8.2 Exploring the Sun

The Sun is the most important celestial object for life on Earth. It is not surprising that astronomers use some of the technological tools described in Section 8.1, such as the SOHO satellite, to learn as much as they can about the Sun. In spite of the Sun's importance, people generally take for granted that it will continue to shine steadily and reliably every day, year after year, allowing us to enjoy each day from sunrise to sunset (**Figure 8.17**).

Key Terms

- solar nebula theory
- star
- nebula
- protostar
- nuclear fusion
- photosphere
- sunspot
- solar wind

The Formation of the Sun and the Solar System

One major question about the Sun is, Where did it come from? The current theory regarding how the Sun, other stars, and planets form is called the **solar nebula theory**. This theory says that stars and planets form together. A **star** is a celestial body made of hot gases, mainly hydrogen and some helium. When a star forms, such as the Sun, its hot core remains surrounded by gas and dust—called a **nebula**—that have not been pulled into the centre. Sometimes this leftover material just drifts off into space. In other cases, it remains in the nebula, bound to the star by gravity.

solar nebula theory the theory that describes how stars and planets form from contracting, spinning disks of gas and dust

star a celestial body made of hot gases, mainly hydrogen and some helium

nebula a vast cloud of gas and dust, which may be the birthplace of stars and planets

Figure 8.17 Kayaking on a lake allows for unobstructed views of sunrises, sunsets, and the night sky.

protostar hot, condensed object at the centre of a nebula

How the Solar System Formed

As you read this paragraph, refer to **Figure 8.18**. Gravity can set the gas and dust particles in the nebula into motion around the core of the young star, which is called a protostar (**Figure 8.18A**). The **protostar** is a hot and condensed object. The particles begin to gather in the centre of the spinning cloud. You can see a similar effect if you stir a glass of water that has a small amount of sand at the bottom—the more you stir, the more the sand gathers in the middle of the bottom of the glass. The spinning nebula begins to contract, and tiny grains start to collect, building up into bigger, rocky lumps called planetesimals (**Figure 8.18B**). If the planetesimals can survive collisions with each other, they may build up and eventually develop into full-fledged planets like those in our solar system (**Figure 8.18C**).

Study Toolkit

Making Study Notes After you read the paragraph on evidence for the formation of the solar system, you could arrange your notes in a T-chart, like the one on page 316. A T-chart illustrates the text's main idea and supporting details.

Evidence for the Formation of the Solar System

The early solar system was a very cluttered and disorganized place. Dust and rocky materials ranging from particles the size of grains of sand to balls of rock the size of planets orbited the new Sun. Collisions were common in this crowded, jumbled environment. Stray rocks and dust that had not fallen into the Sun pounded the planets and their moons. The cratered surfaces of the Moon and Mercury are evidence of this pounding.

