Section 9 The Lives of Stars

What Do You See?

Learning Outcomes

In this section, you will

- **Identify** the place of our solar system in the Milky Way Galaxy.
- **Study** stellar structure and the stellar evolution (the life cycle of stars).
- **Explore** the relationship between the brightness of an object (its luminosity) and its magnitude.
- **Estimate** the chances of another star affecting Earth in some way.

Think About It

If you gaze across the sky at night, you will notice stars. If you live in a city, it may be difficult for you to see all of the stars in the night sky because of the city lights. People who live in the suburbs or out in the country usually have a much better chance to see the sky lit up with stars on a clear night. Did you know that when you look at the night sky, you are looking across huge distances of space?

- **As you stargaze, what do you notice about the stars?**
- **Do some stars appear brighter than others? Do some appear larger or smaller? What colors are the stars?**

Record your ideas and sketch some of the stars in your *Geo* log. Be prepared to discuss your responses with your small group and the class.

Investigate

You will be investigating the relationship between distance and brightness of stars, first using three different wattages of light bulbs and then the Hertzsprung-Russell (HR) diagram.

Part A: Brightness Versus Distance From the Source

⚠ Do not stare at the light bulbs for extended periods of time.

1. Set up a series of lamps with 40-, 60-, and 100-W bulbs (of the same size and all with frosted glass) at one end of a room (at least 10 m away). Use the other end of the room for your observing site. Turn all the lamps on. Close all of the shades in the room.
   a) Can you tell the differences in brightness between the lamps?
2. Move the lamp with the 40-W bulb forward 5 m toward you.
   a) Does the light look brighter than the 60-W lamp?
   b) Does it look brighter than the 100-W lamp?
3. Shift the positions of the lamps so that the 40-W lamp and the 100-W lamp are in the back of the room and the 60-W lamp is halfway between you and the other lamps.
   a) How do the brightness levels compare?
4. Using a light meter, test one bulb at a time. If you do not have a light meter, you will have to construct a qualitative scale for brightness.
   a) Record the brightness of each bulb at different distances.
5. Graph the brightness versus the distance from the source for each bulb.
   a) Plot distance on the horizontal axis of the graph and brightness on the vertical axis. Leave room on the graph so that you can extrapolate the graph beyond the data you have collected. Plot the data for each bulb and connect the points with lines.
   b) Extrapolate the data by extending the lines on the graph using dashes.
6. Use your graph to answer the following questions:
   a) Explain the general relationship between wattage and brightness (as measured by your light meter or qualitative scale).
   b) What is the general relationship between distance and brightness?
   c) Do all the bulbs follow the same pattern? Explain your answer.
   d) Draw a light, horizontal line across your graph so that it crosses several of the lines you have graphed.
   e) Does a low-wattage bulb ever have the same brightness as a high-wattage bulb? Describe one or two such cases in your data.
   f) The easiest way to determine the absolute brightness of objects of different brightness and distance is to move all objects to the same distance. How do you think astronomers handle this problem when trying to determine the brightness and distances to stars?
7. When you have completed this investigation, spend some time outside stargazing. Think about the relationship between brightness and distance as it applies to stars.
   a) Write your thoughts in your *Geo* log.

Part B: Luminosity and Temperature of Stars

1. The Hertzsprung-Russell (HR) diagram is a very important tool in the study of stars. Obtain a copy of the first HR diagram shown below. Examine it and answer the following questions:

   a) What does the vertical axis represent?

   b) What does the horizontal axis represent?

   c) The yellow dot on the figure is the Sun. What is its temperature and luminosity?

