Section 29.3

Objectives

- **Determine** the effect of mass on a star's evolution.
- **Identify** the features of massive and regular star life cycles.
- **Explain** how the universe is affected by the life cycles of stars.

Review Vocabulary

evolution: a radical change in composition over a star's lifetime

New Vocabulary

nebula
protostar
neutron star
pulsar
supernova
black hole

Stellar Evolution

MAIN Idea **The Sun and other stars follow similar life cycles, leaving the galaxy enriched with heavy elements.**

Real-World Reading Link A campfire glows brightly as long as it has fuel to burn. When the fuel is depleted, the light becomes dimmer, and the fire extinguishes. Unlike a campfire, stars shine because of nuclear reactions in their interior. Stars also die out when their nuclear fuel is gone.

Basic Structure of Stars

Mass governs a star's temperature, luminosity, and diameter. In fact, astronomers have discovered that the mass and the composition of a star determine nearly all its other properties.

Mass effects The more massive a star is, the greater the gravity pressing inward, and the hotter and more dense the star must be inside to balance its own gravity. The temperature inside a star governs the rate of nuclear reactions, which in turn determines the star's energy output—its luminosity. The balance between gravity squeezing inward and outward pressure is maintained by heat due to nuclear reactions and compression. This balance is called hydrostatic equilibrium and it must hold for any stable star, as illustrated in **Figure 29.17,** otherwise the star would expand or contract. This balance is governed by the mass of a star.

Fusion Inside a star, conditions vary in much the same way that they do inside the Sun. The density and temperature increase toward the center, where energy is generated by nuclear fusion. Stars on the main sequence produce energy by fusing hydrogen into helium, as the Sun does. Stars that are not on the main sequence either fuse elements other than hydrogen in their cores or do not undergo fusion at all.

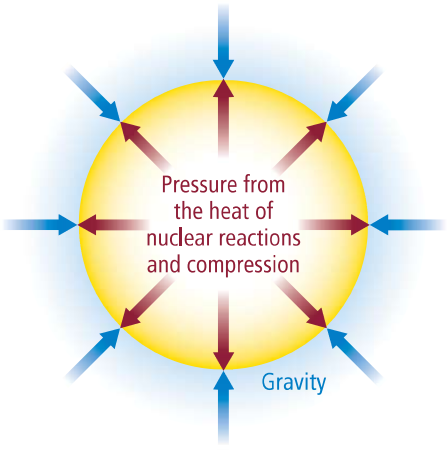


Figure 29.17 When the pressure from radiation and fusion is balanced by gravity, a star is stable and will not expand or contract.

Stellar Evolution

A star changes as it ages because its internal composition changes as nuclear-fusion reactions in the star's core convert one element into another. With a change in the core composition, the star's density increases, its temperature rises, and its luminosity increases. As long as the star is stable and converting hydrogen to helium, it is considered a main-sequence star. Eventually, when the nuclear fuel runs out, the star's internal structure and mechanism for producing pressure must change to counteract gravity. The changes a star undergoes during its evolution begin with its formation.

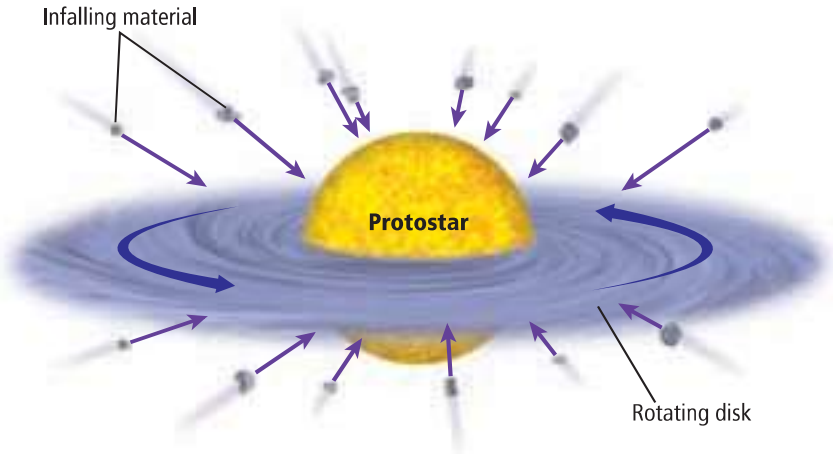


Figure 29.18 Temperatures will continue to build as gravity pulls the infalling matter to the center of the rotating disk. The center region is a protostar until fusion initiates and a star ignites.
Infer *what happens to the remaining material in the disk.*

Concepts in Motion
Interactive Figure To see an animation of star formation, visit glencoe.com.