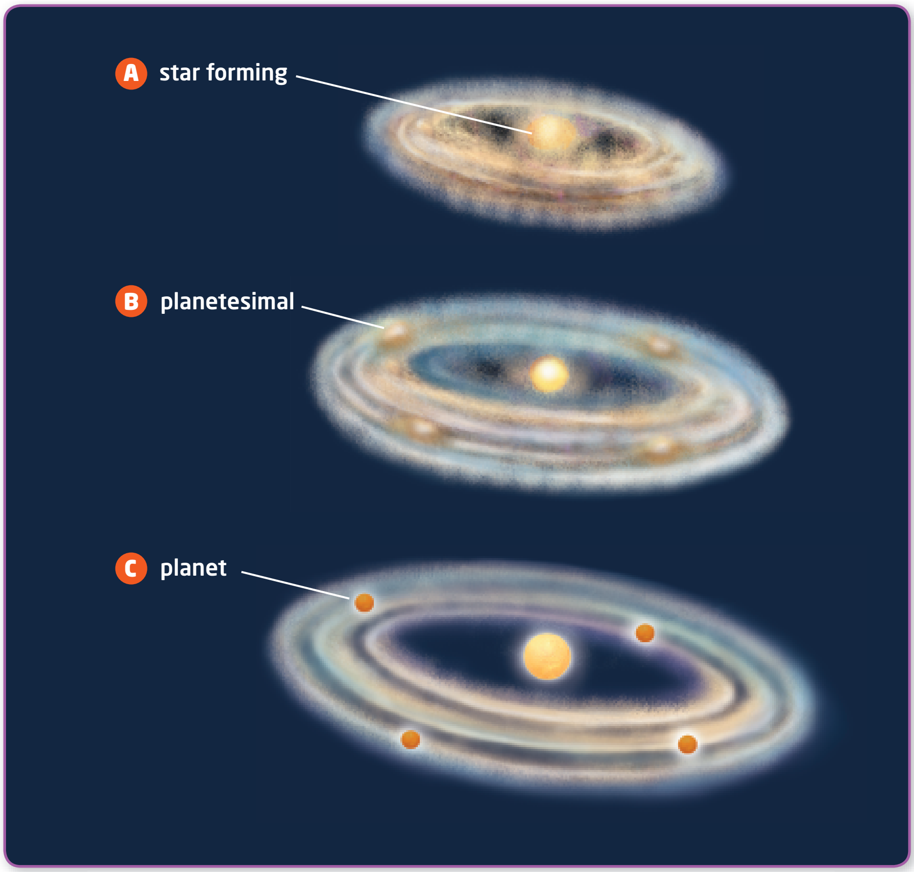

Figure 8.18 The solar nebula theory is the leading theory of planet formation.

A Flat, Rotating Disk

Over time, as the nebula spins, it flattens into a disk-like shape while spinning in one direction. Astronomers theorize that any planets and other bodies that form at this stage would form in the flat plane of the disk. As a result, they would rotate and revolve around the star in the same direction. All the planets in the solar system are more or less in the plane of the disk, most rotate in the same direction, and they all revolve around the Sun in the same direction.

Using various technologies and tools such as telescopes, astronomers have also discovered flattening dust clouds around young stars that are beyond our solar system. This evidence strongly supports the solar nebula theory.

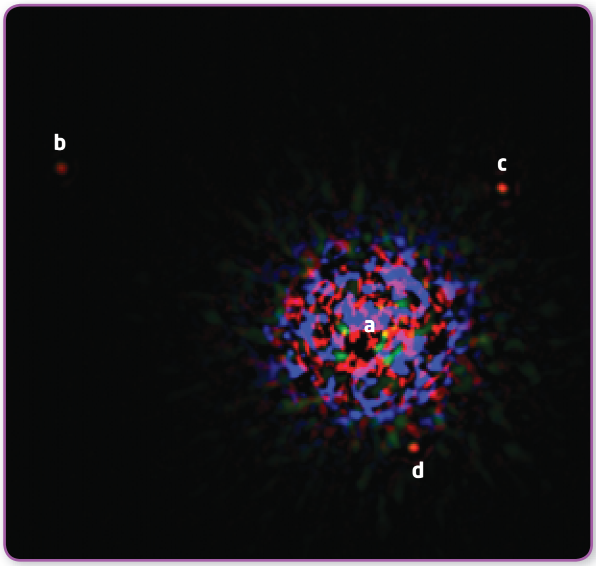

Figure 8.19 The extrasolar planets are labelled in order of discovery, so **a** is the star, which was discovered first. Then planets **b**, **c**, and **d** were discovered, all of which are larger than Jupiter.

Extrasolar Planets

The solar nebula theory indicates that planets are by-products of star formation, so planets should be fairly common. In fact, astronomers have discovered over 300 planets orbiting stars other than the Sun. These are called *extrasolar planets*. There are several techniques that astronomers use to detect extrasolar planets. For example, astronomers have discovered some extrasolar planets by detecting changes in a star's light levels as the planet orbits the star. When the planet is between the star and the observer on Earth, the amount of light coming from the star decreases slightly.

