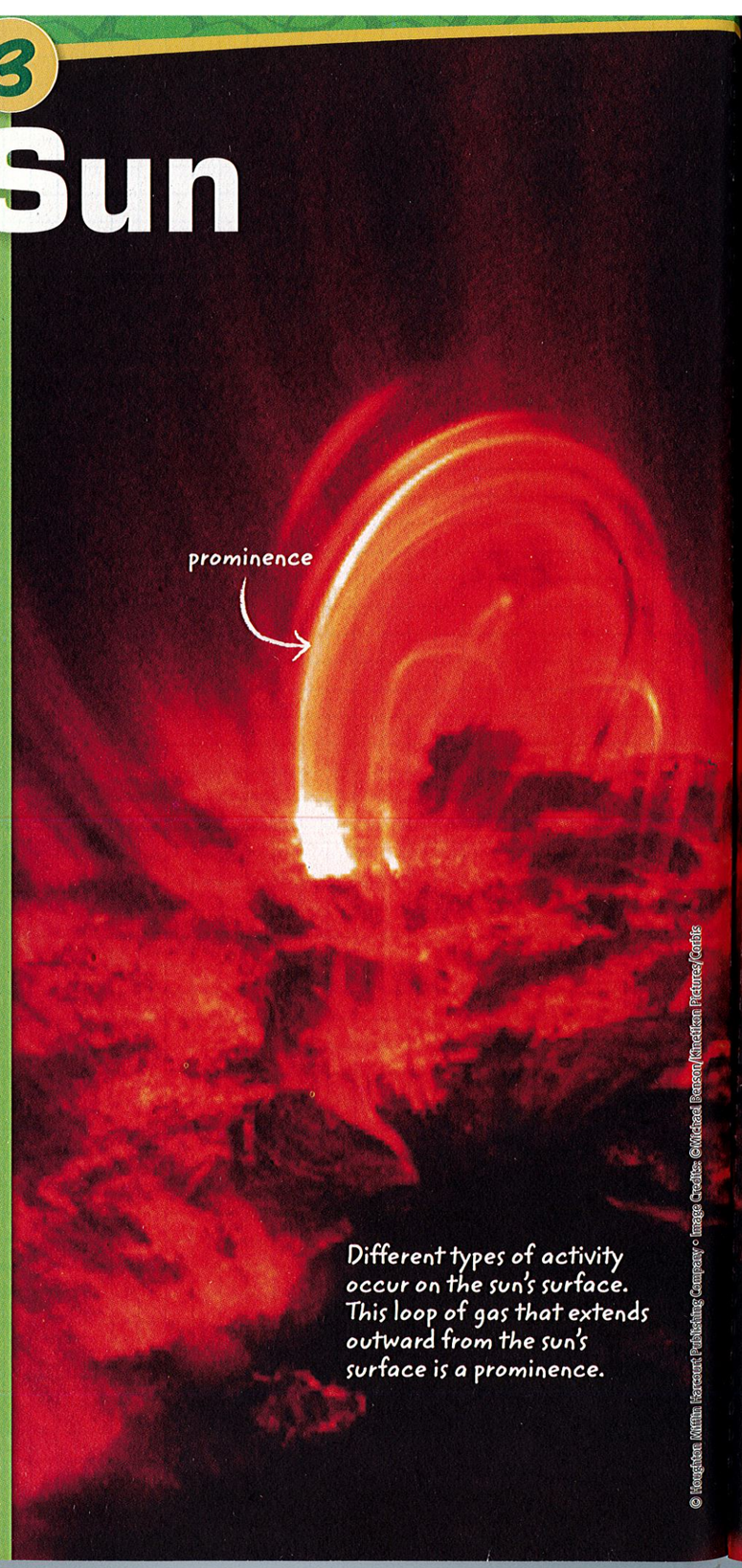
Lesson 3

The Sun

ESSENTIAL QUESTION

What are the properties of the sun?

By the end of this lesson, you should be able to describe the structure and rotation of the sun, energy production and energy transport in the sun, and solar activity on the sun.



Different types of activity occur on the sun's surface. This loop of gas that extends outward from the sun's surface is a prominence.

