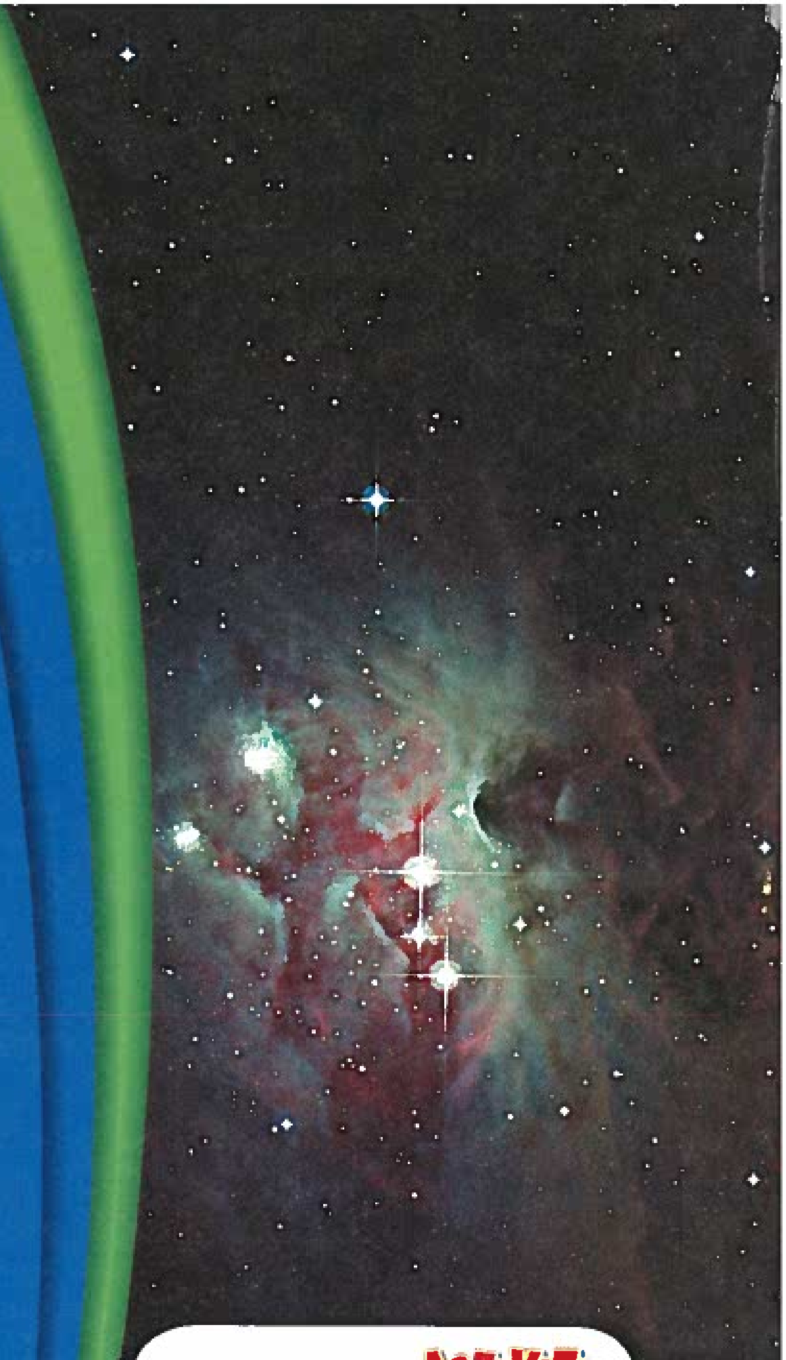
3

Formation of the Solar System



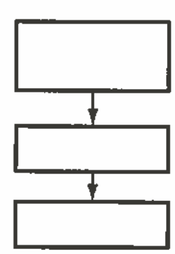
About the PHOTO

The Orion Nebula, a vast cloud of dust and gas that is 35 trillion miles wide, is part of the familiar Orion constellation. Here, swirling clouds of dust and gas give birth to systems like our own solar system.

PRE-READING ACTIVITY

Graphic Organizer

Chain-of-Events Chart Before you read the chapter, create the graphic organizer entitled "Chain-of-Events Chart" described in the Study Skills section of the Appendix. As you read the chapter, fill in the chart with details about each step of the formation of the solar system.



