SECTION

# 3 Evolution of Stars

**As You Read**

### *What* You'll Learn

- **Describe** how stars are classified.
- **Explain** how the temperature of a star relates to its color.
- **Describe** how a star evolves.

### Vocabulary

nebula
giant
white dwarf
supergiant
neutron star
black hole

### *Why* It's Important

Like humans, stars are born, mature, grow old, and die.

## Classifying Stars

When you look at the night sky, all stars might appear to be similar, but they are quite different. Like people, they vary in age and size, but stars also vary in temperature.

In the early 1900s, Ejnar Hertzsprung and Henry Russell made some important observations. They noticed that in general, stars with higher temperatures also have brighter absolute magnitudes.

Hertzsprung and Russell developed a graph, shown in **Figure 10,** to show this relationship. They placed temperatures across the bottom and absolute magnitudes up one side. A graph that shows the relationship of a star's temperature to its absolute magnitude is called a Hertzsprung-Russell (H-R) diagram.

**The Main Sequence** As you can see, stars seem to fit into specific areas of the graph. Most stars fit into a diagonal band that runs from the upper left to the lower right of the chart. This band, called the main sequence, contains hot, blue, bright stars in the upper left and cool, red, dim stars in the lower right. Yellow, main sequence stars, like the Sun, fall in between.

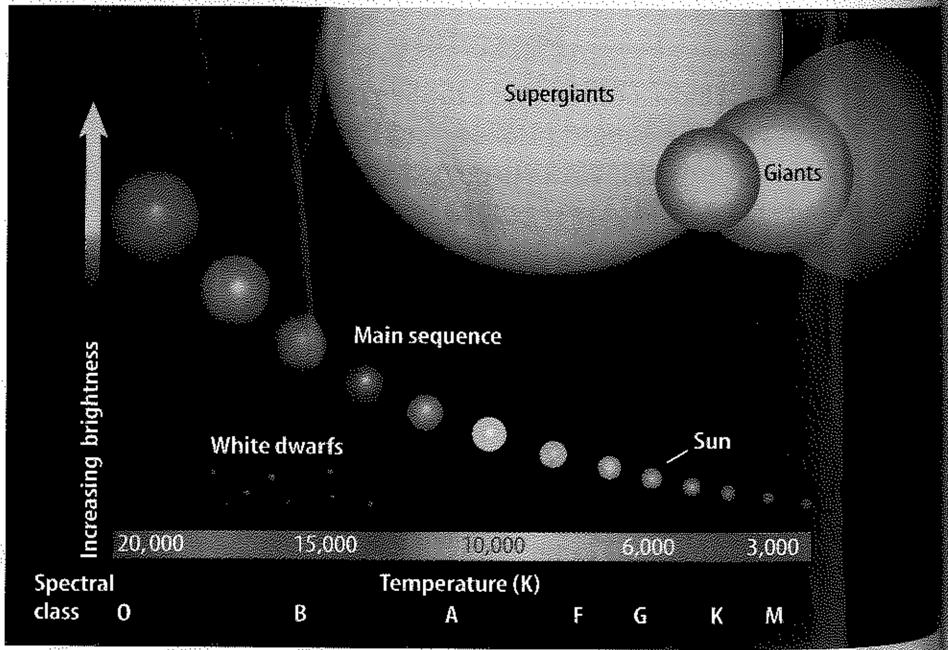


**Figure 10**
**The relationships among a star's color, temperature, and brightness are shown in this Hertzsprung-Russell diagram. Main sequence stars run from the upper-left corner to the lower-right corner. Stars in the upper left are hot, bright stars, and stars in the lower right are cool, faint stars.** *What type of star shown in the diagram is the coolest, brightest star?*

**Dwarfs and Giants** About 90 percent of all stars are main sequence stars. Most of these are small, red stars found in the lower right of the H-R diagram. Among main sequence stars, the hottest stars generate the most light and the coolest ones generate the least. What about the ten percent of stars that are not part of the main sequence? Some of these stars are hot but not bright. These small stars are located on the lower left of the H-R diagram and are called white dwarfs. Other stars are extremely bright but not hot. These large stars on the upper right of the H-R diagram are called giants, or red giants because they are usually red in color. The largest giants are called supergiants. **Figure 11** shows the supergiant, Antares—a star 300 times the Sun's diameter—in the constellation Scorpius. It is 5,600 times as bright as the Sun.