Lesson Labs

Quick Labs
- Model Solar Composition
- Model Solar Rotation

S.T.E.M. Lab
- Create a Model of the Sun

Engage Your Brain

1 Predict Check T or F to show whether you think each statement is true or false.

T	F	
☐	☐	The sun is composed mostly of hydrogen and helium.
☐	☐	Energy is produced in the sun's core.
☐	☐	The process by which energy is produced in the sun is known as *nuclear fission*.
☐	☐	Energy is transferred to the surface of the sun by the processes of radiation and conduction.
☐	☐	A dark area of the sun's surface that is cooler than the surrounding areas is called a *sunspot*.

2 Explain In your own words, explain the meaning of the word *sunlight*.

Active Reading

3 Synthesize You can often define an unknown word if you know the meaning of its word parts. Use the word parts and sentence below to make an educated guess about the meaning of the word *photosphere*.

Word Part	Meaning
photo-	light
-sphere	ball

Example sentence
Energy is transferred to the sun's photosphere by convection cells.

photosphere:

Vocabulary Terms

- **nuclear fusion**
- **sunspot**
- **solar flare**
- **prominence**

4 Apply This list contains the key terms you'll learn in this section. As you read, circle the definition of each term.

Here Comes the Sun

What do we know about the sun?

Since early in human history, people have marveled at the sun. Civilizations have referred to the sun by different names. Gods and goddesses who represented the sun were worshipped in different cultures. In addition, early astronomical observatories were established to track the sun's motion across the sky.

By the mid-19th century, astronomers had discovered that the sun was actually a hot ball of gas that is composed mostly of the elements hydrogen and helium. Scientists now know that the sun was born about 4.6 billion years ago. Every second, 4 million tons of solar matter is converted into energy. Of the light emitted from the sun, 41% is visible light, another 9% is ultraviolet light, and 50% is infrared radiation. And, perhaps most important of all, without the sun, there would be no life on Earth.

Active Reading

5 Identify As you read the text, underline different discoveries that scientists have made about the sun.

Sun Statistics	
Avg. dist. from Earth	149.6 million km
Diameter	1,390,000 km
Average density	1.41 g/cm³
Period of rotation	25 days (equator); 35 days (poles)
Avg. surface temp.	5,527 °C
Core temp.	15,000,000 °C
Composition	74% hydrogen, 25% helium, 1% other elements

Do the Math You Try It

6 Calculate The diameter of Earth is 12,756 km. How many times greater is the sun's diameter than the diameter of Earth?

A solar flare, which is shown in this image, is a sudden, explosive release of energy in the sun's atmosphere.

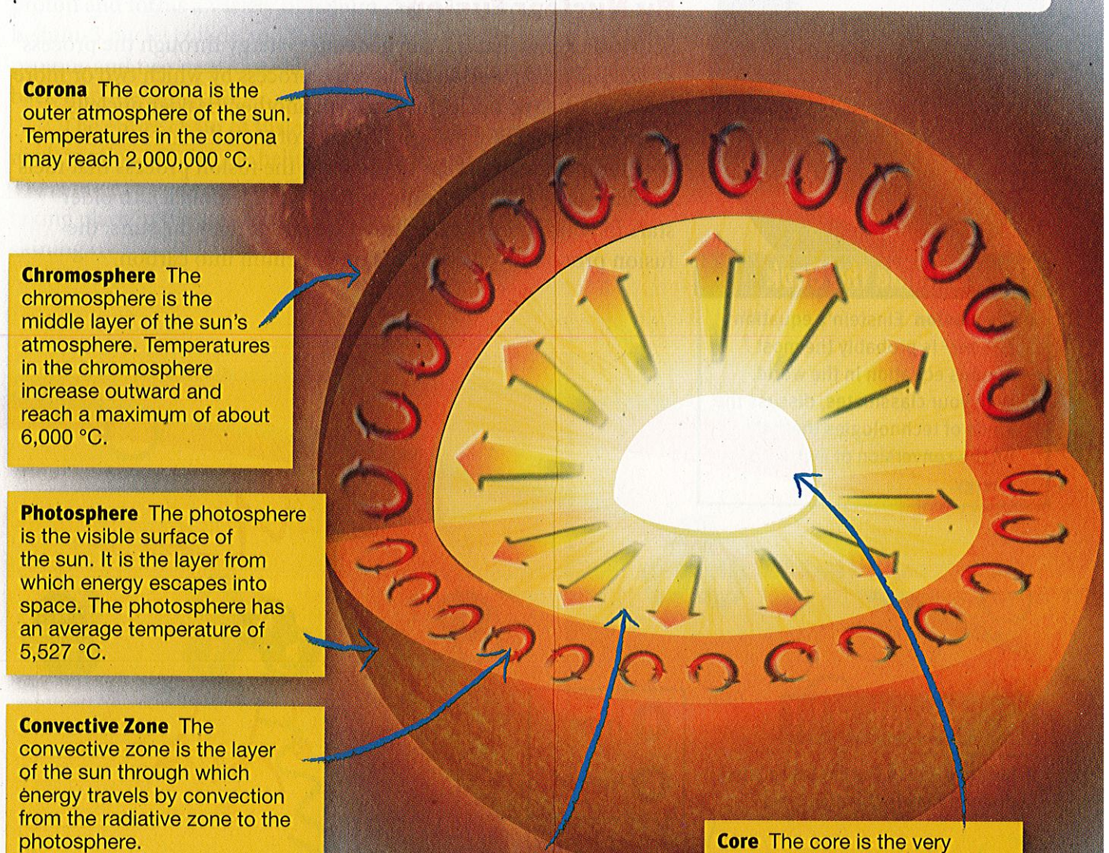
What is the structure of the sun?