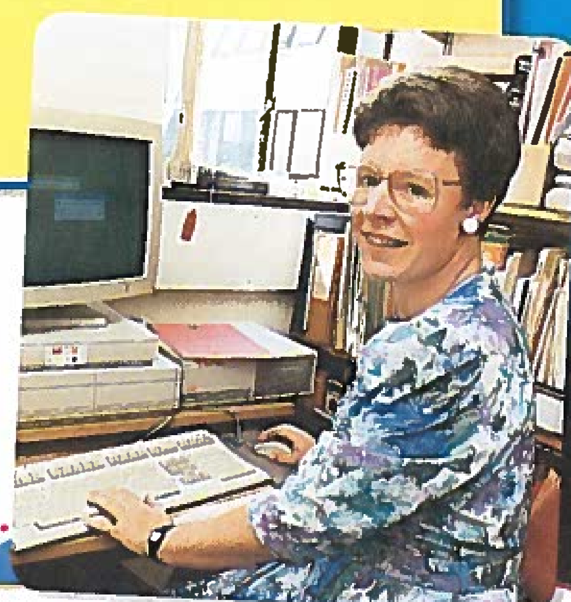
Careers

Jocelyn Bell-Burnell

Astrophysicist Imagine getting a signal from far out in space and not knowing what or whom it's coming from. That's what happened to astrophysicist Jocelyn Bell-Burnell. Bell-Burnell is known for discovering pulsars, objects in space that emit radio waves at short, regular intervals. But before she and her advisor discovered that the signals came from pulsars, they thought that the signals may have come from aliens!

Born in 1943 in Belfast, Northern Ireland, Jocelyn Bell-Burnell became interested in astronomy at an early age. At Cambridge University in 1967, Bell-Burnell, who was a graduate student, and her advisor, Anthony Hewish, completed work on a huge radio telescope designed to pick up signals from quasars. Bell-Burnell's job was to operate the telescope and analyze its chart paper recordings on a graph. Each day, the telescope recordings used 29.2 m of chart paper! After a month, Bell-Burnell noticed that the recordings showed a few "bits of scruff"—very short, pulsating radio signals—that she could not explain. Bell-Burnell and Hewish struggled to find the source of the mysterious signal. They checked the equipment and began eliminating possible sources of the signal, such as satellites, television, and radar. Shortly after finding the first signal, Bell-Burnell discovered a second. The second signal was similar to the first but came from a different position in the sky. By January 1968, Bell-Burnell had discovered two more pulsating signals. In March of 1968, her findings that the signals were from a new kind of star were published and amazed the scientific community. The scientific press named the newly discovered stars *pulsars*.

Today, Bell-Burnell is a leading expert in the field of astrophysics and the study of stars. She is currently head of the physics department at the Open University, in Milton Keynes, England.



Social Studies ACTIVITY

Use the Internet or library resources to research historical events that occurred during 1967 and 1968. Find out if the prediction that the signals from pulsars were coming from aliens affected historical events during this time.

go.hrw.com

To learn more about these Science in Action topics, visit go.hrw.com and type in the keyword HZ5UNVF.

Current Science

Check out Current Science® articles related to this chapter by visiting go.hrw.com. Just type in the keyword HZ5CS19.

START-UP ACTIVITY

Strange Gravity

If you drop a heavy object, will it fall faster than a lighter one? According to the law of gravity, the answer is no. In 1971, *Apollo 15* astronaut David Scott stood on the moon and dropped a feather and a hammer. Television audiences were amazed to see both objects strike the moon's surface at the same time. Now, you can perform a similar experiment.

Procedure

1. Select **two pieces of identical notebook paper.** Crumple one piece of paper into a ball.
2. Place the flat piece of paper on top of a **book** and the paper ball on top of the flat piece of paper.
3. Hold the book waist high, and then drop it to the floor.

Analysis

1. Which piece of paper reached the bottom first? Did either piece of paper fall slower than the book? Explain your observations.
2. Now, hold the crumpled paper in one hand and the flat piece of paper in the other. Drop both pieces of paper at the same time. Besides gravity, what affected the speed of the falling paper? Record your observations.

SECTION 1

A Solar System Is Born

READING WARM-UP

Objectives

- Explain the relationship between gravity and pressure in a nebula.
- Describe how the solar system formed.

Terms to Learn

nebula
solar nebula

READING STRATEGY

Reading Organizer As you read this section, make a flowchart of the steps of the formation of a solar system.

As you read this sentence, you are traveling at a speed of about 30 km/s around an incredibly hot star shining in the vastness of space!

Earth is not the only planet orbiting the sun. In fact, Earth has eight fellow travelers in its cosmic neighborhood. The solar system includes a star we call the sun, nine planets, and many moons and small bodies that travel around the sun. For almost 5 billion years, planets have been orbiting the sun. But how did the solar system come to be?