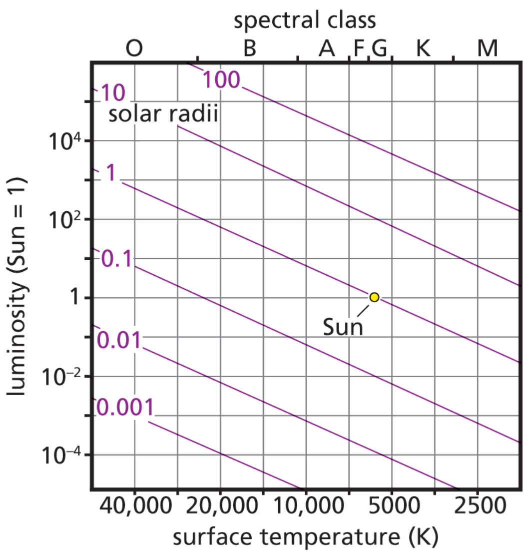
   d) Put four more dots on the diagram labeled A through D to show the locations of stars that are:

      A. hot and bright

      B. hot and dim

      C. cool and dim

      D. cool and bright



2. Obtain a copy of *Table 1* and the second HR diagram that shows the locations of main-sequence stars, supergiants, giants, and white dwarfs.

   a) Using the luminosity of the stars and their surface temperatures, plot the locations of stars shown in *Table 1* on the second HR diagram.

3. Classify each of the stars into one of the following four categories and record the name in your copy of the table.

   a) Main sequence

   b) Giants

   c) Supergiants

   d) White dwarfs

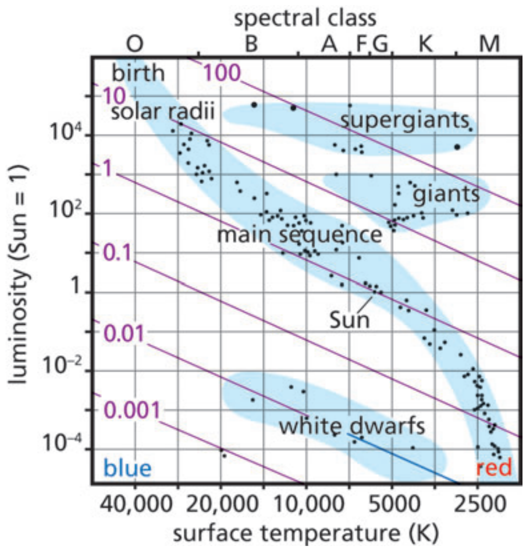


Table 1: Selected Properties of Some Stars							
Star	**Surface Temperature (K)**	**Luminosity (Relative to Sun)**	**Distance (Light-Years)**	**Mass (Solar Masses)**	**Diameter (Solar Diameters)**	**Color**	**Type of Star**
Sirius A	9100	22.6	8.6	2.3	2.03	Blue	
Arcturus	4300	115	36.7	4.5	31.5	Red	
Vega	10,300	50.8	25.3	3.07	3.1	Blue	
Capella	5300	75.8	42.2	3	10.8	Red	
Rigel	11,000	38,679	733	20	62	Blue	
Procyon A	6500	7.5	11.4	1.78	1.4	Yellow	
Betelgeuse	2300	105,000	640	20	1183	Red	
Altair	7800	11.3	65.1	2	1.6	Yellow	
Aldebaran	4300	156–171 (variable)	65	25	51.5	Red	
Spica	25,300	2121	262	10.9	7.3	Blue	
Pollux	4500	31	33	4	8	Red	
Deneb	10,500	66,500	1600	25	116	Yellow	
Procyon B	8700	0.0006	11.2	0.65	0.02	White	
Sirius B	24,000	0.00255	13.2	0.98	0.008	Blue-white	

Note: Mass, diameter, and luminosity are given in solar units. For example, Sirius A has 2.3 solar masses, a diameter 2.03 times that of the Sun, and has luminosity 22.6 times brighter than the Sun.
1 solar mass $= 2 \times 10^{30}$ kg $= 330{,}000$ Earth masses; 1 solar diameter $= 700{,}000$ km $= 110$ Earth diameters.

Digging Deeper

EARTH'S STELLAR NEIGHBORS

Classifying Stars

In the *Investigate,* you explored the relationship between distance and brightness of stars. You also used the Hertzsprung-Russell (HR) diagram to study other properties of stars. You read earlier that our solar system is part of the Milky Way Galaxy. Our stellar neighborhood is about two thirds of the way out on a spiral arm that stretches from the core of the galaxy. (Stellar means of or pertaining to stars.) The galaxy contains hundreds of billions of stars. Astronomers use a magnitude scale to describe the brightness of objects they see in the sky. A star's brightness decreases with the square of the distance. Thus, a star twice as far from Earth as another identical star would be one fourth as bright as the closer star. The first magnitude scales were quite simple. The brightest stars were described as first magnitude, the next-brightest stars were second magnitude, and so on, down to magnitude 6. Magnitude 6 stars are barely visible to the unaided eye. The smaller the number, the brighter the star, and the larger the number, the dimmer the star.