The composition of the sun and Earth are different. However, the two bodies are similar in structure. Both are spheres. And both have a layered atmosphere and an interior composed of layers.

In the middle of the sun is the core. This is where energy is produced. From the core, energy is transported to the sun's surface through the radiative zone and the convective zone.

The sun's atmosphere has three layers—the photosphere, the chromosphere, and the corona. The sun's surface is the photosphere. Energy escapes the sun from this layer. The chromosphere is the middle layer of the sun's atmosphere. The temperature of the chromosphere rises with distance from the photosphere. The sun's outer atmosphere is the corona. The corona extends millions of kilometers into space.

7 Analyze Why is the structure of the sun different from the structure of Earth?



Let's Get Together

How does the sun produce energy?

Early in the 20th century, physicist Albert Einstein proposed that matter and energy are interchangeable. Matter can change into energy according to his famous equation $E = mc^2$. E is energy, m is mass, and c is the speed of light. Because c is such a large number, tiny amounts of matter can produce huge amounts of energy. Using Einstein's formula, scientists were able to explain the huge quantities of energy produced by the sun.

Think Outside the Book

8 Discussion Einstein's equation $E = mc^2$ is probably the most famous equation in the world. With your classmates, discuss the kinds of technologies that rely on the conversion of matter to energy.

By Nuclear Fusion

Scientists know that the sun generates energy through the process of *nuclear fusion*. **Nuclear fusion** is the process by which two or more low-mass atomic nuclei fuse to form another, heavier nucleus. Nuclear fusion takes place in the core of stars. In stars that have core temperatures similar to the sun's, the fusion process that fuels the star starts with the fusion of two hydrogen nuclei. In older stars in which core temperatures are hotter than the sun's, the fusion process involves the fusion of helium into carbon.

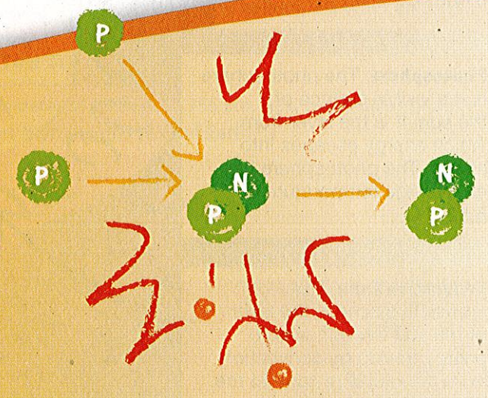
Visualize It!

9 Identify Fill in the circles to label the particles in the diagrams.

P Proton

N Neutron

Three Steps of Nuclear Fusion in the Sun



Step 1: Deuterium Two hydrogen nuclei (protons) collide. One proton emits particles and energy and then becomes a neutron. The proton and neutron combine to produce a heavy form of hydrogen called ***deuterium***.