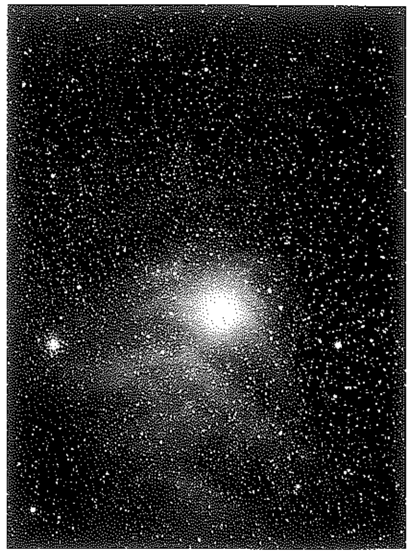


**Figure 11**
**Antares is a bright, supergiant located 400 light-years from Earth. Although its temperature is only about 3,500 K, it is the 16th brightest star in the sky.**

**✓ Reading Check** *What kinds of stars are on the main sequence?*

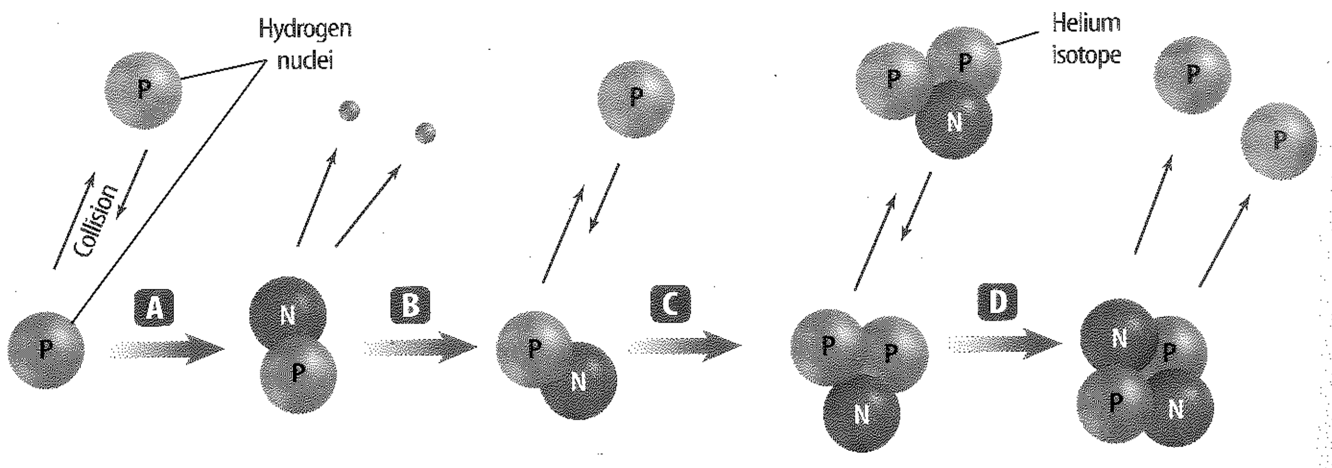
## How do stars shine?

When the H-R diagram was developed, scientists didn't know what caused stars to shine. Hertzsprung and Russell developed their diagram without knowing what produced the light and heat of stars.

For centuries, people were puzzled by the questions of what stars were made of and how they produced light. Many people had estimated that Earth was only a few thousand years old. The Sun could have been made of coal and shined for that long. However, when people realized that Earth was much older, they wondered what material possibly could burn for so many years. Early in the twentieth century, scientists began to understand the process that keeps stars shining for billions of years.

**Generating Energy** In the 1930s, scientists discovered reactions between the nuclei of atoms. They hypothesized that temperatures in the center of the Sun must be high enough to cause hydrogen to fuse to make helium. That reaction would release tremendous amounts of energy. In this reaction, four hydrogen nuclei combine to create one helium nucleus. The mass of one helium nucleus is less than the mass of four hydrogen nuclei, so some mass is lost in the reaction.

Years earlier, in 1905, Albert Einstein had proposed a theory stating that mass can be converted into energy. This was stated as the famous equation $E = mc^2$. In this equation, $E$ is the energy produced, $m$ is the mass, and $c$ is the speed of light. The small amount of mass "lost" when hydrogen atoms fuse to form a helium atom is converted to a large amount of energy.



