior The innermost layer of the Sun is the core. This is where fusion occurs. The energy produced at the core may take millions of years to reach the photosphere where it is radiated into space.

The layer of the Sun just above the core is the radiation zone. In this layer, gases are completely ionized. Since no electrons remain on atoms to capture photons, this layer of the Sun is transparent to radiation. Energy formed by fusion travels easily through the radiation zone.

As you move farther outward from the Sun’s core, the temperature drops and some electrons remain bound to their atoms. Here the gas becomes opaque to radiation and by the time you reach the outer edge of the radiation zone, all of the photons generated in the core have been absorbed. The energy from these photons is carried to the Sun’s surface by convection through the next layer, the convection zone. Hotter gases from the bottom of this zone move upward toward the Sun’s surface and cooler gases sink, setting up convection cells.
**Photosphere** The Sun’s photosphere, or surface, is at the top of the convection zone and has a mottled appearance, called granulation. This is caused by rising hot material and sinking cooler material within the convection cells. Each granule shown in Figure 12 is about 1,000 km across and is a direct result of convection cells in the convection zone.

**Sunspots** Some areas of the Sun appear darker than others. These darker areas of the Sun’s photosphere, called sunspots, are cooler than surrounding areas. Scientists can observe the movement of individual sunspots as they move with the Sun’s rotation. They show that the Sun doesn’t rotate as a solid body—it rotates faster at its equator than at its poles. Sunspots near the equator take about 25 days to go around the Sun, but at about 60 degrees north or south latitude, they take about 31 days. Figure 12 shows a closeup view of some sunspots.

What is a sunspot? Sunspots aren’t permanent features of the Sun. They appear and disappear over periods of days, weeks, or months. The number of sunspots changes in a fairly regular pattern called the sunspot, or solar activity, cycle. Periods of sunspot maximum occur about every 11 years, with periods of sunspot minimum occurring in between. At a sunspot minimum, sunspots appear at high latitudes. As the cycle progresses, they appear closer to the Sun’s equator. By the next minimum, they again cluster at high latitudes.

**Prominences and Flares** Intense magnetic fields associated with sunspots can cause huge arching columns of gas called prominences to erupt, as shown in Figure 13. Convection in the convection zone causes magnetized gases to flow upward toward the photosphere. Sometimes the magnetic field strength is great enough that magnetic field lines shoot out from the surface near a pair of sunspots and cause a prominence of solar material to loop from one spot to the other. Some prominences blast material from the Sun into space at speeds ranging from 600 km/s to more than 1,000 km/s.

Gases near a sunspot sometimes brighten suddenly, shooting gas outward at high speed in what are called solar flares. Temperatures within these flares can reach 100 million K. Particles produced in a flare possess so much energy that the Sun’s magnetic field cannot hold them as it can hold prominences and they blast into space.
SECTION 2 Evolution of Stars

CMEs Sometimes large bubbles of ionized gas are emitted from the Sun. These are known as CMEs (coronal mass ejections). During sunspot minimums there is usually one CME per week, but during a sunspot maximum, there are two to three per day. When a CME is released in the direction of Earth, it appears as a halo around the Sun, as shown in Figure 14. As it passes Earth, the planet is exposed to a sudden shock wave of increased solar wind. Earth’s atmosphere protects us, but occurrences of auroras increase. When scientists note a CME, they post an alert to watch for auroras at lower latitudes than normal.

Auroras take place when high-energy particles in CMEs and the solar wind are carried past Earth’s magnetic field. This generates large electric currents that flow toward Earth’s poles. These electric currents ionize gases in Earth’s atmosphere. When these ions recombine with electrons and drop to a lower energy level, they produce light. This light is called the aurora borealis, or northern lights, when it occurs in the northern hemisphere. In the southern hemisphere, it is called the aurora australis. CMEs present little danger to life on Earth, but some of the highly charged solar wind material disrupts Earth’s magnetosphere and interferes with orbiting satellites and radio signals.

Summary

How do stars form?
- Stars form from a large cloud of gas, ice, and dust. Once the temperature inside the nebula reaches 10 million K, fusion begins.
- The H-R diagram plots temperature v. absolute magnitude of stars.

How do stars change?
- Once fusion begins, a star develops stellar equilibrium and becomes a main sequence star.
- When the hydrogen fuel is depleted, a star loses stellar equilibrium and evolves into a giant, or a supergiant.