By the Fusion of Hydrogen into Helium

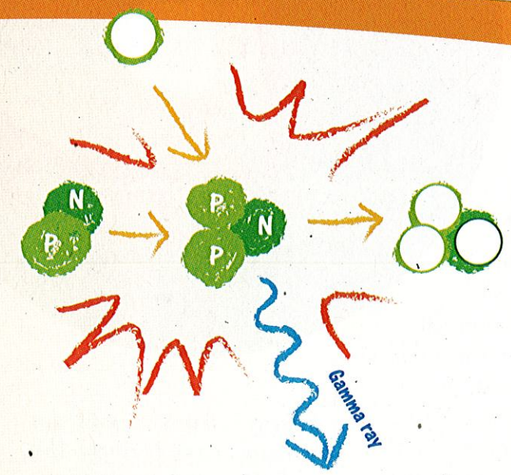
The most common elements in the sun are hydrogen and helium. Under the crushing force of gravity, these gases are compressed and heated in the sun's core, where temperatures reach 15,000,000 °C. In the sun's core, hydrogen nuclei sometimes fuse to form a helium nucleus. This process takes three steps to complete. This three-step process is illustrated below.

Most of the time, when protons are on a collision course with other protons, their positive charges instantly repel them. The protons do not collide. But sometimes one proton will encounter another proton and, at that exact moment, turn into a neutron and eject an electron. This collision forms a nucleus that contains one proton and one neutron. This nucleus is an isotope of hydrogen called *deuterium*. The deuterium nucleus collides with another proton and forms a variety of helium called *helium-3*. Then, two helium-3 nuclei collide and form a helium-4 nucleus that has two protons and two neutrons. The remaining two protons are released back into the sun's core.

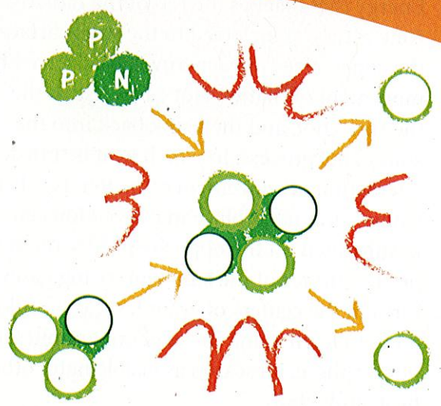
The entire chain of fusion reactions requires six hydrogen nuclei and results in one helium nucleus and two hydrogen nuclei. There are approximately 10^{38} collisions between hydrogen nuclei taking place in the sun's core every second, which keeps the sun shining.

Active Reading

10 Identify As you read the text, underline the steps in the nuclear fusion process in the sun.



Step 2: Helium-3 Deuterium combines with another hydrogen nucleus to form a variety of helium called ***helium-3***. More energy, including gamma rays, is released.



Step 3: Helium-4 Two helium-3 nuclei combine to form helium-4, which releases more energy and a pair of hydrogen nuclei (protons).

Mixing It Up

How is energy transferred to the sun's surface?

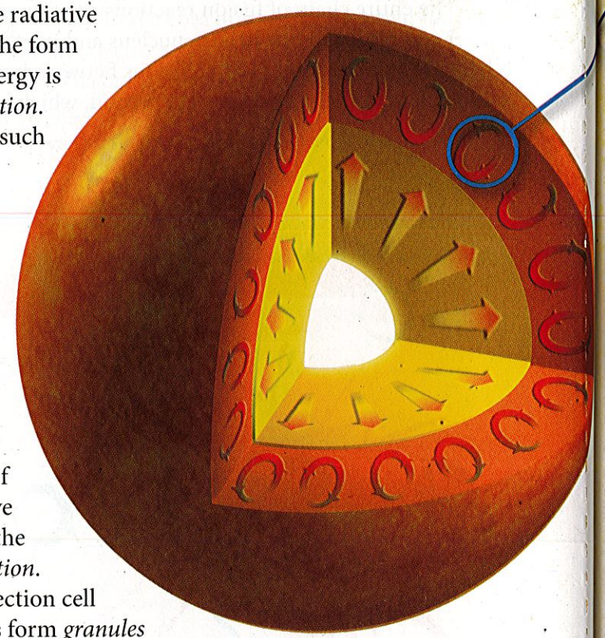
Energy is transferred to the surface of the sun by two different processes. Energy that is transferred from the sun's core through the radiative zone is transferred by the process of radiation. Energy that is transferred from the top of the radiative zone through the convective zone to the photosphere is transferred by the process of convection. Energy flow from the sun's core outward to the sun's surface by radiation and convection happens continuously.