**A** One proton decays to a neutron, releasing subatomic particles and some energy.

**B** Another proton fuses with a proton and neutron to form an isotope of helium. Energy is given off again.

**C** Two helium isotopes fuse.

**D** A helium nucleus (two protons and two neutrons) forms as two protons break away. In the process, still more energy is released.

**Figure 12**
**Fusion begins in a star's core as protons (hydrogen nuclei) collide.** *What happens to the "lost" mass during this process?*

**Fusion** Shown in **Figure 12,** fusion occurs in the cores of stars. Only in the core are temperatures high enough to cause atoms to fuse. Normally, they would repel each other, but in the core of a star where temperatures can exceed 15,000,000 K, atoms can move so fast that some of them fuse upon colliding.

## Evolution of Stars

**Physics INTEGRATION**

The H-R diagram explained a lot about stars. However, it also led to more questions. Many wondered why some stars didn't fit in the main sequence group and what happened when a star depleted its supply of hydrogen fuel. Today, scientists have theories of how stars evolve, what makes them different from one another, and what happens when they die. **Figure 13** illustrates the lives of different types of stars.

When hydrogen fuel is depleted, a star loses its main sequence status. This can take less than 1 million years for the brightest stars to many billions of years for the faintest stars. The Sun has a main sequence life span of about 10 billion years. Half of its life span is still in the future.

**Nebula** Stars begin as a large cloud of gas and dust called a **nebula.** As the particles of gas and dust exert a gravitational force on each other, the nebula begins to contract. Gravitational forces cause instability within the nebula. The nebula can break apart into smaller pieces. Each piece eventually will collapse to form a star.

**SCIENCE Online**

**Research** Visit the Glencoe Science Web site at **science.glencoe.com** to find out more about the evolution of stars. Record this information in your Science Journal.

**A Star Is Born** As the particles in the smaller clouds move closer together, the temperatures in each nebula increase. When the temperature inside the core of a nebula reaches 10 million K, fusion begins. The energy released radiates outward through the condensing ball of gas. As the energy radiates into space, stars are born.

**✓ Reading Check** *How are stars born?*

**Main Sequence to Giant Stars** In the newly formed star, the heat from fusion causes pressure that balances the attraction due to gravity. The star becomes a main sequence star. It continues to use up its hydrogen fuel.

When hydrogen in the core of the star is depleted, a balance no longer exists between pressure and gravity. The core contracts, and temperatures inside the star increase. This causes the outer layers of the star to expand and cool. In this late stage of its life cycle, a star is called a **giant.**

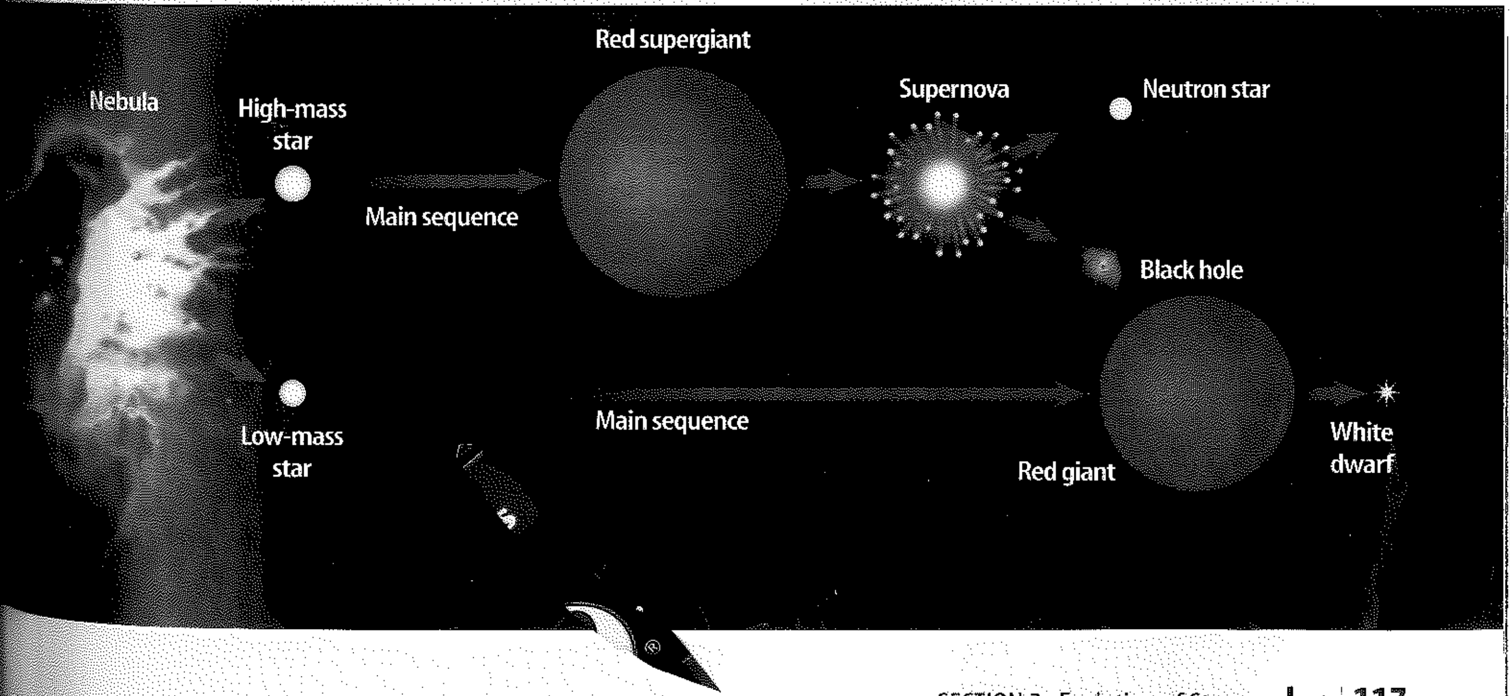
After the core temperature reaches 100 million K, helium nuclei fuse to form carbon in the giant's core. By this time, the star has expanded to an enormous size, and its outer layers are much cooler than they were when it was a main sequence star. In about 5 billion years, the Sun will become a giant.