The Sun—A Main Sequence Star
- The Sun’s energy is produced by fusion.
- Sunspots are dark, cooler regions on the Sun’s photosphere.
- Other solar features that can affect Earth are prominences, flares, and CMEs.

Self Check

1. Explain how stars form from nebulae.
2. Describe the different evolution stages of stars as shown on the H-R diagram.
3. Describe the structure of the Sun.
4. Explain the difference between Type I and Type II supernovas.
5. Think Critically What happens to stellar equilibrium to make a main sequence star evolve into a giant star?

Applying Math

6. Use Percentages Eighty percent of all stars are red dwarfs. Out of a random sample of 2,000 stars in the galaxy, about how many will plot on the H-R diagram as a red dwarf?
7. Use Numbers If the Sun will remain a main sequence star for a total of 10 billion years and Proxima Centauri will remain one for 16 trillion years, how many times longer will Proxima Centauri be a main sequence star?
Stars are plotted on the H-R diagram based on their temperature and brightness. You can determine the age of a cluster of stars by studying the H-R diagram of the stars within the cluster. Massive main sequence stars, located at the upper left of the diagram, evolve faster than stars farther down the main sequence. Stars in the lower right of the diagram evolve more slowly. How could you use this idea to help determine the relative ages of star clusters from their H-R diagrams?

**Real-World Problem**
How can the relative age of star clusters be determined from H-R diagrams of each cluster?

**Goals**
- Compare and contrast H-R diagrams of several star clusters.
- Determine the relative ages of four star clusters.

**Materials**
four H-R diagrams of star clusters

**Procedure**
1. Study the four H-R diagrams your teacher gives you.
2. Note which types of stars remain on the main sequence and which stars have evolved off the main sequence.
3. Based on the evolution of the stars within each star cluster, decide which cluster is youngest and which is oldest. Also decide the relative ages of the other two star clusters. HINT: The oldest cluster will have some that have evolved to white dwarfs.

**Conclude and Apply**
1. Compare and contrast H-R diagrams of four star clusters.
2. Determine which star cluster was youngest and which was oldest.
3. Explain how you determined the ages of these two star clusters.
4. Determine the relative ages of the remaining two star clusters.
5. Explain how you determined the ages of these two star clusters.

**Communicating Your Data**
Explain to your friends how the relative ages of star clusters can be found by studying H-R diagrams.
One reason to study astronomy is to learn about your place in the universe. Long ago, people thought Earth was at the center of the universe. You know this isn’t true, but do you know where you are in the universe?

You are on Earth, and Earth orbits the Sun. But the Sun orbits something else and it interacts with other objects in the universe. The Sun is one star among billions of stars in a galaxy. A galaxy is a large group of stars, gas, and dust held together by gravity, shown in Figure 15. Our galaxy, called the Milky Way, contains 400 billion stars, by most recent estimates, including the Sun. Countless other galaxies exist throughout the universe—an estimated 40 billion galaxies can be seen. Each of these galaxies contains the same elements, forces, and types of energy as our galaxy. There are three major types of galaxies: spiral, elliptical, and irregular.

Spiral Galaxies Take another look at Figure 15. Notice that spiral galaxies have spiral arms that wind outward from the galaxy’s center. These spiral arms are made up of bright stars, dust, and gas. Our neighbor, the Andromeda galaxy, is visible to the unaided eye as a fuzzy patch in the constellation Andromeda. It is a normal spiral galaxy with its arms starting close to center. Barred spirals are another type of galaxy that have spiral arms extending from a large central bar of stars, dust, and gas that passes through the center, or hub, of the galaxy. Astronomers are not certain whether the Milky Way is normal or barred spiral.
Elliptical Galaxies  Astronomers once thought that spiral galaxies were the most common galaxies because they are relatively large and easy to see. But as observations of the universe became more detailed, it became clear that most galaxies are elliptical galaxies, and most of these are dwarf galaxies. They are just too small and dim to be easily seen.

These galaxies are shaped like large, three-dimensional ellipses. Many are football-shaped, but others are spherical as shown in Figure 16. These giant elliptical galaxies can be over 9 million light-years across and contain trillions of stars. However, most dwarf ellipticals are only about 3,000 light-years across and contain fewer than a million stars.