The Solar Nebula

All of the ingredients for building planets, moons, and stars are found in the vast, seemingly empty regions of space between the stars. Just as there are clouds in the sky, there are clouds in space. These clouds are called nebulas. **Nebulas** (or nebulae) are mixtures of gases—mainly hydrogen and helium—and dust made of elements such as carbon and iron. Although nebulas are normally dark and invisible to optical telescopes, they can be seen when nearby stars illuminate them. So, how can a cloud of gas and dust such as the Horsehead Nebula, shown in **Figure 1**, form planets and stars? To answer this question, you must explore two forces that interact in nebulas—gravity and pressure.

nebula a large cloud of gas and dust in interstellar space; a region in space where stars are born or where stars explode at the end of their lives

Gravity Pulls Matter Together

The gas and dust that make up nebulas are made of matter. The matter of a nebula is held together by the force of gravity. In most nebulas, there is a lot of space between the particles. In fact, nebulas are less dense than air! Thus, the gravitational attraction between the particles in a nebula is very weak. The force is just enough to keep the nebula from drifting apart.

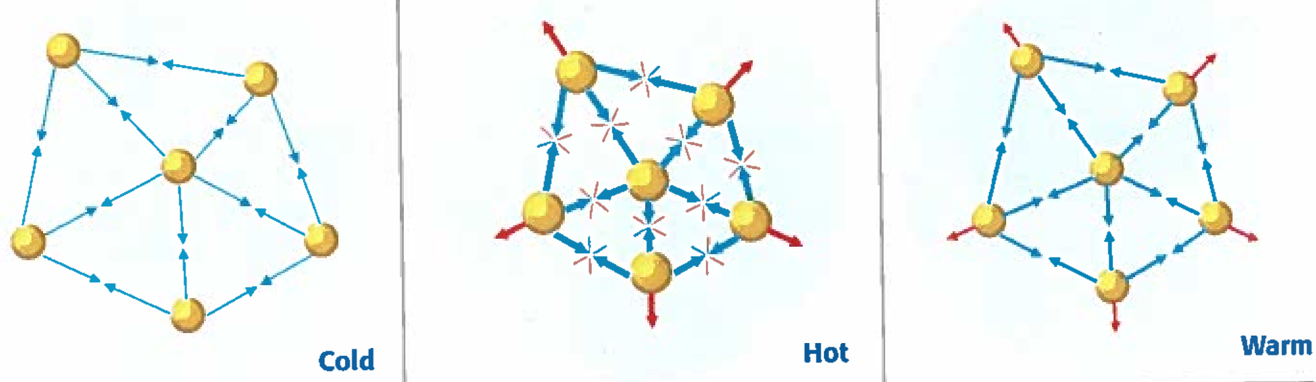
Figure 1 *The Horsehead Nebula is a cold, dark cloud of gas and dust. But observations suggest that it is also a site where stars form.*

Figure 2 Gravity and Pressure in a Nebula

1 Gravity causes the particles in a nebula to be attracted to each other.

2 As particles move closer together, collisions cause pressure to increase and particles are pushed apart.

3 If the inward force of gravity is balanced by outward pressure, the nebula becomes stable.



Pressure Pushes Matter Apart

If gravity pulls on all of the particles in a nebula, why don't nebulas slowly collapse? The answer has to do with the relationship between temperature and pressure in a nebula. *Temperature* is a measure of the average kinetic energy, or the energy of motion, of the particles in an object. If the particles in a nebula have little kinetic energy, they move slowly and the temperature of the cloud is very low. If the particles move fast, the temperature of the cloud is high. As particles move around, they sometimes crash into each other. As shown in **Figure 2,** these collisions cause particles to push away from each other, which creates *pressure*. If you have ever blown up a balloon, you understand how pressure works—pressure keeps a balloon from collapsing. In a nebula, outward pressure balances the inward gravitational pull and keeps the cloud from collapsing.