Today, scientists use a more precise system of magnitudes to describe brightness. The brightest star in the sky is called Sirius A, and its magnitude is –1.5. The Sun is much brighter at –27 and the Moon is –12.6. The dimmest stars seen by the unaided eye are still 6th magnitude. To see anything dimmer than that, you have to magnify your view with binoculars or a telescope. The best ground-based telescopes can detect objects as faint as 25th magnitude. To get a better view of very faint, distant objects, you have to get above Earth's atmosphere. The Hubble Space Telescope, for example, can detect objects as dim as 30th magnitude.

Figure 1 This NASA Hubble Space Telescope near-infrared image of newborn binary stars reveals a long, thin nebula pointing toward a faint companion object, which could be the first extrasolar planet to be imaged directly.

Perhaps you have seen a star described as a G-type star or an O-type star. This is a way of classifying stars that depends on the color and temperature of the star. They also help astronomers understand where a given star is in its life cycle. To get such information, astronomers study stars with spectrographs. They use the spectrographs to determine temperature and chemical makeup of the stars. As you can see in the table below, there are seven main categories of stars.

Stellar Classification	Temperature Classification
O	25,000 K and higher
B	11,000–25,000 K
A	7500–11,000 K
F	6000–7500 K
G	5000–6000 K
K	3500–5000 K
M	less than 3500 K

Geo Words

luminosity: the total amount of energy radiated by an object every second.

The Lives of Stars

Astronomers also use the term luminosity to describe stars. **Luminosity** is the total rate at which a star emits radiation energy. You looked at apparent brightness before. (That is, how bright the star appears to be.) Apparent brightness depends on how far away a star is. On the other hand, luminosity does not depend on how far away the star is. In the early 1900s, Ejnar Hertzsprung and Henry Norris Russell independently made the discovery that the luminosity of a star was related to its surface temperature. In the second part of the *Investigate*, you worked with a graph that shows this relationship. It is called the Hertzsprung-Russell (HR) diagram in honor of the astronomers who discovered this relationship. The HR diagram alone does not tell you about why the stars appear where they do on the diagram.

Think about what would happen if you were to plot the IQ versus the weight of everyone in your school. You would probably find a very weak relationship between these two variables. Your graph would resemble a scatterplot more than it would a line. What would happen if you plotted the height versus weight for the same people? You are more likely to find a strong relationship. Your data would be distributed along a trend or line. However, the graph does not tell you why this relationship exists. That is up to you to determine. Similarly, the HR diagram shows that stars do not just appear randomly on a plot of luminosity versus temperature. They fall into classes of luminosity (red giants, white dwarfs, and so on).

The life cycle of a star begins with its formation in a cloud of gas and dust called a **molecular cloud**. The material in the cloud begins to clump together, mixing and swirling. Eventually, the core begins to heat as more material is drawn in by gravitational attraction. When the temperature in the center of the cloud reaches 15 million K, it is high enough for nuclear fusion to occur. As you have read in an earlier section, in the process of nuclear fusion, hydrogen atoms join together to form helium with the release of energy. When this occurs, a star is born. Such stars are called **main-sequence stars**. Many stars spend 90 percent of their lifetime on the main sequence.

Geo Words

molecular cloud: a large, cold cloud made up mostly of molecular hydrogen and helium, but with some other gases, such as carbon monoxide. It is in these clouds that new stars are born.

main-sequence star: star formed when the temperature in the center of a cloud reaches 15 million K, starting up the stellar fusion.