Star formation All stars form in much the same manner as the Sun did. The formation of a star begins with a cloud of interstellar gas and dust, called a **nebula** (plural, nebulae), which collapses on itself as a result of its own gravity. As the cloud contracts, its rotation forces it into a disk shape with a hot, condensed object at the center, called a **protostar,** as illustrated in **Figure 29.18.** Friction from gravity continues to increase the temperature of the protostar, until the condensed object reaches the ignition temperature for nuclear reactions and becomes a new star. A protostar is brightest at infrared wavelengths.

Reading Check **Infer** what causes the disk shape to form.

Fusion begins When the temperature inside a protostar becomes hot enough, nuclear fusion reactions begin. The first reaction to ignite is always the conversion of hydrogen to helium. Once this reaction begins, the star becomes stable because it then has sufficient internal heat to produce the pressure needed to balance gravity. The object is then truly a star and takes its place on the main sequence according to its mass. A new star often illuminates the gas and dust surrounding it, as shown in **Figure 29.19.**

Figure 29.19 Using the Spitzer telescope's infrared wavelengths, protostars are imaged inside the Elephant Trunk nebula.

Life Cycles of Stars Like the Sun

What happens next during a star's life cycle depends on its mass. For example, as a star like the Sun converts hydrogen into helium in its core, it gradually becomes more luminous because the core density and temperature rise slowly and increase the reaction rate. It takes about 10 billion years for a star with the mass of the Sun to convert all of the hydrogen in its core into helium. Thus, such a star has a main-sequence lifetime of 10 billion years. From here, the next step in the life cycle of a small mass star is to become a red giant.

NASA/Photo Researchers

Red giant Only about the innermost 10 percent of a star's mass can undergo nuclear reactions because temperatures outside of this core never become hot enough for reactions to occur. Thus, when the hydrogen in its core is gone, a star has a helium center and outer layers made of hydrogen-dominated gas. Some hydrogen continues to react in a thin layer at the outer edge of the helium core, as illustrated in **Figure 29.20.** The energy produced in this layer forces the outer layers of the star to expand and cool. The star then becomes a red giant because its luminosity increases while its surface temperature decreases due to the expansion.

While the star is a red giant, it loses gas from its outer layers. The star is so large that its surface gravity is low, and thus the outer layers can be released by small expansions and contractions, or pulsations, of the star due to instability. Meanwhile, the core of the star becomes hot enough, at 100 million K, for helium to react and form carbon. The star contracts back to a more normal size, where it again becomes stable for awhile. The helium-reaction phase lasts only about one-tenth as long as the earlier hydrogen-burning phase. Afterward, when the helium in the core is depleted, the star is left with a core made of carbon.

The final stages A star with the same mass as the Sun never becomes hot enough for carbon to fuse, so its energy production ends. The outer layers expand again and are expelled by pulsations that develop in the outer layers. This shell of gas is called a planetary nebula. In the center of a planetary nebula, shown in **Figure 29.21,** the core of the star becomes exposed as a small, hot object about the size of Earth. The star is then a white dwarf made of carbon.

Internal pressure in white dwarfs A white dwarf is stable despite its lack of nuclear reactions because it is supported by the resistance of electrons being squeezed together, and does not require a source of heat to be maintained. This pressure counteracts gravity and can support the core as long as the mass of the remaining core is less than about 1.4 times the mass of the Sun. The main-sequence lifetime of such a star is much longer, however, because low-mass stars are dim and do not deplete their nuclear fuel rapidly.

Life Cycles of Massive Stars

For stars more massive than the Sun, evolution is different. A more massive star begins its life in the same way, with hydrogen being converted to helium, but it is much higher on the main sequence. The star's lifetime in this phase is short because the star is very luminous and uses up its fuel quickly. The electron pressure does not require ongoing reactions, so it can last indefinitely. The white dwarf gradually cools, eventually losing its luminosity and becoming an undetectable black dwarf.