Irregular Galaxies  Most galaxies that aren’t elliptical or spiral are considered irregular galaxies. They take many different shapes and contain 100 million to 10 billion stars, making them larger than dwarf ellipticals but smaller than spirals. Irregular galaxies are less common than spirals or ellipticals.

Two irregular galaxies called the Clouds of Magellan orbit the Milky Way. One of these, known as the Large Magellanic Cloud, is shown in Figure 17. Several other dwarf galaxies also are affected by the Milky Way’s gravity. One of these, the elliptical Sagittarius dwarf, is being absorbed by the Milky Way. This dwarf galaxy lies about 60,000 light-years from the center of the Milky Way on the opposite side of the galaxy from us and 20,000 light-years below the galactic plane.

The Local Group  Just as stars are grouped together within galaxies, galaxies are grouped into clusters. Clusters of galaxies are even grouped into superclusters. Our Milky Way galaxy belongs to a cluster called the Local Group. It is a relatively small cluster containing about 45 galaxies of various types and sizes, most of which are dwarf elliptical galaxies. The largest galaxy in the Local Group is the Andromeda galaxy, a spiral galaxy a little larger than ours that lies about 2.6 million light-years away. If the Andromeda galaxy and the Milky Way galaxy continue to travel through space as they are, they may collide in the distant future.

Figure 16  In ultraviolet light, this elliptical galaxy reveals a core of thousands of old, helium-burning stars. Identify the most common type of galaxies in the universe.

Figure 17  The irregular structure of the Large Magellanic Cloud might have been produced by interactions with the Milky Way galaxy.
How do galaxies form?

Astronomers aren’t sure how galaxies originally formed. It is thought that fluctuations in density of primordial matter in the universe began to form blobs of gas that would eventually form into galaxies. These blobs might have had masses equivalent to the mass of the dwarf galaxies. In fact, one idea is that the dwarf galaxies may be remnants of these earlier blobs of matter.

Most astronomers now believe that the galaxies we see closer to us grew by absorbing or merging with other smaller objects. One bit of evidence that supports this idea is that more distant galaxies tend to be much smaller than those closer to the Milky Way. It makes sense to conclude that these smaller galaxies that existed long ago merged to make the larger, more organized galaxies of the universe today. Also, we have evidence that galaxies do collide.

Colliding Galaxies In some galaxy clusters, the galaxies are concentrated very close together. In the Virgo Cluster, for example, thousands of galaxies orbit within 10 million light-years of each other. Do these galaxies collide? If so, what happens to them and to the stars within them? It seems that little happens to the individual stars within the galaxies. There is so much open space between the stars that the individual stars of the two galaxies just move past each other.

What happens to individual stars in colliding galaxies?

However, galaxy collisions have a strong effect on the overall structure and shape of the colliding galaxies. They may lose all of their spiral shape, if they had any.

It is thought that the two galaxies shown in Figure 18 will eventually collide. The smaller galaxy on the right does not seem to have enough energy to escape the larger one to the left. When galaxies interact by passing close to each other or by colliding, there is a burst of star formation in each. Their interstellar gas and dust clouds are shocked and squeezed, leading to star formation. This can be detected by the blue light emitted by young, hot stars.

Figure 18 In about a billion years, these two galaxies will merge. Much of their spiral structures probably will be lost.
The Milky Way

Recall that the Milky Way galaxy contains about 400 billion stars, including our Sun. The Sun makes one complete orbit around the center of the Milky Way in about 225 million years, traveling at a speed of 220 km/s. This means that since it formed, the Sun has made a little over 22 orbits of the Milky Way.

The Milky Way is usually classified as a normal spiral galaxy. However, recent evidence suggests that it might be a barred spiral. It is difficult to know for sure because astronomers can never see our galaxy from the outside. You can’t see the normal spiral or barred shape of the Milky Way because the Sun and Earth are located within one of its spiral arms. However, you can see the Milky Way stretching across the sky as a faint band of light. All of the stars you can see belong to the Milky Way galaxy.

What type of galaxy is the Milky Way?

Evidence indicates that the Milky Way, like many galaxies, grows by absorbing other galaxies. It has been gobbling up the Sagittarius dwarf elliptical galaxy for 2 billion years. If we could see infrared light, we could see stars and other material from this galaxy becoming part of our section of the Milky Way, as shown in Figure 19. Eventually, the Milky Way probably will absorb both Clouds of Magellan and several other dwarf galaxies.