**Chemistry INTEGRATION**

The spectrum of a star shows dark absorption lines of helium and hydrogen and is bright in the blue end. Describe as much as you can about the star's composition and surface temperature.

**White Dwarfs** After the star's core uses up its helium, it contracts even more and its outer layers escape into space. This leaves behind the hot, dense core. The core contracts under the force of gravity. At this stage in a star's evolution, it becomes a **white dwarf.** A white dwarf is about the size of Earth.

**Figure 13**
**The life of a star depends greatly on its mass. Massive stars eventually become neutron stars or possibly black holes.** *What happens to stars that are the size of the Sun?*



**Physics INTEGRATION**

About forty years ago, radio waves were detected coming from some small regions of space. These radio sources were called quasi-stellar radio sources, which was shortened to quasars. Today, quasars are known to be distant galaxies with supermassive, rotating black holes in their centers. Radio waves and other types of radiation are produced as matter falls into the black holes. Research to learn how scientists solved the mystery of quasars.

**Supergiants and Supernovas** In stars that are more than ten times more massive than the Sun, the stages of evolution occur more quickly and more violently. Look back at **Figure 13.** In massive stars, the core heats up to much higher temperatures. Heavier and heavier elements form by fusion, and the star expands into a **supergiant.** Eventually, iron forms in the core. Much of the star's energy is no longer used to produce light and heat, and the core collapses violently, sending a shock wave outward through the star. The outer portion of the star explodes, producing a supernova. A supernova can be millions of times brighter than the original star was.

**Neutron Stars** If the collapsed core of a supernova is about twice as massive as the Sun, it may shrink to approximately 20 km in diameter. Only neutrons can exist in the dense core, and it becomes a **neutron star.** Neutron stars are so dense that a teaspoonful would weigh about 100 million metric tons in Earth's gravity. As dense as neutron stars are, they can contract only so far because the neutrons resist the inward pull of gravity.

**Black Holes** If the remaining dense core from a supernova is more than three times more massive than the Sun, probably nothing can stop the core's collapse. Under these conditions, all of the core's mass collapses to a point that has no volume. The gravity from this mass is so strong that nothing can escape from it, not even light. Because light cannot escape, the region is called a **black hole.** If you could shine a flashlight on a black hole, the light simply would disappear into it.

**Reading Check** *What is a black hole?*

Black holes, however, are not like giant vacuum cleaners, sucking in distant objects. A black hole has an event horizon, which is a region inside of which nothing can escape. If something—including light—crosses the event horizon, it will be pulled into the black hole. Beyond the event horizon, the black hole's gravity pulls on objects just as it would if the mass had not collapsed. Stars and planets can orbit around a black hole.