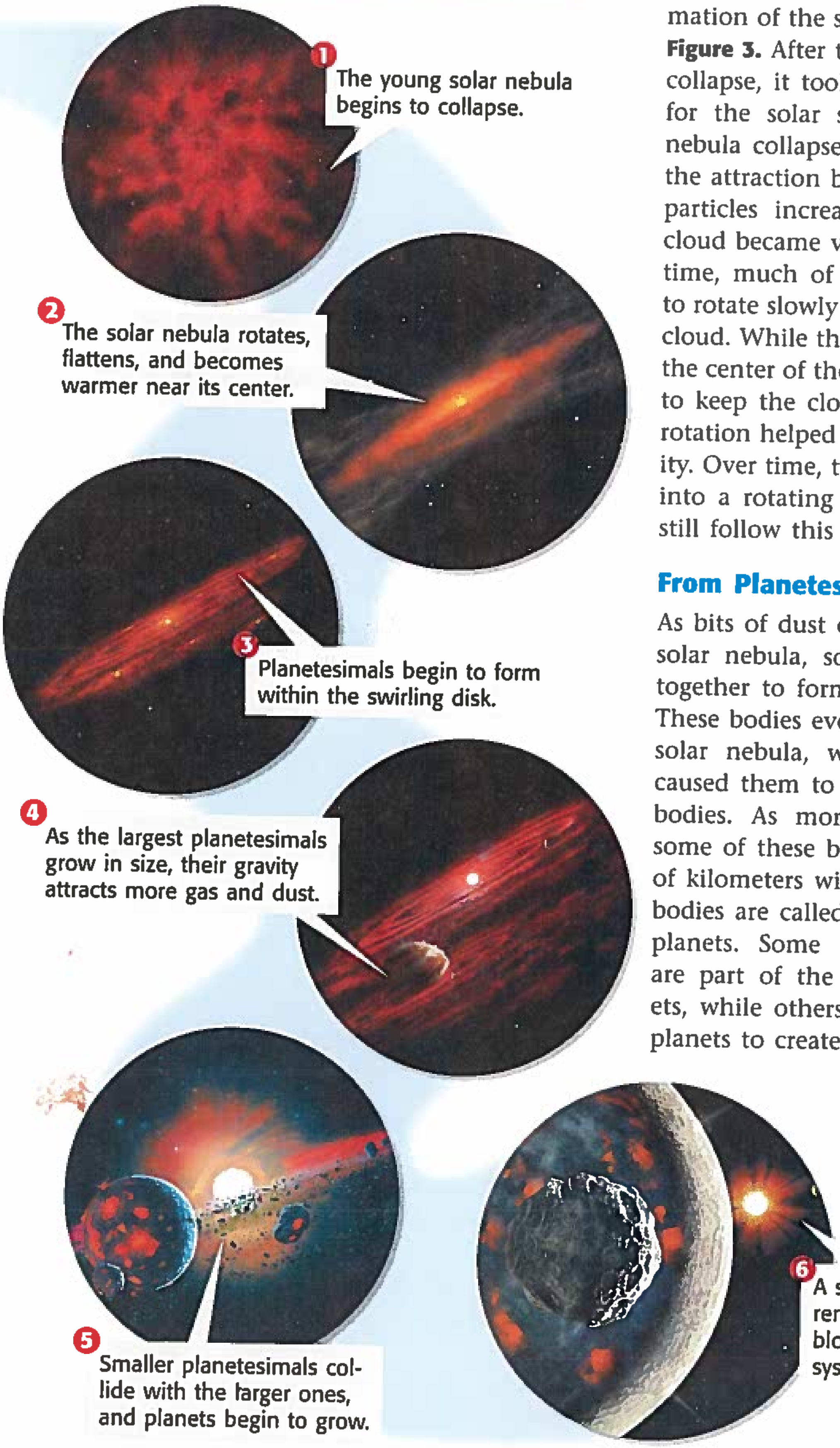
Upsetting the Balance

The balance between gravity and pressure in a nebula can be upset if two nebulas collide or a nearby star explodes. These events compress, or push together, small regions of a nebula called *globules*, or gas clouds. Globules can become so dense that they contract under their own gravity. As the matter in a globule collapses inward, the temperature increases and the stage is set for stars to form. The **solar nebula**—the cloud of gas and dust that formed our solar system—may have formed in this way.

solar nebula the cloud of gas and dust that formed our solar system

Reading Check What is the solar nebula? (*See the Appendix for answers to Reading Checks.*)

Figure 3 The Formation of the Solar System



How the Solar System Formed

The events that may have led to the formation of the solar system are shown in **Figure 3.** After the solar nebula began to collapse, it took about 10 million years for the solar system to form. As the nebula collapsed, it became denser and the attraction between the gas and dust particles increased. The center of the cloud became very dense and hot. Over time, much of the gas and dust began to rotate slowly around the center of the cloud. While the tremendous pressure at the center of the nebula was not enough to keep the cloud from collapsing, this rotation helped balance the pull of gravity. Over time, the solar nebula flattened into a rotating disk. All of the planets still follow this rotation.