In 2008, astronomers took the first images of extrasolar planets, which you can see in **Figure 8.19**. The star is HR 8799 (labelled **a**) in the constellation Pegasus. Canadian astronomer Christian Marois, of the Herzberg Institute of Astrophysics in Victoria, British Columbia, and colleagues developed a way to separate a star's bright light from the light emitted by the still-forming planets. Otherwise, the light from a star is so bright that it prevents astronomers from seeing the planets. The image in **Figure 8.19** was taken at the Keck Observatory in Hawaii.

How the Sun Formed

As a star-forming nebula collapses and contracts, the gas compresses. As a result of the compression, the temperature of the protostar increases. When the temperature reaches around 10 000 000°C, nuclear fusion begins. During **nuclear fusion**, hydrogen nuclei combine to form helium nuclei. It takes enormous pressure and temperatures to do this. Such conditions only exist in the cores of stars. Note that nuclear fusion is not a chemical or physical reaction—it is a nuclear reaction.

nuclear fusion the process of energy production in which hydrogen nuclei combine to form helium nuclei

A Growing Sun

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Once the fusion process begins, the protostar starts to consume the hydrogen fuel. Helium from nuclear fusion begins to build up in the protostar's core. The core continues to heat up, which increases the pressure and temperature. At the same time, there is always a balancing act going on with gravity. The pressure is always trying to balance with gravity pulling matter toward the core. When gravity and pressure are balanced, the result is a stable star such as the Sun, as shown in **Figure 8.20**.

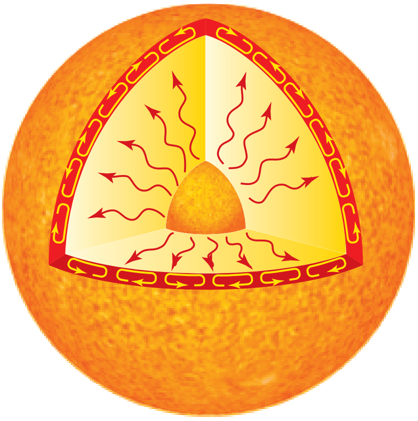


Figure 8.20 Energy in the Sun is transferred mostly by radiation from the core outward to about 86 percent of its radius. The outer layers transfer energy in convection currents.

When the Sun has converted about 10 percent of its hydrogen to helium, the helium in the core will accumulate and also begin to undergo fusion. At this point, the Sun will physically change, as will be described in Section 8.3. Solar astronomers (astronomers who study the Sun) know that the Sun can produce energy by nuclear hydrogen fusion for about 10 billion years. This estimate is based on the energy output of the Sun and the mass of hydrogen it contains. The Sun is now about five billion years old, so you might say the Sun is in mid-life.

Helium is denser than hydrogen, so helium settles in the Sun's core. As the Sun continues to fuse hydrogen into helium, the helium core grows larger. The region of hydrogen fusion, which lies around the helium core like the shell on an egg, also grows larger. So the Sun is getting larger. Solar astronomers estimate that the Sun is 30 percent larger today than when it was a protostar about five billion years ago.

Learning Check

1. Why is the theory shown in **Figure 8.18** called the solar nebula theory?
2. List three pieces of evidence that support the solar nebula theory.
3. Define *protostar*.
4. Name and describe the process that fuels the Sun.

Features of the Sun

Since the Sun is really a large sphere of gas, it has no surface as such. The area recognized as the surface is called the **photosphere**. The photosphere is several thousand kilometres deep.

photosphere the surface layer of the Sun

sunspot an area of strong magnetic fields on the photosphere

Sunspots

For centuries, observers of the Sun have noticed dark spots on the photosphere, called sunspots. **Sunspots** are areas of strong magnetic fields. A magnetic field is a region of force around a magnetically charged area, such as a magnet. When you observe a compass needle pointing toward north, you are seeing evidence of Earth's magnetic field. Like Earth, the Sun has a magnetic field, although the Sun's magnetic field is much more complicated than Earth's.

Sometimes, when charged particles disturb the Sun's photosphere, sunspots appear. Sunspots are not actually dark—they are bright. They look dark because they are a different temperature from the photosphere, and one temperature contrasts with the other. The photosphere is about 6000°C, and sunspots are about 4500°C.