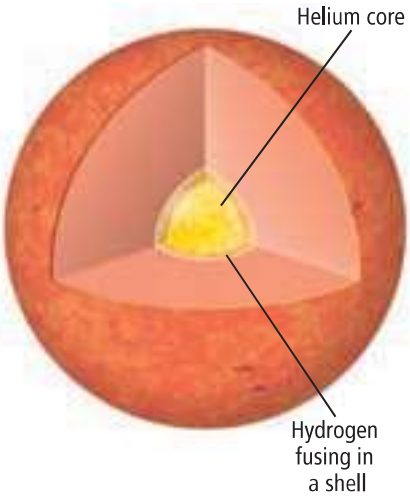


Figure 29.20 In a red giant's central region, helium is converted to carbon. In the spherical shell just outside, hydrogen continues to be converted to helium. The low temperature of the outer atmosphere due to expansion and cooling causes the red color.

Concepts in Motion

Interactive Figure To see an animation of the helium core, visit glencoe.com.

Figure 29.21 The star at the center of the Eskimo nebula, now a white dwarf, was the source of the remnant gases surrounding it.

NASA/Andrew Fruchter/ERO Team/Sylvia Baggett (STScI)/Richard Hook (ST-ECF)/Zoltan Levay (STScI)

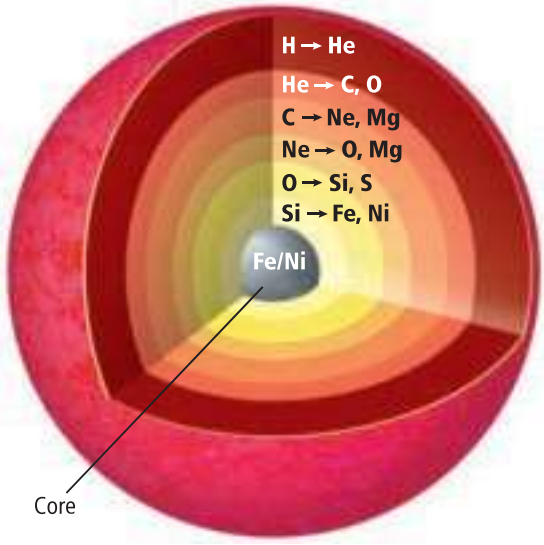


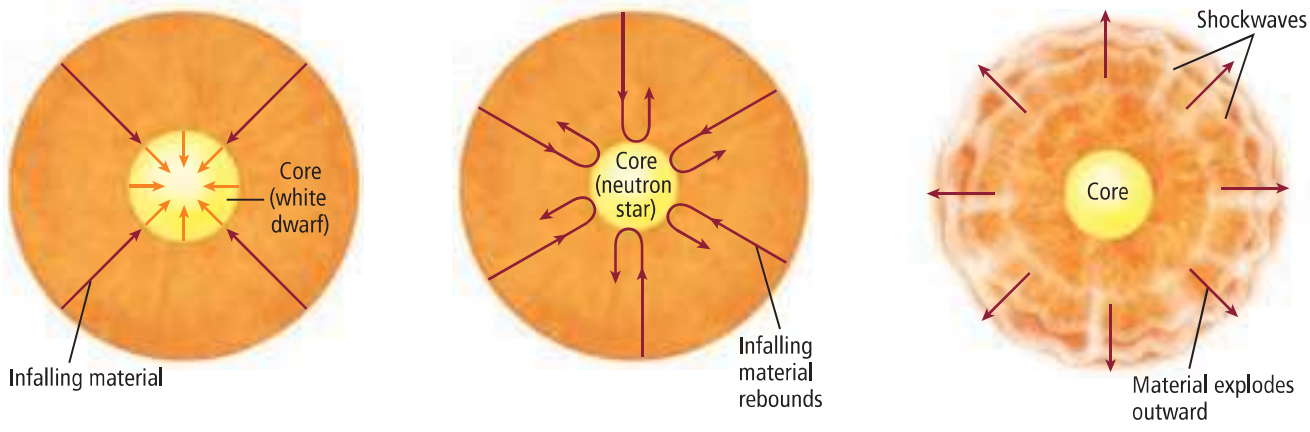
Figure 29.22 A massive star can have many shells fusing different elements. These stars are the source of heavier elements in the universe.