Structure of the Milky Way The Milky Way galaxy, shown in Figure 20, measures about 100,000 light-years from one side to the other. The Sun lies about 26,000 light-years from the galactic center on the edge of one of the spiral arms. The Milky Way’s disk is about 1,000 light-years thick—it would take 1,000 years to travel from top to bottom even at the speed of light. The central bulge of the Milky Way is about 10,000 light-years in diameter.

Figure 19 The swirls of red seen in this model are stars in the remnants of the Sagittarius dwarf elliptical galaxy.

Figure 20 Star density is greatest near the center of the Milky Way, with over 1,400 stars in every cubic light-year of space. The Sun is located about halfway out on the Orion arm of the Milky Way galaxy.

Explain what is meant by a cubic light-year.
**Spiral Arms** The arms of a spiral galaxy look like pinwheels that begin near the galactic center and extend outward through the disk of the galaxy. These spiral arms contain both young stars and prestellar material, such as glowing nebulae. Young open star clusters are present too. This is the part of a spiral galaxy where stars are forming. Astronomers do not yet fully understand what causes the spiral structure to form. They speculate that it might be caused by instabilities in the gas near the galactic bulge or gravitational effects of other galaxies that are or were nearby, or might be just an extension of the shape of the galactic bulge itself. They just don’t know.

**Galaxy Center** What strange objects lurk in the very dense population of stars at a galaxy’s core? Recent theories suggest that extremely massive black holes might exist at the cores of galaxies. The problem is that this part of a galaxy is hidden from view by material that exists in between the densely packed stars. The total energy emitted from an object called Sgr A* (saj-ay-star), located in the nucleus of the Milky Way, is equivalent to the energy that would be emitted by a million suns. The leading theory about this object, shown in Figure 21, is that it is a supermassive black hole, containing the mass of 3 million suns.

**Summary**

**Galaxies**
- A galaxy is a large group of stars, gas, and dust held together by gravity.
- The three main types of galaxies are elliptical, irregular, and spiral.

**How do galaxies form?**
- Astronomers believe that galaxies form by absorbing or merging with smaller objects.
- Young, hot stars form when galaxies collide, but individual stars within each galaxy are not affected much.

**The Milky Way Galaxy**
- The Milky Way galaxy contains about 400 billion stars and has a spiral shape.
- The Milky Way galaxy is about 100,000 light-years across and the Sun lies about 26,000 light-years from its center.
- Supermassive black holes are thought to exist in the centers of galaxies.

**Self Check**

1. Compare and contrast the Milky Way galaxy to other galaxies in the universe.
2. Describe the three main types of galaxies.
3. Draw the overall structure of the Milky Way galaxy and indicate where the Sun is located.
4. Describe the most common type of galaxy.
5. Think Critically How might the Sun be affected if the Andromeda galaxy and the Milky Way galaxy collide.

**Applying Math**

6. Use Numbers Assume there are 400 billion stars in the Milky Way galaxy, plus or minus 200 billion. Based on this estimate, what is the range of the number of stars that might exist in the Milky Way?
7. Use Percentages A dwarf elliptical galaxy has fewer than 1 million stars and a small irregular galaxy contains 100 million stars. What percent of the number of stars found in a small irregular galaxy are found in a dwarf elliptical galaxy?
Figure 22 This map produced by the WMAP team has been called a “baby picture” of the universe. It is oval because it is a projection, just as maps of Earth can be projected as ovals. Infer why this map is called a “baby picture” of the universe.

How did it begin?

The study of the universe—how it began, how it evolves, and what it is made of—is known as cosmology. Several models of the origin and evolution of the universe have been proposed.

One model, proposed in 1948, is called the steady state theory. In this theory, the universe has always existed and it always will. As the universe expands, new matter is created. The density of the universe remains the same or in steady state.

A second idea is called the oscillating model. In this model, the universe expanded rapidly, then slowed, and eventually contracted. This oscillating process continues back and forth through time. Some scientists currently believe that enough matter exists to cause the universe to eventually contract.
The Big Bang Theory

The most accepted theory of how the universe formed is the **big bang theory**. It states that the universe started with a big bang, or explosion, and has been expanding ever since. The big bang is not like an explosion of matter into empty space; it is the rapid expansion of space itself.