The photograph in **Figure 14** was taken by the *Hubble Space Telescope.* It shows a jet of gas streaming out of the center of galaxy M87. This jet of gas formed as matter flowed toward a black hole, and some of the gas was ejected along the polar axis without falling in.

**Figure 14**
**The black hole at the center of galaxy M87 pulls matter into it at extremely high velocities. Some matter is ejected to produce a jet of gas that streams away from the center of the galaxy at nearly light speed.**

**Recycling Matter** A star begins its life as a nebula, such as the one shown in **Figure 15.** Where does the matter in a nebula come from? Nebulas form partly from the matter that was once in other stars. A star ejects enormous amounts of matter during its lifetime. Some of this matter is incorporated into nebulas, which can evolve to form new stars. The matter in stars is recycled many times.

What about the matter created in the cores of stars? Are elements such as carbon and iron also recycled? These elements can become parts of new stars. In fact, spectrographs have shown that the Sun contains some carbon, iron, and other such elements. Because the Sun is an average, main sequence star, it is too young and its mass is too small to have formed these elements itself. The Sun condensed from material that was created in stars that died many billions of years ago.

Some elements condense to form planets and other bodies rather than stars. In fact, your body contains many atoms that were fused in the cores of ancient stars. Evidence suggests that the first stars formed from hydrogen and helium and that all the other elements have formed in the cores of stars or as stars explode.

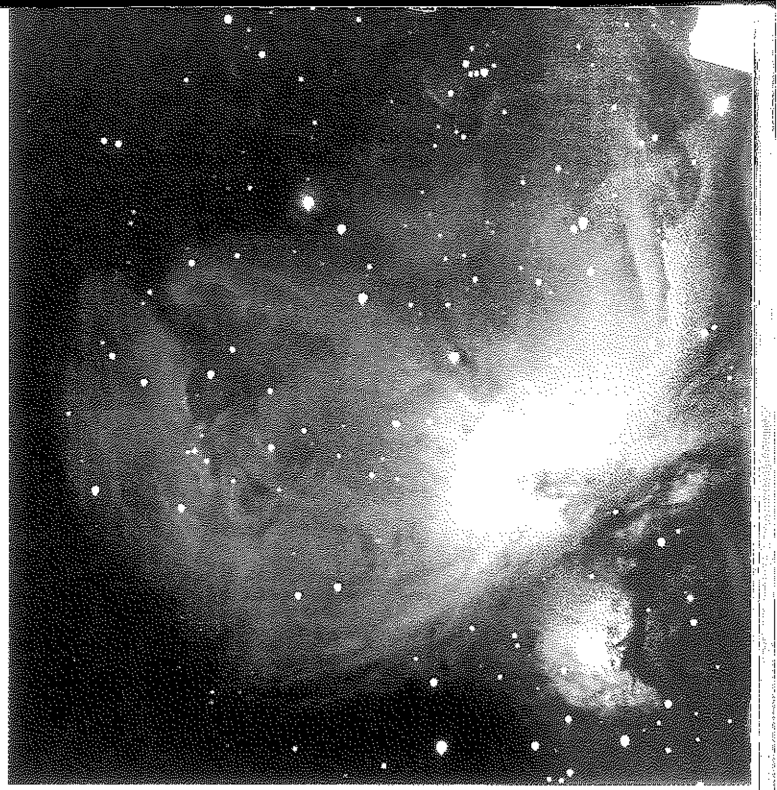


**Figure 15**
**Stars are forming in the Orion Nebula and other similar nebulae.**

## Section 3 Assessment

1. Explain why giants are not in the main sequence on the H-R diagram. How do their temperatures and absolute magnitudes compare with those of main sequence stars?
2. What can be said about the absolute magnitudes of two equal-sized stars whose colors are blue and yellow?
3. How do stars produce energy?
4. Outline the history a[illegible]robable future of the Sun.
5. **Think Critically** Why do[illegible]he helium currently in the Sun's core unde[illegible]sion?

### Skill Builder Activities

6. **Sequencing** Sequence the following in order of most evolved to least evolved: *main sequence star, supergiant, neutron star,* and *nebula.* **For more help, refer to the** Science Skill Handbook.
7. **Solving One-Step Equations** Assume that a star's core has shrunk to a diameter of 12 km. What would be the circumference of the shrunken stellar core? Use the equation $C = \pi d$. How does this compare with the circumference of Earth with a diameter of 12,756 km? **For more help, refer to the** Math Skill Handbook.