By Radiation

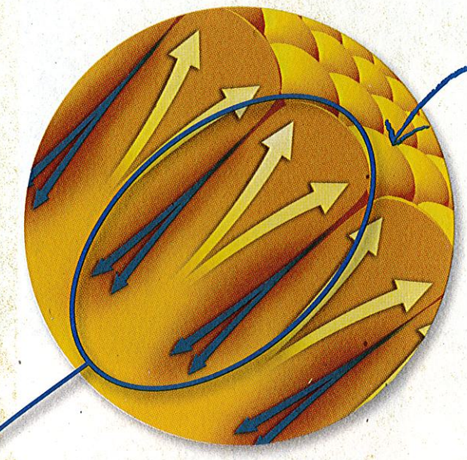
When energy leaves the sun's core, it moves into the radiative zone. Energy travels through the radiative zone in the form of electromagnetic waves. The process by which energy is transferred as electromagnetic waves is called *radiation*. The radiative zone is densely packed with particles such as hydrogen, helium, and free electrons. Therefore, electromagnetic waves cannot travel directly through the radiative zone. Instead, they are repeatedly absorbed and re-emitted by particles until they reach the top of the radiative zone.

By Convection

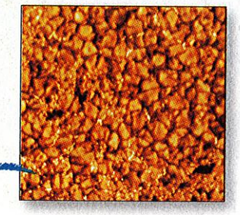
Energy that reaches the top of the radiative zone is then transferred to the sun's surface. In the convective zone, energy is transferred by the movement of matter. Hot gases rise to the surface of the sun, cool, and then sink back into the convective zone. This process, in which heat is transferred by the circulation or movement of matter, is called *convection*. Convection takes place in convection cells. A convection cell is illustrated on the opposite page. Convection cells form *granules* on the surface of the sun. Hot, rising gases cause bright spots to form in the centers of granules. Cold, sinking gases cause dark areas to form along the edges of granules. Once energy reaches the photosphere, it escapes as visible light, other forms of radiation, heat, and wind.



Energy is transferred from the sun's core through the radiative and convective zones to the sun's surface.



Hot, rising gases and colder, sinking gases form convection cells in the convective zone.



The tops of convection cells form granules on the sun's surface.

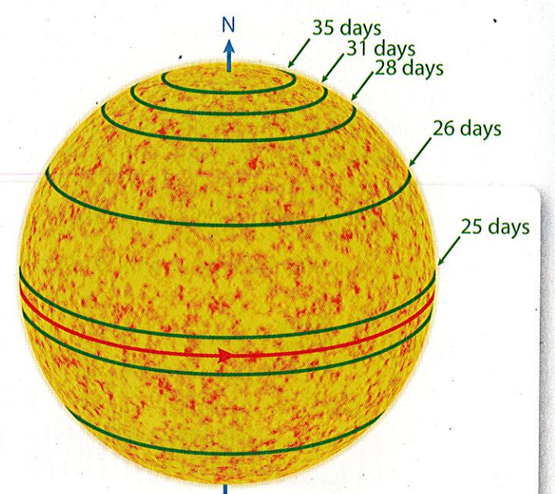
11 Compare How is energy transferred from the sun's core to the sun's surface in the radiative zone and in the convective zone?

Radiative zone	Convective zone

How does the sun rotate?

The sun rotates on its axis like other large bodies in the solar system. However, because the sun is a giant ball of gas, it does not rotate in the same way as a solid body like Earth does. Instead, the sun rotates faster at its equator than it does at higher latitudes. This kind of rotation is known as differential rotation. *Differential rotation* is the rotation of a body in which different parts of a body have different periods of rotation. Near the equator, the sun rotates once in about 25 days. However, at the poles, the sun rotates once in about 35 days.

Even stranger is the fact that the sun's interior does not rotate in the same way as the sun's surface does. Scientists think that the sun's core and radiative zone rotate together, at the same speed. Therefore, the sun's radiative zone and core rotate like Earth.



The sun's period of rotation varies with latitude.

12 Define In your own words, define the term *differential rotation*.

The Ring of Fire

What is solar activity?

Solar activity refers to variations in the appearance or energy output of the sun. Solar activity includes dark areas that occur on the sun's surface known as *sunspots*. Solar activity also includes sudden explosive events on the sun's surface, which are called *solar flares*. Prominences are another form of solar activity. *Prominences* are vast loops of gases that extend into the sun's outer atmosphere.