From Planetesimals to Planets

As bits of dust circled the center of the solar nebula, some collided and stuck together to form golf ball–sized bodies. These bodies eventually drifted into the solar nebula, where further collisions caused them to grow to kilometer-wide bodies. As more collisions happened, some of these bodies grew to hundreds of kilometers wide. The largest of these bodies are called *planetesimals,* or small planets. Some of these planetesimals are part of the cores of current planets, while others collided with forming planets to create enormous craters.

Gas Giant or Rocky Planet?

The largest planetesimals formed near the outside of the rotating solar disk, where hydrogen and helium were located. These planetesimals were far enough from the solar disk that their gravity could attract the nebula gases. These outer planets grew to huge sizes and became the gas giants—Jupiter, Saturn, Uranus, and Neptune. Closer to the center of the nebula, where Mercury, Venus, Earth, and Mars formed, temperatures were too hot for gases to remain. Therefore, the inner planets in our solar system are made mostly of rocky material.

Reading Check Which planets are gas giants?

The Birth of a Star

As the planets were forming, other matter in the solar nebula was traveling toward the center. The center became so dense and hot that hydrogen atoms began to fuse, or join, to form helium. Fusion released huge amounts of energy and created enough outward pressure to balance the inward pull of gravity. At this point, when the gas stopped collapsing, our sun was born and the new solar system was complete!

CONNECTION TO Language Arts

WRITING SKILL **Eyewitness Account** Research information on the formation of the outer planets, inner planets, and the sun. Then, imagine that you witnessed the formation of the planets and sun. Write a short story describing your experience.

SECTION Review

Summary

- The solar system formed out of a vast cloud of gas and dust called the *nebula*.
- Gravity and pressure were balanced until something upset the balance. Then, the nebula began to collapse.
- Collapse of the solar nebula caused heating at the center, while planetesimals formed in surrounding space.
- The central mass of the nebula became the sun. Planets formed from the surrounding materials.

Using Key Terms

1. In your own words, write a definition for each of the following terms: *nebula* and *solar nebula*.

Understanding Key Ideas

2. What is the relationship between gravity and pressure in a nebula?
   a. Gravity reduces pressure.
   b. Pressure balances gravity.
   c. Pressure increases gravity.
   d. None of the above
3. Describe how our solar system formed.
4. Compare the inner planets with the outer planets.

Math Skills

5. If the planets, moons, and other bodies make up 0.15% of the solar system's mass, what percentage does the sun make up?

Critical Thinking

6. **Evaluating Hypotheses** Pluto, the outermost planet, is small and rocky. Some scientists argue that Pluto is a captured asteroid, not a planet. Use what you know about how solar systems form to evaluate this hypothesis.
7. **Making Inferences** Why do all of the planets go around the sun in the same direction, and why do the planets lie on a relatively flat plane?

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For a variety of links related to this chapter, go to www.scilinks.org

Topic: The Planets
SciLinks code: HSM1152

SECTION 2

The Sun: Our Very Own Star

Can you imagine what life on Earth would be like if there were no sun? Without the sun, life on Earth would be impossible!

Energy from the sun lights and heats Earth's surface. Energy from the sun even drives the weather. Making up more than 99% of the solar system's mass, the sun is the dominant member of our solar system. The sun is basically a large ball of gas made mostly of hydrogen and helium held together by gravity. But what does the inside of the sun look like?

READING WARM-UP

Objectives

- Describe the basic structure and composition of the sun.
- Explain how the sun generates energy.
- Describe the surface activity of the sun, and identify how this activity affects Earth.