Supergiant A massive star undergoes many more reaction phases and thus produces a rich stew of many elements in its interior. The star becomes a red giant several times as it expands following the end of each reaction stage. As more shells are formed by the fusion of different elements, illustrated in **Figure 29.22,** the star expands to a larger size and becomes a supergiant, such as Betelgeuse in the Orion constellation.

Supernova formation A star that begins with a mass between about 8 and 20 times the Sun's mass will end up with a core that is too massive to be supported by electron pressure. Such a star comes to a violent end. Once reactions in the core of the star have created iron, no further energy-producing reactions can occur, and the core of the star violently collapses in on itself, as illustrated in **Figure 29.23.** Protons and electrons in the core merge to form neutrons. Like electrons, a neutron's resistance to being squeezed close together creates a pressure that halts the collapse of the core, and the core becomes a collapsed star remnant—a **neutron star.** A neutron star has a mass of 1.5 to 3 times the Sun's mass but a radius of only about 10 km. Its density is extremely high—about 100 trillion times the density of water—and is comparable to that of an atomic nucleus.

Pulsar Some neutron stars are unique in that they have a pulsating pattern of light. The magnetic fields of these stars focus the light they emit into cones. Then as these stars rotate on their axes, the light from each spinning neutron star is observed as a series of pulses of light, as each of the cones sweeps out a path in Earth's direction. This pulsating star is known as a **pulsar.**

Figure 29.23 When the outer layers of a star collapse into the neutron core, the central mass of neutrons creates a pressure that causes this mass to explode outward as a supernova, leaving a neutron star.
Compare *the diameter of a supergiant with that of a neutron star.*



(t)David Malin/Anglo-Australian Observatory, (b)David Malin/Anglo-Australian Observatory

Supernova A neutron star forms quickly while the outer layers of the star are still falling inward. This infalling gas rebounds when it strikes the hard surface of the neutron star and explodes outward. The entire outer portion of the star is blown off in a massive explosion called a **supernova** (plural, supernovae). This explosion creates elements that are heavier than iron and enriches the universe. **Figure 29.24** shows photos of before and during a supernova explosion. A distant supernova explosion might be brighter than the galaxy in which it is found.

Black holes Some stars are too massive to form neutron stars. The pressure from the resistance of neutrons being squeezed together cannot support the core of a star if the star's mass is greater than about three times the mass of the Sun. A star that begins with more than 20 times the Sun's mass will end up above this mass limit, and it cannot form a neutron star. The resistance of neutrons to being squeezed is not great enough to stop the collapse and the core of the star continues to collapse, compacting matter into a smaller volume. The small, extremely dense object that remains is called a **black hole** because its gravity is so immense that nothing, not even light, can escape it. Astronomers cannot observe what goes on inside a black hole, but they can observe the X-ray-emitting gas that spirals into it.

Before supernova

During supernova

Figure 29.24 The region of sky in the Large Magellanic Cloud seemed ordinary before one of its stars underwent a supernova explosion.

Section 29.3 Assessment

Section Summary

- The mass of a star determines its internal structure and its other properties.
- Gravity and pressure balance each other in a star.
- If the temperature in the core of a star becomes high enough, elements heavier than hydrogen can fuse together.
- A supernova occurs when the outer layers of the star bounce off the neutron star core, and explode outward.

Understand Main Ideas

1. MAIN Idea **Explain** how mass determines a star's evolution.
2. **Infer** how the diameter of a star is determined by mass.
3. **Determine** how the lifetimes of stars depend on their masses.
4. **Determine** why only the most massive stars are important contributors in enriching the galaxy with heavy elements.

Think Critically

5. **Explain** how the universe would be different if massive stars did not explode at the end of their lives.
6. **Distinguish** whether there is a balance between pressure and gravity in main-sequence stars, white dwarfs, neutron stars, and black holes.

WRITING in Earth Science

7. Write a description of an observation of a supernova in another galaxy.