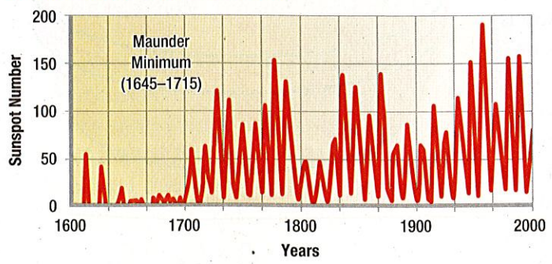
Sunspots

Dark areas that form on the surface of the sun are called **sunspots**. They are about 1,500 °C cooler than the areas that surround them. Sunspots are places where hot, convecting gases are prevented from reaching the sun's surface.

Sunspots can appear for periods of a few hours or a few months. Some sunspots are only a few hundred kilometers across. Others have widths that are 10 to 15 times the diameter of Earth.

Sunspot activity occurs on average in 11-year cycles. When a cycle begins, the number of sunspots is at a minimum. The number of sunspots then increases until it reaches a maximum. The number then begins to decrease. A new sunspot cycle begins when the sunspot number reaches a minimum again.

Sunspot Activity from 1600 to 2000

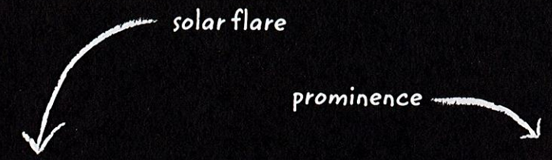


Do the Math **You Try It**

13 Analyze The sunspot range is the difference between the maximum number of sunspots and the minimum number of sunspots for a certain period of time. To find this range, subtract the minimum number of sunspots from the maximum number of sunspots. What is the range of sunspot activity between 1700 and 1800?

Sunspots, solar flares, and prominences are three kinds of solar activity that occur on the sun's surface.

sunspot



Solar Flares

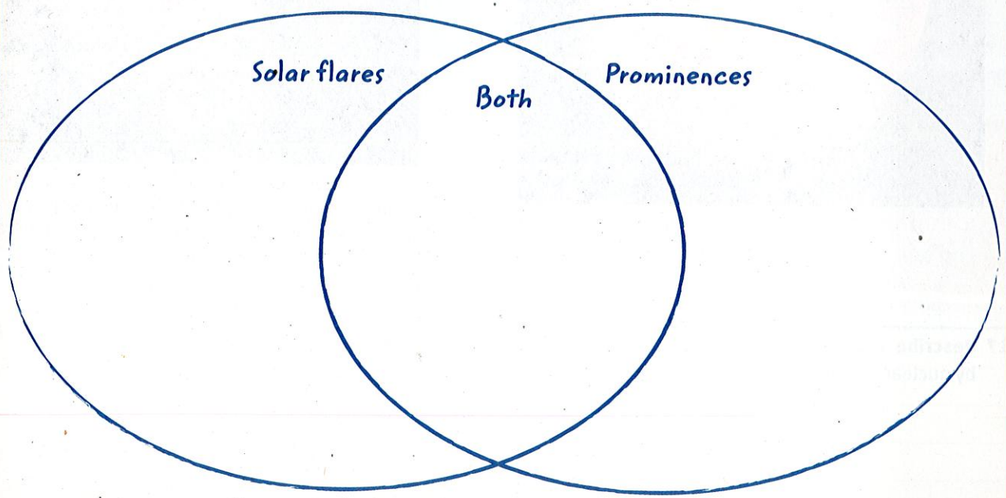
Solar flares appear as very bright spots on the sun's photosphere. A **solar flare** is an explosive release of energy that can extend outward as far as the sun's outer atmosphere. During a solar flare, enormous numbers of high-energy particles are ejected at near the speed of light. Radiation is released across the entire electromagnetic spectrum, from radio waves to x-rays and gamma rays. Temperatures within solar flares reach millions of degrees Celsius.

Prominences

Huge loops of relatively cool gas that extend outward from the photosphere thousands of kilometers into the outer atmosphere are called **prominences**. Several objects the size of Earth could fit inside a loop of a prominence. The gases in prominences are cooler than the surrounding atmosphere.

Prominences generally last from several hours to a day. However, some prominences can last for as long as several months.