Terms to Learn

nuclear fusion
sunspot

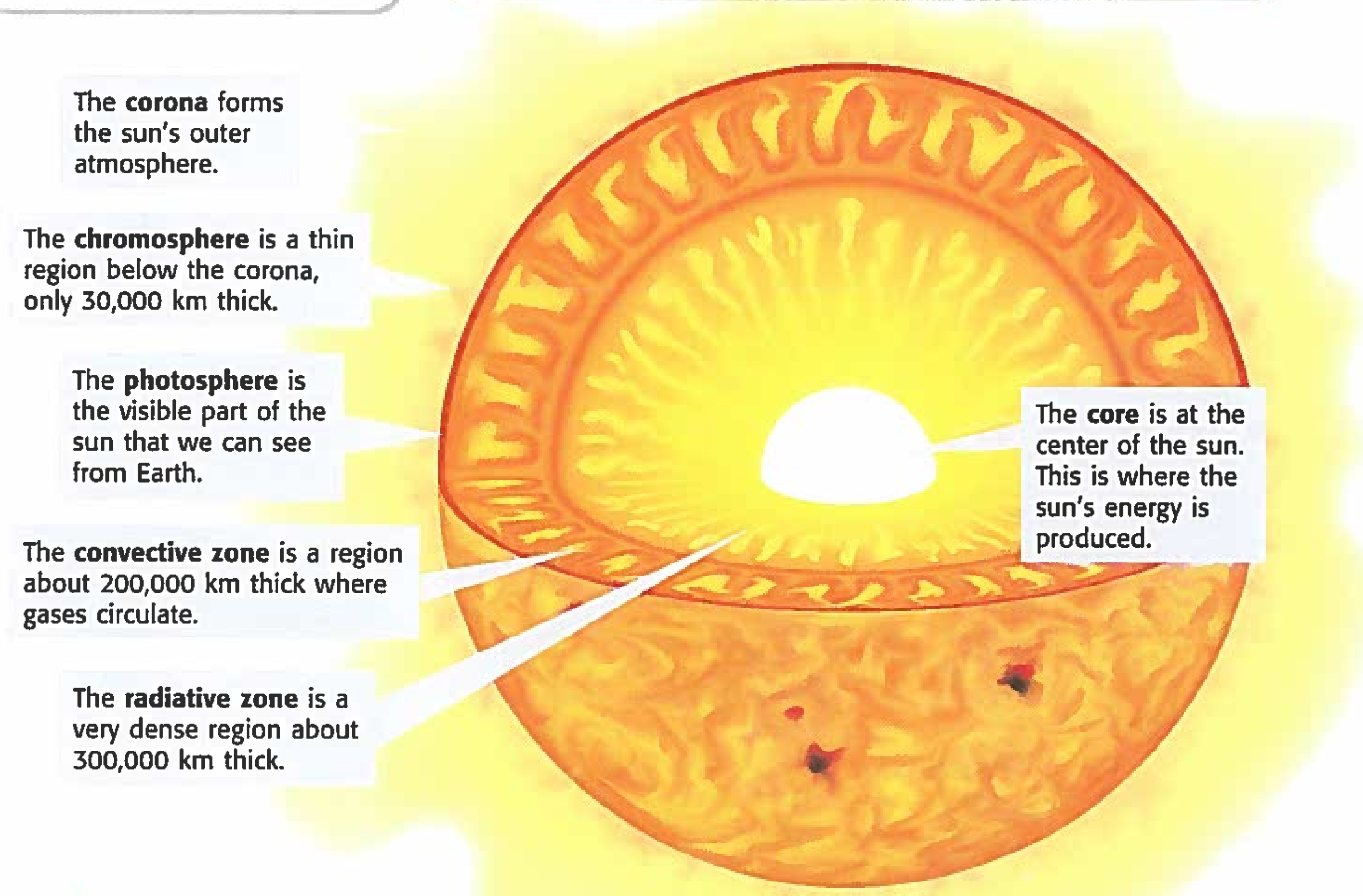
READING STRATEGY

Reading Organizer As you read this section, create an outline of the section. Use the headings from the section in your outline.

The Structure of the Sun

Although the sun may appear to have a solid surface, it does not. When you see a picture of the sun, you are really seeing through the sun's outer atmosphere. The visible surface of the sun starts at the point where the gas becomes so thick that you cannot see through it. As **Figure 1** shows, the sun is made of several layers.

