19.2 Stars

On a clear night, about 6,000 stars can be seen without a telescope. Some of those stars form familiar constellations (Figure 19.8). A **constellation** is a group of stars that, when seen from Earth, form a pattern. Ancient astronomers thought that the Sun and the stars were different from each other. Today we know that the Sun is just one star like all the others in the night sky. The others appear to be so dim because they are incredibly far away. What are stars and where do they come from?

Stars and fusion

How do stars generate light and heat?

You have learned that a star is an enormous, hot ball of gas held together by gravity. Stars generate light and heat through nuclear fusion. Specifically, they are powered by the fusion of hydrogen under conditions of enormous temperature, mass, and density.
When hydrogen atoms fuse, helium is created.

The conditions for fusion

The conditions required for the continuous fusion of hydrogen are extremely high temperature, density and pressure. These conditions are found when the mass of hydrogen is very large.
Hydrogen fusion does not take place throughout the star, but only deep in its core, where the temperature is hot enough. The minimum temperature required for fusion to occur is 7 million °C. The Sun's core reaches a temperature of 15 million °C!

Density and mass

Even though stars are made of gas, they have extremely high values for density and mass. For example, the density of the Sun's core is about 158.0 g/cm3. This is about 18 times the density of copper. The Sun has a total mass that is equal to 330,000 Earths. Stars can range in mass from about 100 times that of the Sun to less than one-twelfth its mass. At masses lower than this, the internal temperature does not get hot enough to sustain the nuclear fusion of hydrogen.

Figure 19.8: *The star at the tip of the Little Dipper's handle is called Polaris. If you look toward Polaris, you are facing the North Pole.*

constellation - a group of stars that, when seen from Earth, form a pattern.

Constellations

The stars in the sky are divided into 88 constellations. The largest, Centaurus, contains 101 stars. The most familiar star formation, the Big Dipper, is actually part of a larger constellation called Ursa Major (the Great Bear). The Little Dipper, part of Ursa Minor, contains Polaris, the North Star, which is located at the tip of the handle (Figure 19.8). Anybody in the Northern Hemisphere who is looking toward Polaris is facing the North Pole.

The size of stars

The size range of stars

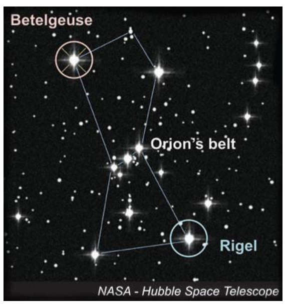
Stars come in a range of sizes. The largest stars have a mass of about 100 times the mass of the Sun. The smallest stars are about one-twelfth the mass of the Sun. This is about the minimum required to create enough gravitational pressure to ignite hydrogen fusion in the core. The Sun is a medium-sized star (Figure 19.9), as is Alpha Centauri, the nearest star to the Sun.

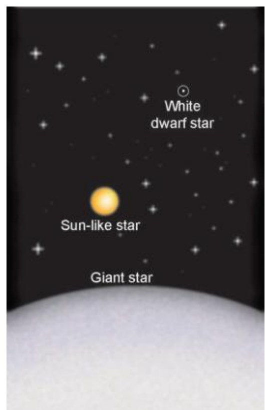
Giant stars

There are two types of giant stars. Blue giant stars are hot and much more massive than the Sun. Rigel, in the constellation of Orion is a blue giant star. Red giants are of similar mass to the Sun and much cooler. The red giants are huge because they began as Sun-like stars but have expanded to become much larger. As they expanded, they cooled down. Betelgeuse, also in the constellation of Orion, is an example of a red giant star. It is easy to find this constellation because of the three stars that form its belt.

Dwarf stars

Stars that are smaller than the Sun come in two main categories, *dwarfs* and *neutron stars*. Dwarf stars are about the size of the smaller planets. Sirius B, the largest known dwarf star, is slightly smaller than Earth. Neutron stars are even smaller. Their diameter is only 20 to 30 kilometers, about the size of a big city.