**When did it begin?** A NASA-related mission, called the Wilkinson Microwave Anisotropy Probe (WMAP), produced a map of the oldest light in the universe. Based on the map, shown in Figure 22, and other data, the WMAP team proposed a more specific age of the universe. Their findings indicate that the universe began about 13.7 billion years ago with a big bang. The team believes its data are correct within a one percent margin of error. They measured temperature variations over the entire universe found in the cosmic microwave background radiation. This radiation is thought to have been produced about 400,000 years after the big bang when temperatures became low enough for atoms to form. Bright areas of the map are thought to indicate places that collapsed, forming the galaxies that we see today.

**Reading Check**  **When did the universe begin?**

Expansion of the Universe

The motion of stars within the Milky Way can be detected by using the Doppler effect. For example, sound waves from a moving source are compressed as the object approaches and stretched as it recedes. Doppler shifts occur in light as well as sound. If a star approaches Earth, its wavelengths of light are compressed, causing a blue shift. If a star moves away, its wavelengths are stretched, causing a red shift. Using the Doppler shift, scientists found that some galaxies in the Local Group are moving toward, some are moving away, and others are moving with the Milky Way. A red shift is also seen in the light from distant galaxies, but this is explained differently.

![Figure 23](image)

The observer on the right experiences a blue shift as wavelengths of light emitted by an approaching object are compressed. The observer on the left experiences a red shift as wavelengths are stretched.
The Doppler shift does not explain the shift in wavelength of light coming from distant galaxies. This shift is known as the Hubble red shift. It is caused by the stretching of space itself as the universe expands. Light waves traveling through space lengthen as space expands. The fact that this red shift is seen in the light from all galaxies outside the Local Group indicates that the entire universe is expanding.

**What is the universe made of?**

The way in which galaxies like the Milky Way rotate and move should depend on the amounts of mass they contain. The problem is that if only the visible or otherwise detectable mass (called regular matter) is counted, the Milky Way and other galaxies shouldn’t be rotating, moving, and interacting with other galaxies the way they are. It appears that regular matter makes up only a very small amount of the known universe. Much of the mass that must be present cannot be seen. However, its effect on other galaxies can be seen, shown in Figure 24. This unseen and little-understood matter that affects galaxies has been named dark matter.

*Which type of matter is considered to make up the least amount of the universe?*
**Dark Matter** Although scientists are uncertain about what dark matter is, the concept helps them explain how the universe may have formed. Temperature variations, as shown on the WMAP map, could have led to density fluctuations in the early universe. As the universe expanded, gravity from dark matter pulled matter together in regions with higher density. Galaxies could have formed in the denser regions and voids could have formed elsewhere. This structure is seen when sections of the universe are mapped, as shown in Figure 25.

**Dark Energy** Data indicate that the expansion of the universe is accelerating. Explaining this acceleration is difficult. One hypothesis is that a form of energy, called dark energy, might be causing the acceleration. When matter was closer together in the early universe, gravity could easily overcome expansion caused by dark energy. Now, with matter farther apart, gravity is insufficient to overcome it and expansion accelerates. This does not mean, however, that dark energy is related to dark matter.
Real-World Problem

You have read that the universe is expanding. In fact, recent calculations indicate that it is expanding more quickly now than it did in the past. Astronomers are able to measure this expansion because it stretches the wavelengths of light coming from distant objects. Can you make a model that demonstrates how this happens?

Make a Model

1. Work in teams of two or more. Collect all needed materials.
2. Sketch an image on the balloon slightly inflated. Model the positions of galaxy clusters by placing three or four dots at four different locations and different distances apart on the surface of the balloon. Mark the locations R (for reference), A, B, and C.
3. Make a table for data.
4. Check to see if the binder clip can hold air in the balloon long enough for you to make measurements and to draw on the balloon.
5. Obtain your teacher’s approval of your sketches and data table before proceeding.

Test Your Model

1. Slightly inflate your balloon so that it is not very big.
2. Use the binder clip to temporarily seal the balloon (or have your partner hold it closed). Do not tie it.
3. Measure the distance from your reference galaxy cluster (R) to each of the other galaxy clusters and record these distances on your data table.

Goals

- Model the stretching of the wavelengths of light caused by the expansion of the universe.
- Measure the amount of wavelength lengthening produced in the model.