Figure 1 The Structure and Atmosphere of the Sun



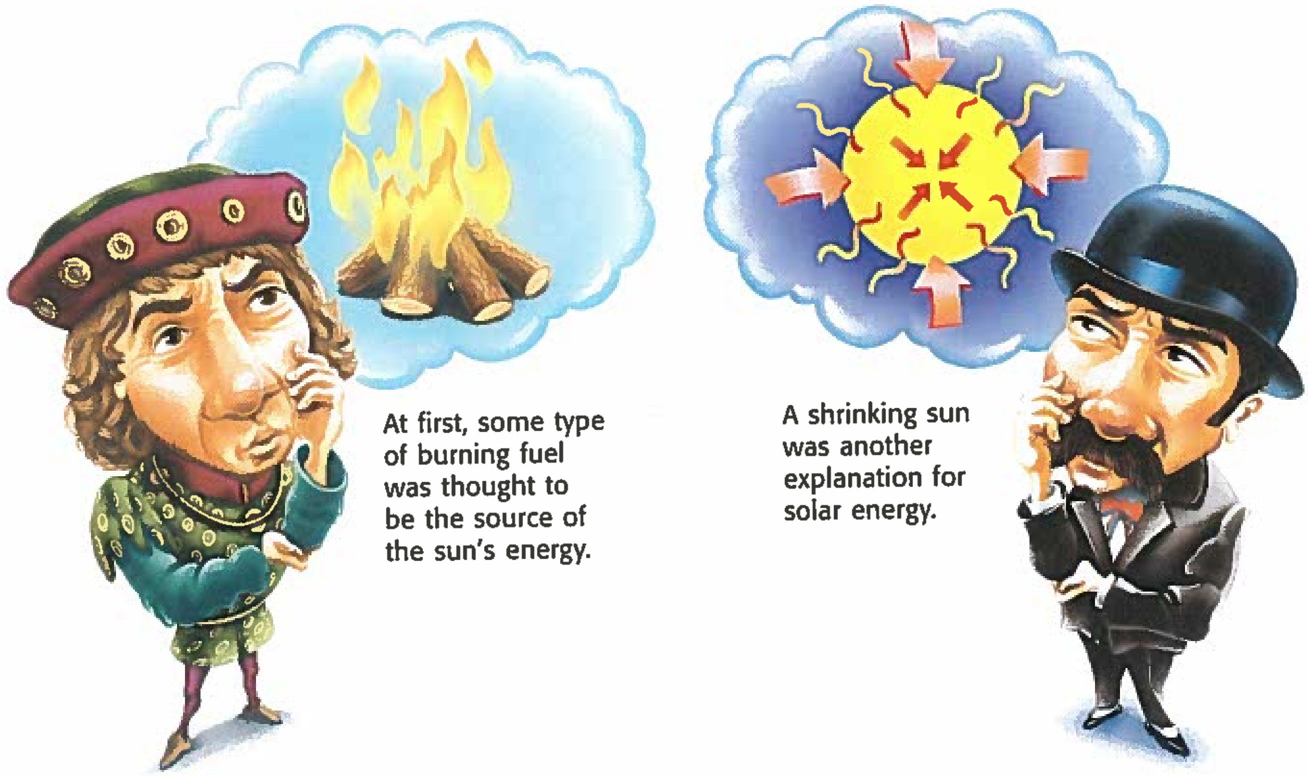


Figure 2 *Ideas about the source of the sun's energy have changed over time.*

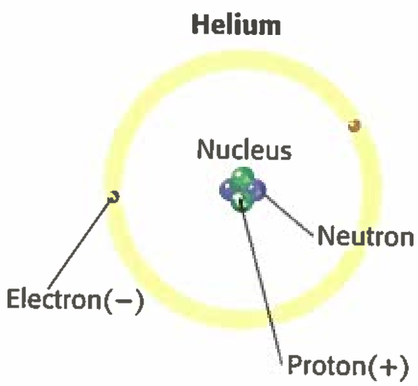
Energy Production in the Sun

The sun has been shining on Earth for about 4.6 billion years. How can the sun stay hot for so long? And what makes it shine? **Figure 2** shows two theories that were proposed to answer these questions. Many scientists thought that the sun burned fuel to generate its energy. But the amount of energy that is released by burning would not be enough to power the sun. If the sun were simply burning, it would last for only 10,000 years.

Burning or Shrinking?

It eventually became clear to scientists that burning wouldn't last long enough to keep the sun shining. Then, scientists began to think that gravity was causing the sun to slowly shrink. They thought that perhaps gravity would release enough energy to heat the sun. While the release of gravitational energy is more powerful than burning, it is not enough to power the sun. If all of the sun's gravitational energy were released, the sun would last for only 45 million years. However, fossils that have been discovered prove that dinosaurs roamed the Earth more than 65 million years ago, so this couldn't be the case. Therefore, something even more powerful than gravity was needed.

Reading Check **Why isn't energy from gravity enough to power the sun?** (*See the Appendix for answers to Reading Checks.*)



CONNECTION TO Chemistry

Atoms An atom consists of a nucleus surrounded by one or more electrons. Electrons have a negative charge. In most elements, the atom's nucleus is made up of two types of particles: *protons,* which have a positive charge, and *neutrons,* which have no charge. The protons in the nucleus are usually balanced by an equal number of electrons. The number of protons and electrons gives the atom its chemical identity. A helium atom, shown at left, has two protons, two neutrons, and two electrons. Use a Periodic Table to find the chemical identity of the following atoms: nitrogen, oxygen, and carbon.