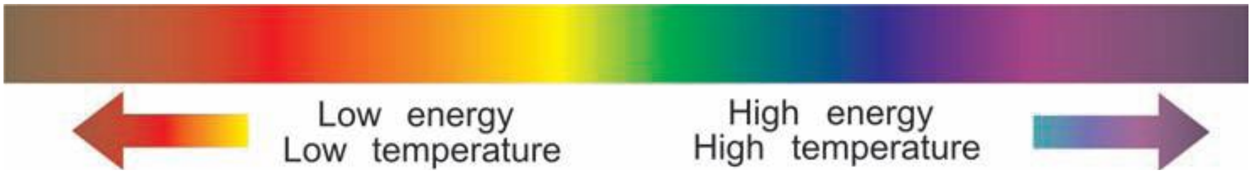
Temperature and color of stars

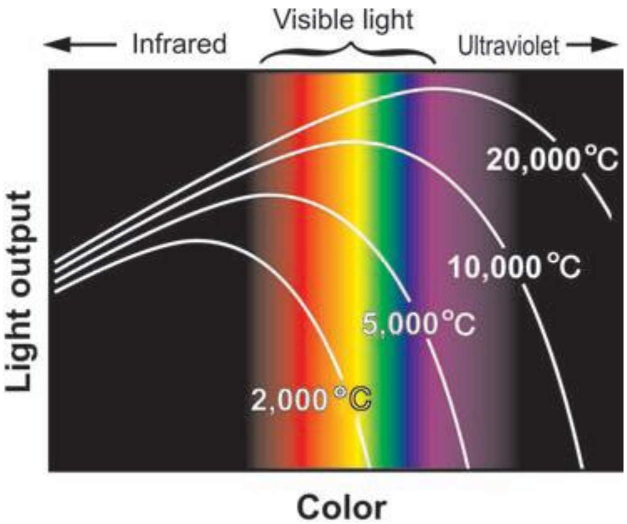
Temperatures of stars

If you look closely at the stars on a clear night, you might see a slight reddish or bluish tints to some stars. This is because stars' surface temperatures are different. Red stars are cooler than white stars, and blue stars are the hottest. The table below lists some stars, their colors, and their surface temperatures. The color of light is related to its energy. Red light has the lowest energy of the colors we can see. Blue and violet light have the most energy. Yellow, green, and orange are in between. White light is a mixture of all colors at equal brightness (Figure 19.10).

Color and temperature

When matter is heated, it first glows red at about 600 °C. As the temperature increases, the color changes to orange, yellow, and finally white. The graph in Figure 19.11 shows the colors of light given off at different temperatures. The curve for 2,000 °C crosses red and yellow, but drops off before getting to blue. That means a surface at 2,000 °C gives off mostly red and some yellow light. At 10,000 °C a star gives off an even mix of red to blue so it appears white. At 20,000 °C the emitted light is white with a bluish color.





Betelgeuse	red	2,000 to 3,500
Arcturus	orange	3,500 to 5,000
Sun	yellow	5,000 to 6,000
Polaris	yellow-white	6,000 to 7,500
Sirius (Figure 19.10)	white	7,500 to 11,000
Rigel	blue-white	11,000 to 25,000
Zeta Orionis	blue	25,000 to 50,000

Brightness and luminosity of stars

Light radiates in all directions

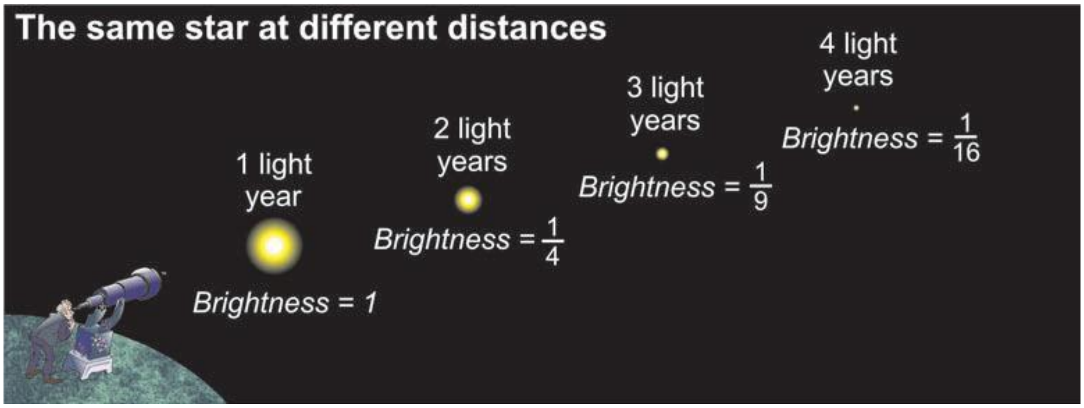
You can see a bare light bulb from anywhere in a room because the bulb emits light in all directions. When the rays of light are represented by arrows, the light coming from a bulb looks like Figure 19.12. A star also emits light equally in all directions.