Study Toolkit

Compound Words Think about the compound word *sunspot*. If you identify the two smaller words that make up this compound word, you can use their meanings to figure out the meaning of *sunspot*.

Evidence of a Rotating Sun

Astronomers have observed that sunspots that form near the Sun's north and south poles take about 35 days to complete one rotation, and sunspots that form near the Sun's equator take about 27 days to complete one rotation. Based on these observations, astronomers infer that not only does the Sun rotate, but it rotates faster at its equator than at its poles. This means that the Sun does not rotate as a solid body the way Earth does. **Figure 8.21** shows the movement of a group of sunspots across the photosphere.

Sunspots usually start off small, gradually grow larger and sometimes form in clusters, eventually fade, and then disappear altogether. Sunspots occur in 22-year cycles, peaking in number at intervals of about every 11 years. The precise time at which the maximum sunspot activity occurs is difficult to predict.

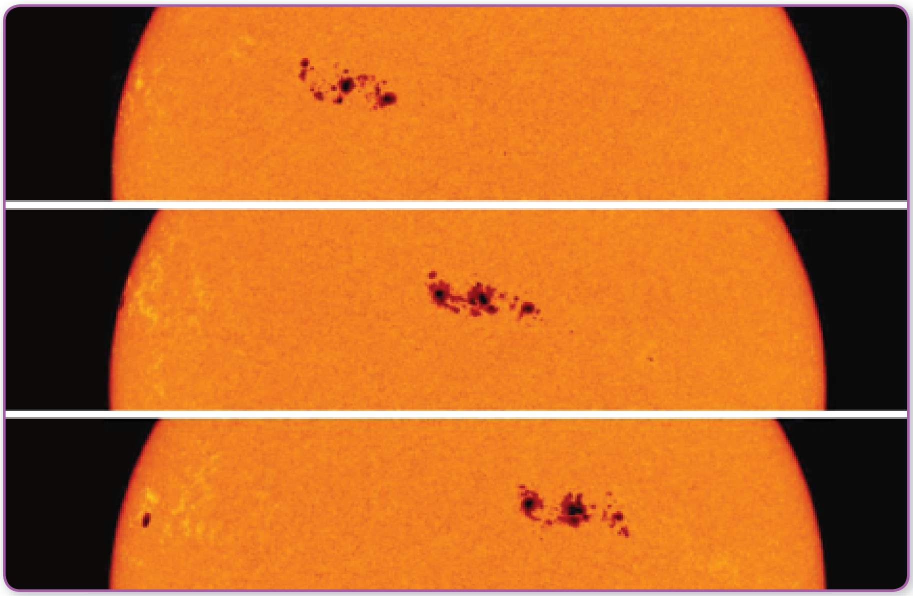


Figure 8.21 Notice how sunspots move as the Sun rotates. The SOHO satellite took the top image on July 15, the middle image on July 16, and the bottom image on July 17, 2007.

solar wind a stream of fast-moving charged particles ejected by the Sun into the solar system

Solar Flares

Occasionally, solar flares can occur where there are complex groups of sunspots. A solar flare, seen in **Figure 8.22A**, is an event in which magnetic fields explosively eject intense streams of charged particles into space. If one of these streams, called the **solar wind**, hits Earth, the results can be quite spectacular. On the one hand, these events, called solar storms, can disrupt telecommunications and damage electronic equipment aboard spacecraft. They can also overload the electrical power network, causing large-scale power blackouts. The radiation from a solar storm can also be harmful to astronauts.

On the other hand, solar flares usually result in beautiful auroras, as shown in **Figure 8.22B**. Auroras are shimmering curtains of green and/or red light in Earth's polar regions. They result when the high-energy charged particles are carried past Earth's magnetic field, generating electric currents that flow toward Earth's poles. These electric currents charge gases in Earth's upper atmosphere, producing the light in auroras. Auroras at Earth's North Pole are called aurora borealis. Auroras at Earth's South Pole are called aurora australis.

Figure 8.22 **A** Solar flares eject intense blasts of charged subatomic particles toward Earth. The SOHO satellite took this X-ray image of the Sun. **B** When the charged particles from the Sun collide with Earth's upper atmosphere, spectacular auroras can result.