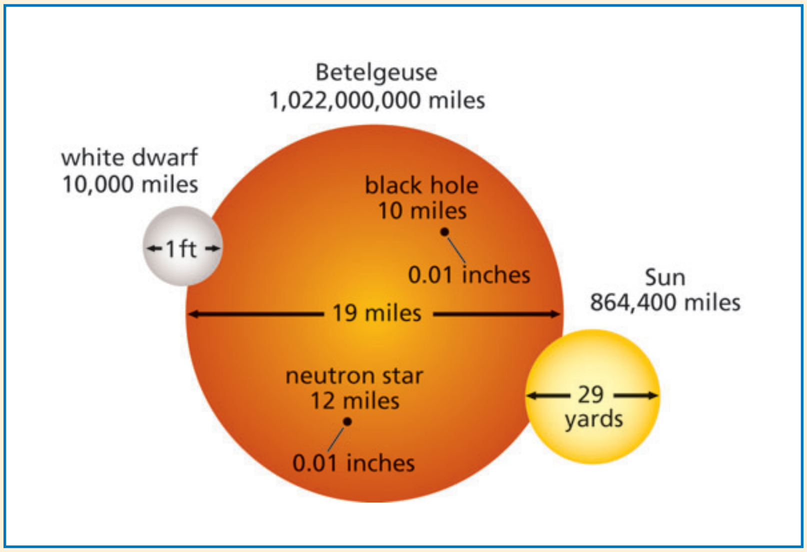


Figure 2 Scaling stars to 10,000 miles to 1 ft reveals the widely varying sizes of stars. The relative sizes of the stars are not to scale.

As these infant stars grow, the cloud surrounding them is flooded with strong ultraviolet radiation. This action vaporizes the cloud, creating beautiful, sculpted shapes in the cloud. In the photograph in *Figure 3*, the Hubble Space Telescope studied a region of star birth called NGC 604. Notice the cluster of bright white stars in the center "cavern" of the cloud of gas and dust. Their ultraviolet light has carved out a shell of gas and dust around the newborn stars.

Figure 3 The starforming region NGC 604 in Galaxy M33.

Figure 4 The Orion Nebula is an example of a molecular cloud, from which new stars are born.

How long a star lives depends on its mass. (Masses of selected stars are shown in *Table 1* in the *Investigate*.) Stars like our Sun will live about 10 billion years. Smaller, cooler stars might go on twice that long, slowly burning their fuel. Massive, supergiant stars consume their mass much more quickly, living only a few tens of millions of years. Very hot stars also go through their fuel very quickly, existing perhaps only a few hundred thousand years. The time a star spends on the main sequence can be determined using the following formula:

$$\text{Time on main sequence} = \frac{1}{M^{2.5}} \times 10 \text{ billion years}$$

where M is the mass of the star in units of solar masses.

Even though high-mass stars have more mass, they burn it much more quickly and end up having very short lives.

In the end, however, stars of all types must die. Throughout its life, a star loses mass in the form of a stellar wind. In the case of the Sun, this is called the solar wind. As a star ages, it loses more and more mass. Stars about the size of the Sun and smaller end their days as tiny, shrunken remnants of their former selves, surrounded by beautiful shells of gas and dust. These are called planetary nebulae. In about 5 billion years, the Sun will start to resemble one of these ghostly nebulae, ending its days surrounded by the shell of its former self.

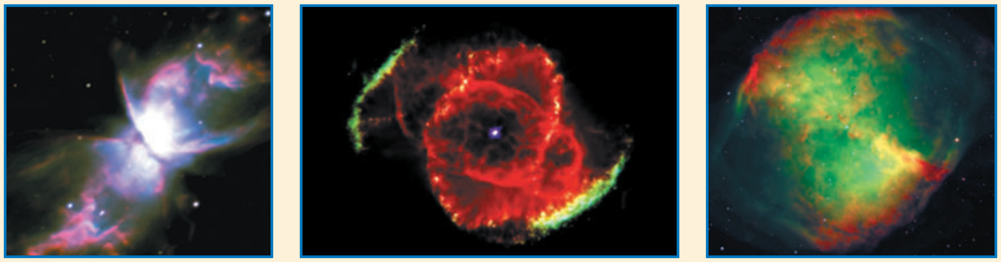


Figure 5 Three examples of the deaths of stars about the size of the Sun. **A:** The Butterfly Nebula. **B:** The Cat's-Eye Nebula. In both cases, the dying star lies embedded in a cloud of material exhaled by the star as it grew older. **C:** The Dumbbell Nebula. European Southern Observatory.