Possible Materials

- round balloon
- permanent marker (black or dark blue)
- medium-sized binder clip (3 cm)

Safety Precautions

Data

<table>
<thead>
<tr>
<th>Location</th>
<th>First Distance Measurement</th>
<th>Second Distance Measurement</th>
<th>Change in Distance Measurement</th>
<th>First ( \lambda ) Measurement</th>
<th>Second ( \lambda ) Measurement</th>
<th>Change in ( \lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
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<tr>
<td>C</td>
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</tr>
</tbody>
</table>
4. Draw a wavy line from your reference galaxy cluster to each of the other galaxy clusters marked to represent the wavelength (\( \lambda \)) of light coming from each galaxy cluster. Measure and record the wavelength of each wavy line.

5. Inflate your balloon farther (be careful not to inflate it too much). Replace the binder clip or tie the end shut.

6. **Measure** and record the distances from your reference galaxy cluster to each of the other galaxy clusters.

7. **Measure** and record the wavelength of each wavy line on your inflated model.

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### Analyze Your Data

1. **Calculate** the change in distance and the change in wavelength for each galaxy cluster and record it on your data table.

2. **Analyze** whether objects moved on your model or whether your entire model expanded.

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### Conclude and Apply

1. **Explain** any changes in distance or wavelength noted.

2. **Conclude** whether the objects moved apart because of their individual motions or because the model expanded.

3. **Infer** how measurements on your model can be related to measurements of the universe.
Stars
Sara Teasdale

Alone in the night
On a dark hill
With pines around me
Spicy and still,

And a heaven full of stars
Over my head,
White and topaz
And misty red;

Myriads with beating
Hearts of fire
That aeons
Cannot vex or tire;

Up the dome of heaven
Like a great hill,
I watch them marching
Stately and still,

And I know that I
Am honored to be
Witness
Of so much majesty.

Understanding Literature

Imagery Imagery refers to how a literary work invites the reader to see, hear, smell, touch, or taste something in his mind. Authors often use related images throughout a work, encouraging the reader to consider the subject using more than one sense. Of what specific senses does this poet make the reader aware?

Respond to the Reading

1. How does the author use personification to make the stars in the poem seem alive?
2. Tone refers to the overall mood of a literary work. Describe the tone of this poem.
3. Linking Science and Writing The poet refers to the color, age, energy source, and apparent movement of stars. Write a paragraph relating what you have learned about these properties to how they are mentioned in the poem.

On a clear, dark night, it is possible to see as many as 1,500 stars with the unaided eye. However, this number is far lower because of light pollution. Light from houses, shopping areas, signs, and street lights floods the sky, making it difficult to see the stars. Inside major cities, fewer than 50 stars may be visible in the night sky.
Section 1  Observing the Universe

1. Constellations are patterns of stars that resemble things familiar to the observer.
2. Optical telescopes collect visible light and magnify viewed objects.
3. A refracting telescope uses lenses to collect light and magnify the image, and a reflecting telescope uses a mirror to collect light and a lens to magnify the image.
4. A radio telescope collects and amplifies radio waves.

Section 2  Evolution of Stars

1. Stars form from a large cloud of gas, ice, and dust, called a nebula like the one shown here. When the temperature inside the contracting nebula reaches 10 million K, fusion begins, and a star is born.
2. Stars are classified as main sequence stars, giants, and white dwarfs on the H-R diagram.
3. When a star reaches stellar equilibrium it is considered a main sequence star. When the hydrogen fuel is depleted, a star loses equilibrium and evolves into a giant or supergiant.
4. After losing its outer layers, a giant becomes a white dwarf. A supergiant can evolve into a neutron star or a black hole.
5. The Sun’s energy is produced at its core by nuclear fusion.

Section 3  Galaxies and the Milky Way

1. A galaxy is a large group of stars, gas, and dust held together by gravity. The Local Group of galaxies is a cluster that contains the Milky Way Galaxy.
2. The three main types of galaxies are elliptical, irregular, and spiral as shown here.
3. Astronomers believe that galaxies form by absorbing or merging with smaller objects. They continue to evolve by colliding or merging with other galaxies.
4. The Milky Way galaxy is about 100,000 light-years across and the Sun lies about 26,000 light-years from its center.

Section 4  Cosmology

1. The big bang theory is the most accepted theory of how the universe began.
2. The universe is 13.7 billion years old and appears to be expanding faster now than in the past.
3. The Hubble red shift is caused by the expansion of space, not the movement of galaxies.