Learning Check

5. Name the two most abundant elements that the Sun is composed of, and identify which element is in the higher proportion.
6. What is the difference between a solar flare and the solar wind?
7. Explain why sunspots look dark.
8. If you were an astronaut on the International Space Station, would you be concerned about solar flares? Why or why not?

The Importance of the Sun

The Sun is needed for all life on Earth. The Sun's energy drives most processes on Earth that support our daily activities, like finding sufficient food and providing ourselves with adequate shelter.

Solar energy powers the winds and ocean currents. It also drives all weather, from soft summer winds to gigantic hurricanes. Sunlight provides the energy required for photosynthesis. Photosynthesis is the process in which green plants provide all the vital oxygen in the atmosphere and all the food at the base of the food chain.

Sense of Value

For as long as there have been humans, humans have realized the importance of the Sun. Ancient Egyptians worshipped Re, the Sun god and creator. In Hindu mythology, the Sun god was Surya, and in Greek mythology, the Sun god was Apollo.

Heating Earth

The Sun's energy, or solar energy, is not just visible light. The Sun emits radiation from across the entire electromagnetic spectrum, such as microwaves, radio waves, light waves, X rays, and gamma rays. Recall from **Figure 8.5** on page 320 that most of the radiation that reaches Earth's surface is visible light and shorter-wavelength infrared radiation. This radiation goes through a cycle, shown in **Figure 8.23**. Earth's surface absorbs most of the visible light. While absorbing the visible light, Earth also emits longer-wavelength infrared radiation to the atmosphere. In turn, the atmosphere absorbs and emits infrared radiation. The process of reflecting and absorbing energy warms Earth's surface.