Brightness

From experience, you know that as you move away from a source of light, the brightness decreases. **Brightness** describes the amount of light per second falling on a surface. The brightness of a star is described as the *light reaching Earth*.

Brightness and distance

For a distant source of light like a star, the brightness decreases mathematically with distance. For example, a star that is twice as far away will appear only one-quarter as bright. A star that is
three times as far away will appear one-ninth as bright.



Luminosity The brightness of a star also depends on how much light the star actually gives off. This is called a star's luminosity. **Luminosity** is the total amount of light given off by a star in all directions. Luminosity is a property of a star whereas brightness depends on both luminosity and distance. Therefore, to find the luminosity of a star we need to know both its brightness and its distance from Earth.

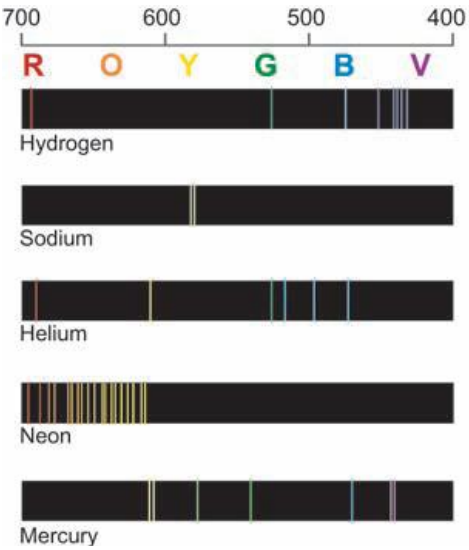
Analyzing the light from stars

What is spectroscopy?

Astronomers analyze the light given off by stars to determine the chemical elements from which they are made. **Spectroscopy** is a tool of astronomy in which the light produced by a star or other object (called its *spectrum*) is analyzed. A *spectrometer* splits light into a spectrum of colors and displays lines of different colors along a scale. The scale measures the wavelength of each of the lines of color in nanometers (nm). Scientists have discovered that each element has its own unique pattern of lines—like a fingerprint. For example, when the element sodium is burned, two yellow lines at 589.0 and 589.6 nm are observed when the light is passed through a spectrometer (Figure 19.13).

The composition of the Sun

In 1861, Sir William Huggins (1824–1910), an English astronomer, used spectroscopy to determine that the Sun and the stars are made mostly of hydrogen. A few years later, Sir Joseph Norman Lockyer (1836–1920) observed a line at the precise wavelength of 587.6 nm. Since no known element on Earth had a line at this wavelength, he concluded that this must be an undiscovered element and named it helium, after the Greek name for the Sun, *Helios*. Today, we know that hydrogen is the most abundant element in the universe, with helium second. Figure 19.14 shows the spectral lines of some elements.



The life cycle of a Sun-like star

The birth of a star

Stars begin life inside a huge cloud of gas and dust called a **nebula**. Gravitational forces cause denser regions of the nebula to collapse, forming a protostar. A *protostar* is the earliest stage in the life cycle of a star. The gases at the center of the protostar continue to collapse, causing pressure and temperature to rise. A protostar becomes a star when the temperature and pressure at its center become great enough to start nuclear fusion of hydrogen. Figure 19.15 shows a portion of the Orion Nebula with protostars visible in the center of the nebula.

Main sequence stars

Once nuclear fusion begins, a star is in the *main sequence* stage of its life cycle. This is the longest and most stable part of a star's life. The length of the main sequence stage depends on a star's mass. Stars with large masses burn brighter and hotter than smaller stars. So, they use up their hydrogen fuel quicker. The main sequence stage of Sun-like stars lasts for about 10 billion years.