Foldables  Use the Foldable that you made at the beginning of this chapter to help you review what you learned about cosmology.

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12. Which form of energy are optical telescopes used to study?
   A) infrared radiation
   B) radio waves
   C) visible light
   D) X rays

13. Which magnifies the image in a telescope?
   A) eyepiece
   B) focal length
   C) focus
   D) objective

14. Which is the most common type of star in the universe?
   A) giant
   B) neutron
   C) red dwarf
   D) white dwarf

15. Which forms from a star that is over 25 times the mass of the Sun?
   A) black hole
   B) giant star
   C) neutron star
   D) white dwarf

16. Which is a feature of the Sun that can reach 100 million K?
   A) CME
   B) flare
   C) prominence
   D) sunspot

17. Which type of galaxy is most common?
   A) barred spiral
   B) dwarf elliptical
   C) irregular
   D) spiral

18. Which is the most accepted theory of how the universe formed?
   A) big bang
   B) collision
   C) oscillating
   D) steady state
19. Which adds to the gravity of a galaxy, but cannot be seen or detected?
   A) dark energy
   B) dark matter
   C) regular energy
   D) regular matter

20. Make a table summarizing the absolute brightness (magnitude) and temperatures of stars on this H-R diagram.

21. Draw and label scale models of the following stars: the Sun; Antares, 500 times larger than the Sun; and Sirius B 0.01 times the Sun’s diameter.

22. Draw and label a concept map showing the life history of a star like the Sun.

23. Draw and label the parts in a reflecting telescope.

24. Explain how energy created in the core of the Sun is eventually emitted from the photosphere.

25. Compare and contrast elliptical, irregular, and spiral galaxies.

26. Discuss the benefits of using a radio telescope.

27. Explain why high sunspot activity on the Sun can affect Earth’s magnetic field.

28. Explain how the Sun’s position in the Milky Way affects how we perceive our galaxy.

29. Solve One-Step Equations Use the equation \( M_p = \frac{f_o}{f_e} \) to determine the magnifying power of a telescope in which the focal lengths of the objective and eyepiece are 1500 mm and 9 mm, respectively.

30. A solar storm that took place in 1859 is called “the perfect storm,” because of its great power. The diagram shows the relative destructive power of some solar storms. Using this diagram, calculate approximately how much more destructive was the solar storm of 1859 than the one of 1989.

31. Calculate how long ago the light we see today left a star that is 25 light-years away. Calculate the distance in km to that star.
1. What is used as an objective in a reflecting telescope?
   A. antenna
   B. camera
   C. lens
   D. mirror

2. Which type of telescope is shown?
   A. optical
   B. radio
   C. ultraviolet
   D. X-ray

3. Which group contains most stars on the H-R diagram?
   A. giant
   B. main sequence
   C. supergiant
   D. white dwarf

4. Which stage of stellar evolution occurs when the outer layers escape, leaving behind the hot core?
   A. black hole
   B. giant
   C. main sequence
   D. white dwarf

5. What occurs inside a main sequence star?
   A. Energy from fusion exceeds gravity.
   B. Fusion shuts down.
   C. Gravity exceeds energy from fusion.
   D. It attains stellar equilibrium.

Concentrate Stay focused during the test and don’t rush, even if you notice that other students are finishing the test early.
6. Which may be responsible for the accelerating expansion of the universe?
   A. dark energy
   B. dark matter
   C. regular energy
   D. regular matter

7. If the focal length of a telescope objective is 2,400 mm and the focal length of the eyepiece is 20 mm, what is the magnifying power of the telescope?

8. Use this equation, \( A = \pi r^2 \). What is the area in square meters of one of the four 8.2-meter reflectors in the Very Large Telescope?

9. Describe the structure of the Sun’s interior.

10. What does a spectroscope do to starlight that enables astronomers to determine the star’s composition?

11. What does the H-R diagram show about the stars plotted on it?

12. What are coronal mass ejections?

13. What is the Local Group?

14. How do astronomers think that galaxies like the Milky Way formed?

15. What is cosmology?

16. Why have astronomers proposed the existence of dark energy in the universe?

17. PART A What are the evolutionary stages of a star like the Sun?

   PART B What are the evolutionary stages of a star more than eight times the mass of the Sun?