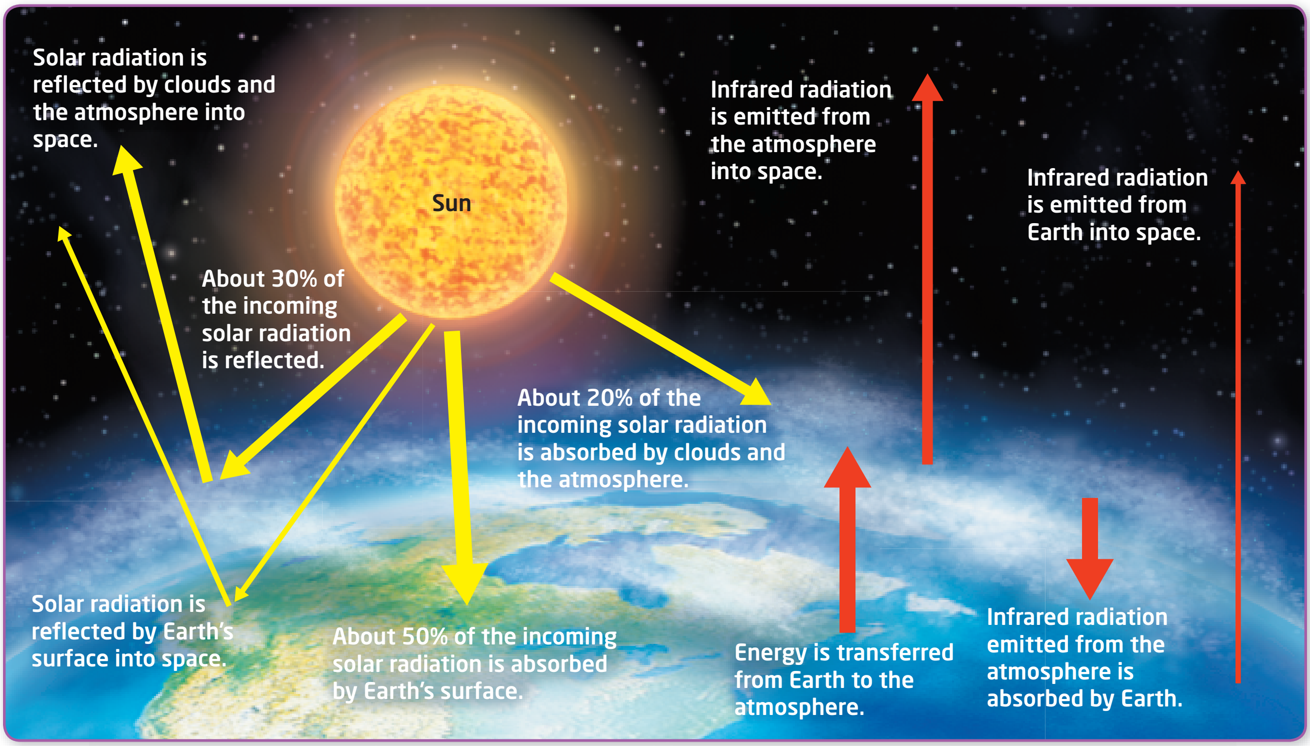


Figure 8.23 About 20 percent of the total incoming solar radiation is absorbed by Earth's atmosphere. About 30 percent is reflected by Earth's atmosphere, clouds, and surface and ocean features. About 50 percent is absorbed by Earth's surface and ocean features.

Section 8.2 Review

Section Summary

- The solar nebula theory says that the Sun and the solar system formed from a spinning, contracting disk of gas and dust particles.
- Evidence supporting the solar nebula theory consists of heavily cratered objects, most planets rotating in about the same direction, most planets revolving in the same direction and in about the same plane, and the existence of other planets around other stars.
- The Sun's energy source is hydrogen. It converts matter into energy through nuclear fusion.
- Sunspots can produce solar flares, which send gigantic beams of charged particles into space.
- Charged particles from the Sun that enter Earth's atmosphere produce auroras, but the charged particles can also damage electronic equipment, cause large-scale power blackouts, and pose a danger to astronauts.
- Energy absorbed and emitted by Earth's surface heats Earth and keeps it warm.

Review Questions

C **1.** In your notebook, draw the stages of the formation of the Sun and the solar system. Review **Figure 8.18**.

K/U **2.** List the types of radiation emitted by the Sun.

T/I **3.** The pie chart on the right shows the current composition of the Sun. Predict how the sizes of the pie portions for hydrogen and helium will change as the Sun gets older. Explain your reasoning.

K/U **4.** List three reasons why the Sun's energy is important to us.

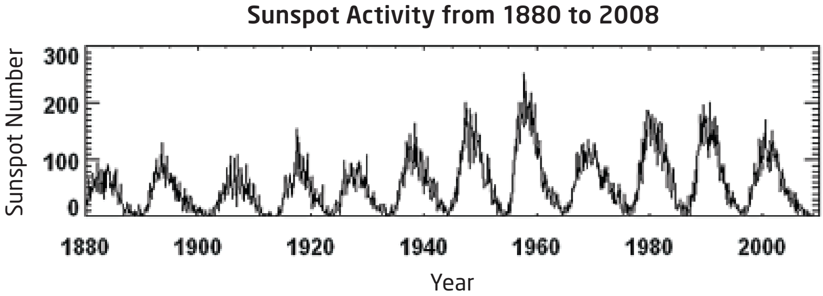
K/U **5.** Give an example of the result of the Sun's energy interacting with Earth's atmosphere.

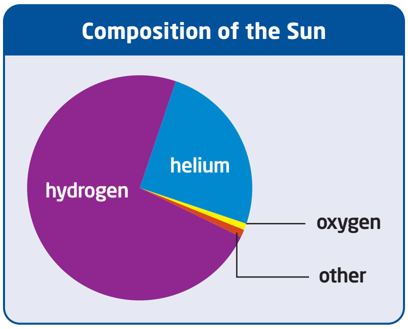
C **6.** In a pie chart, indicate the portions of solar radiation that are absorbed and reflected by Earth's surface features, oceans, and atmosphere. Refer to **Figure 8.23**.

K/U **7.** How does the Sun keep Earth's surface warm?

A **8.** What are the impacts of solar flares on technology, society, and the environment?

T/I **9.** Using the graph below, estimate the year of the next peak in sunspot activity.





Use this pie chart to answer question 3.