Massive stars (supergiants tens of times more massive than the Sun) also lose mass as they age. However, at some point, their cores collapse catastrophically. The end of a supergiant's life is a cataclysmic explosion called a **supernova**. In an instant of time, most of the star's mass is hurled out into space. What is left behind is a tiny remnant called a **neutron star**. If the star is massive enough, the force of the explosion can be so strong that the remnant is imploded into a **stellar black hole**. This is a place where the gravity is so strong that not even light can escape.

Geo Words

supernova: the explosion of a massive star whose core has completely burned out.

neutron star: the imploded core of a massive star produced by a supernova explosion.

stellar black hole: the leftover core of a massive single star after a supernova. Black holes exert such large gravitational pull that not even light can escape.

The material that is shed from dying stars makes its way into the space between the stars. There it mixes with leftover gas and dust from other dead and dying stars. Gravitational attraction slowly contracts the material. It then begins a new episode of star birth and, ultimately, star death. Humans evolved on a planet that was born from a recycled cloud of stellar mass. Therefore, humans are very much star "stuff." They are part of a long cycle of life, death, and rebirth.

Astronomers search the universe to study the mechanics of star formation. Star nurseries and star graveyards are scattered through all the galaxies. In some cases, star birth is triggered when one galaxy collides with (actually passes through) another. The clouds of gas and dust get the push they need to start the process.

Figure 6 The Crab Nebula is the remnant of a supernova explosion, first observed in the year 1054.

Scientists also search for examples of planetary nebulae. They want to understand when and how these events occur. Not only are these nebulae interesting, but they also show scientists what the fate of our solar system will be billions of years from now.

What would happen if there were a supernova explosion in our stellar neighborhood some time in the future? Depending on how close it was, you could be bombarded with strong radiation and shock waves from the explosion. The chances of this happening are extremely small. However, some astronomers think that a supernova some five billion years ago may have started the development of the Sun and the planets.

The Creation of Elements Through Stellar Processes

As you read, nuclear fusion in a star begins in its core. The size of the core depends on the mass of the star. In a star about the size of the Sun, the core extends from its center to about 25 percent of its radius. When the core temperature reaches 15 million K, hydrogen atoms combine or fuse to form heavier helium atoms. In the process, energy is emitted. In stars less massive than the Sun, this is the only reaction that takes place. In all other stars, fusion reactions involving elements heavier than hydrogen also occur. In these stars, once all the hydrogen has been converted into helium, the helium atoms begin to fuse into heavier atoms of carbon and oxygen. In a lower mass star, such as the Sun, fusion reactions stop at this point. The core then collapses under the force of gravity. A planetary nebula forms. All that remains is a shrunken star, made mostly of carbon and oxygen, surrounded by a shell of gas. Eventually, after many thousands of years, the gases of the planetary nebula disperse into space. These gases provide matter for a new episode of star birth.

For stars with masses higher than the Sun, fusion reactions continue. Heavier and heavier elements are created. These elements form in shells within the interior of the star. For example, the fusing of carbon atoms and oxygen atoms forms elements such as neon, sodium, and magnesium. Fusion reactions transform these elements into silicon, sulfur, and phosphorus, among others. These elements, in turn, produce even heavier elements such as cobalt, manganese, and ruthenium. Other reactions produce even heavier atoms. However, few elements heavier than iron are produced. Once iron is formed, nuclear fusion in the star's core comes to a stop. This is because the energy that binds iron atoms together is very strong. Iron cannot be fused with other atoms without the input of additional energy. For many higher-mass stars, the numerous elements produced through fusion reactions are lost to space. During lifetimes of the star, these elements drift as gases from their outer layers. They are also driven away by stellar wind. These stars end their days as shrunken cores, no longer fusing elements together.