Old age

As a star grows old, its core begins to run out of hydrogen fuel. Gravity causes the core to contract, raising its temperature and igniting the helium inside the core, along with any hydrogen in the outer layers. The star expands, and the outer layers begin to cool. At this stage in its life cycle, a Sun-like star becomes a *red giant*.

Death of a star

When hydrogen fusion stops, the core glows brightly and is called a *white dwarf*. It is about the size of Earth, and has about the same mass as the Sun. During the white-dwarf stage, the outer layers of the star expand and drift away from the core, forming what is called a *planetary nebula* (Figure 19.16). This is different from a nebula where stars are born. When a white dwarf stops glowing, it is called a *brown dwarf*, the final stage in the life cycle of Sun-like stars.

How the solar system formed

How was our solar system formed?

Scientists think that the solar system was formed out of the same nebula that created the Sun (Figure 19.17). As the Sun was being formed, it was surrounded by a cloud of dust and gas. This cloud was made mostly of hydrogen and helium, but contained smaller amounts of "heavier" elements such as carbon, nickel, iron, aluminum, and silicon. As this cloud rotated, it flattened, with the help of gravity, into a disk-shape along the axis of its rotation.

Planet formation

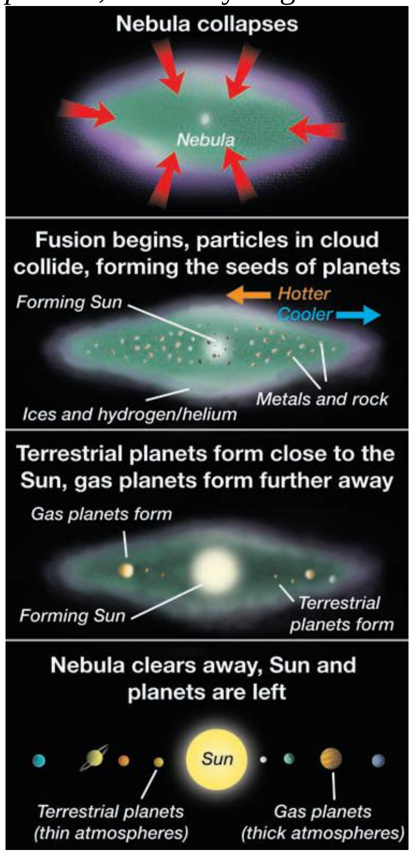
Most of the mass concentrated at the center of the disc under the influence of gravity. At the center, pressures became high enough for fusion to begin, igniting the Sun. Farther away from the center, the heaviest molecules began to condense into solid and liquid droplets. These droplets began to collide, forming small clumps— the seeds of the planets. Through further collisions, these clumps of material grew larger and eventually formed spherical planets.

The terrestrial planets

Terrestrial planets, like Earth, were formed in the warmer, inner regions of the disk. Because the heat drove off the lighter elements such as hydrogen and helium, these planets were made mostly of metals and rock. These materials made up less than one percent of the disk, so these planets could not grow very large. Because of their small masses, their gravity could not attract hydrogen and helium and their atmospheres were thin and contained little of these elements.

The gas planets

The outer regions of the disk were rich in icy materials made of lighter elements and the planets there grew larger than the terrestrial planets. Because of their large masses, they were able to capture hydrogen and helium through their gravitational force and form thick atmospheres. These became *gas planets*, rich in hydrogen and helium with dense cores.



19.2 Section Review

1. What is the basic process through which a star releases energy?

2. To which category below does the Sun currently belong?
a. main sequence star
b. white dwarf
c. red giant
d. neutron star

3. List the stars below from coolest to hottest.
a. Sirius (white)
b. Betelgeuse (red)
c. Rigel (blue-white)
d. Sun (yellow)
e. Arcturus (orange)

4. Explain the difference between a star's brightness and its luminosity.

5. Suppose Star A is three times further away than Star B. If both stars have the same luminosity, how will their brightness compare?

6. What is spectroscopy? How do astronomers use spectroscopy?

7. A star begins its life inside of a huge cloud of gas and dust called a _____.

8. List the following objects from youngest to oldest: red giant, protostar, main sequence star, black dwarf, white dwarf.

9. In the formation of the solar system, why were the gas planets able to grow larger than the terrestrial planets?