14 Compare Use the Venn diagram below to compare solar flares and prominences.



Visual Summary

To complete this summary, fill in the blanks with the correct word or phrase. Then use the key below to check your answers. You can use this page to review the main concepts of the lesson.

Properties of the Sun

The sun is composed of layers.

15 Identify the six layers of the sun, beginning with the innermost layer.

_____

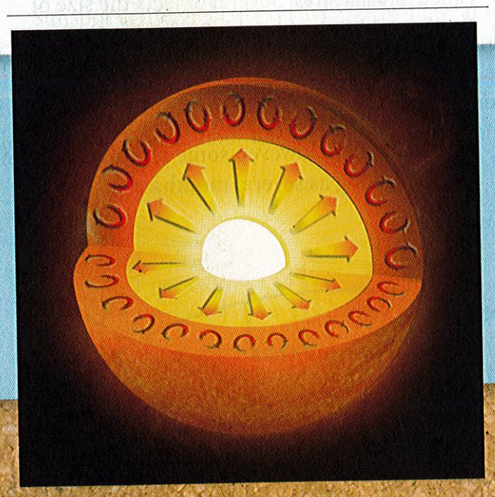
_____

_____

_____

_____

_____



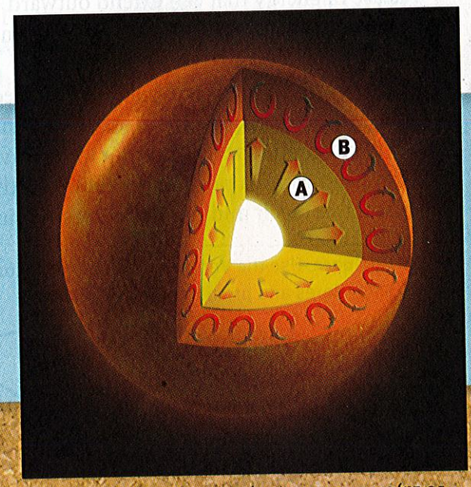
Energy is transferred from the sun's core to the photosphere.

16 By what process is the sun's energy transported in layer A?

_____

By what process is the sun's energy transported in layer B?

_____



Answers: 15 the core, the radiative zone, the convective zone, the photosphere, the chromosphere, and the corona; 16 Layer A: radiation, Layer B: convection

17 Describe In your own words, describe the process of energy production by nuclear fusion in the sun.

Lesson Review

Vocabulary

Fill in the blank with the term that best completes the following sentences.

1 The process by which two or more low-mass atomic nuclei fuse to form another, heavier nucleus is called _____.

2 A _____ is a dark area on the surface of the sun that is cooler than the surrounding areas.

3 A _____ is a loop of relatively cool gas that extends above the photosphere.

Key Concepts

In the following table, write the name of the correct layer next to the definition.

Definition	Layer
4 Identify What is the layer of the sun from which energy escapes into space?	
5 Identify What is the layer of the sun in which energy is produced?	
6 Identify What is the layer of the sun through which energy is transferred away from the core by radiation?	

7 Identify What is the composition of the sun?

_____

_____

8 Explain What is the sunspot cycle?

_____

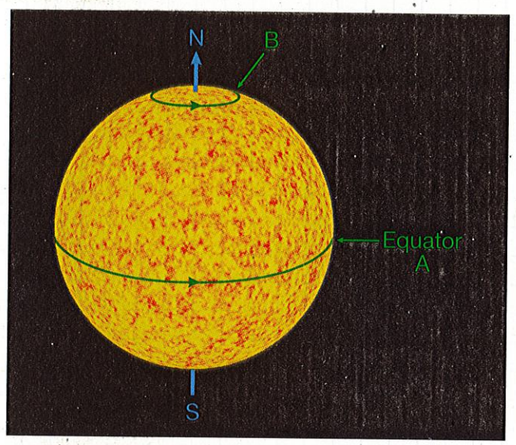
_____

_____

_____

Critical Thinking

Use the illustration to answer the following questions.



9 Determine How many days does it take for the sun to spin once on its axis at location A? How many days does it take for the sun to spin once on its axis at location B?

_____

_____

10 Compare How is the rotation of the sun different from the rotation of Earth?

_____

_____

_____

11 Explain In your own words, explain how energy is transported from the core to the surface of the sun by radiation and by convection.

_____

_____

_____

_____

_____