Elements that are heavier than iron, such as silver, gold, lead, and uranium, can only be created through a supernova explosion. This process occurs in supergiant stars under extreme conditions. When such a star forms an iron core and no longer radiates energy, it collapses under the force of gravity. The core temperature then rises to over 100 billion K. The iron atoms are pulled together. The collapse of the core produces a shock wave. The wave blasts outward into space at thousands of kilometers per second. The shock wave encounters material in the star's outer layers. The material is heated, fusing to form new elements heavier than iron. The shock wave then blasts this material out into space as huge clouds of gas and dust. It is from this matter that nebulae form. Then, under the effects of gravity new stars develop, along with the planets that orbit them.

Figure 7 This image, taken by NASA's Hubble Space Telescope, shows the remnants of a supernova blast 160,000 light-years from Earth.

Checking Up

1. How do astronomers classify stars?
2. Write a brief description of how stars are born.
3. What determines the way a star dies?
4. Explain how lighter and heavier elements are formed in stars.

Think About It Again

At the beginning of this section, you were asked the following:

- **As you stargaze, what do you notice about the stars?**
- **Do some stars appear brighter than others? Do some appear larger or smaller? What colors are the stars?**

Record your ideas about these questions now. Be sure that you describe the relationship between a star's brightness and its distance as well as the relationship between the brightness of a star (its luminosity) and its magnitude.

Reflecting on the Section and the Challenge

You measured the apparent differences in brightness of three light bulbs at different distances. This helped you to see that distance and brightness are important factors in understanding the objects in our universe. When you look at the stars at night, you are seeing stars at different distances and levels of brightness. The Hertzsprung-Russell (HR) diagram that you examined helped you to see that the spectral characteristics of stars reveal something of their temperature, size, and other characteristics. The light from distant stars can also be used to understand our own star, and our own solar system's makeup and evolution. When you assess danger from space, it is important to understand that stars, in and of themselves, do not pose a danger unless they are both relatively nearby and at a stage in their life cycle that could affect Earth. In turn, that helps you to understand if a given star is, or could be, a threat to Earth. This will help you to describe the effects of distant objects on Earth as part of the *Chapter Challenge*.

Understanding and Applying

1. Using an astronomy computer program or a guidebook to the stars, make a list of the 10 nearest stars, their distances, magnitudes, and spectral classes. What do their classes tell you about them?
2. What happens when a star loses its mass and how does it figure in the death of a star? Is the Sun losing its mass?
3. What happens to the material left over from the death of a star?
4. Two identical stars have different apparent levels of brightness. One star is 10 light-years away, and the other is 30 light-years away from us. Which star is brighter, and by how much?
5. Refer to *Table 1* in the *Investigate* to answer the following questions:
   a) Calculate how long the Sun will spend on the main sequence.
   b) Calculate how long Spica will spend on the main sequence.
   c) Relate your results to the statement, "The more massive the star, the shorter it lives."

6. Explain the relationships between temperature, luminosity, mass, and lifetime of stars.
7. ***Preparing for the Chapter Challenge***

   Your script is heading toward completion. Continue describing our solar system's place in the galaxy and how stars are born and die. Explain how stars and the way they come into existence is tied to the birth of our solar system, the formation of our planet, and ultimately, the evolution of life on Earth. To address how extraterrestrial objects and events could affect Earth and your community, explain how the Sun itself is going through a 10-billion-year-long life cycle and will end as a planetary nebula some 5 billion years in the future. Also, explain the potential effects of astronomical phenomena on Earth, such as a supernova explosion, occurring outside of our solar system.

Inquiring Further

1. **Evolution of the Milky Way Galaxy**

   The Milky Way Galaxy formed some 10 billion years ago, when the universe itself was only a fraction of its current age. Research the formation of our galaxy and find out how its ongoing evolution influenced the formation of our solar system.
2. **Starburst knots in other galaxies**

   Other galaxies show signs of star birth and star death. You read about a star-birth region called NGC 604 in the *Digging Deeper* of this section. Astronomers have found evidence of colliding galaxies elsewhere in the universe. In nearly every case, such collisions have spurred the formation of new stars. In the very distant future, the Milky Way will collide with another galaxy, and it is likely that starburst knots will be formed. Look for examples of star-birth nurseries and starburst knots in other galaxies and write a short report on your findings. How do you think such a collision would affect Earth (assuming that anyone is around to experience it)?

Colliding spiral galaxies of NGC 5679.