Nuclear Fusion

At the beginning of the 20th century, Albert Einstein showed that matter and energy are interchangeable. Matter can change into energy according to his famous formula: $E = mc^2$. (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 a huge amount of energy. With this idea, scientists began to understand a very powerful source of energy.

nuclear fusion the combination of the nuclei of small atoms to form a larger nucleus; releases energy

Nuclear fusion is the process by which two or more low-mass nuclei join together, or fuse, to form another nucleus. In this way, four hydrogen nuclei can fuse to form a single nucleus of helium. During the process, energy is produced. Scientists now know that the sun gets its energy from nuclear fusion. Einstein's equation, shown in **Figure 3,** changed ideas about the sun's energy source by equating mass and energy.

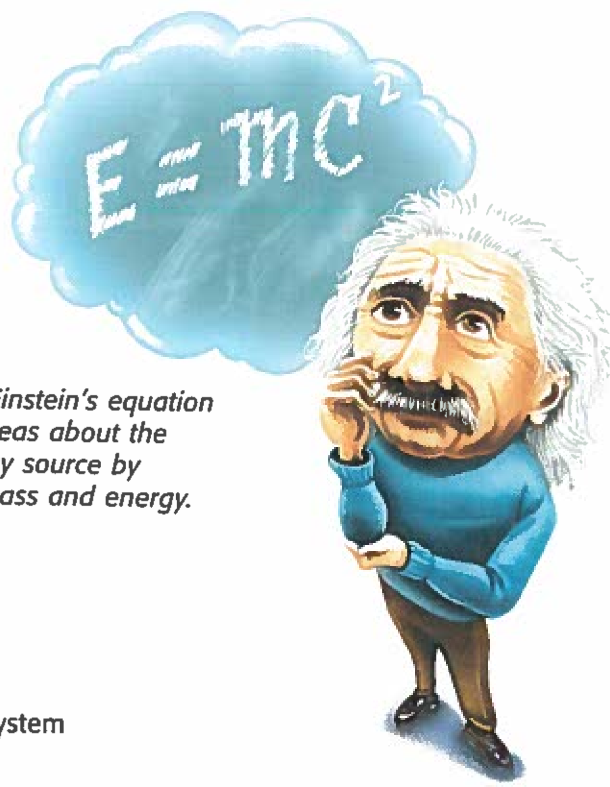


Figure 3 *Einstein's equation changed ideas about the sun's energy source by equating mass and energy.*

Fusion in the Sun

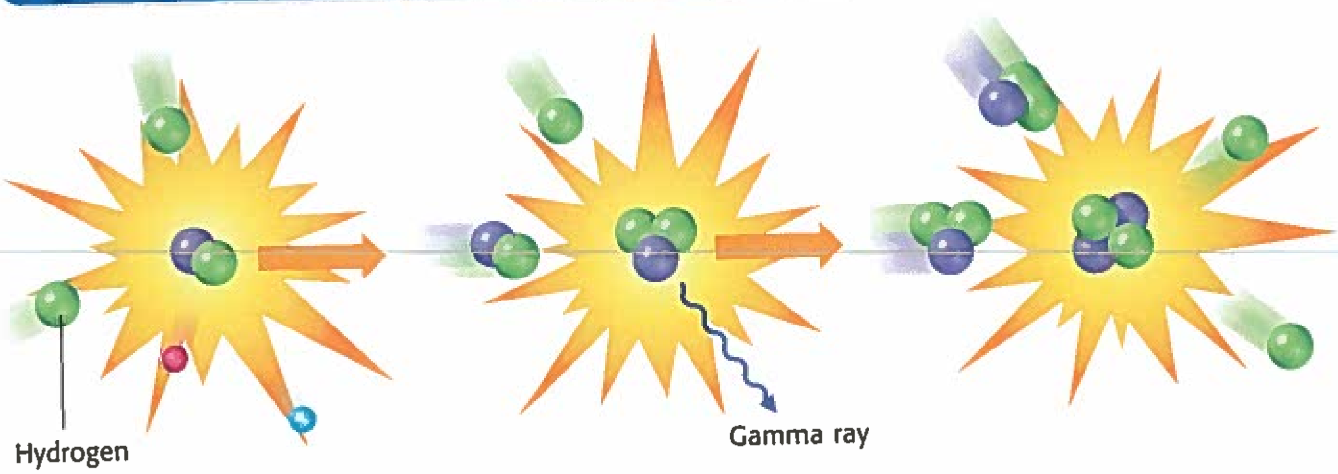
During fusion, under normal conditions, the nuclei of hydrogen atoms never get close enough to combine. The reason is that they are positively charged. Like charges repel each other, as shown in **Figure 4.** In the center of the sun, however, the temperature and pressure are very high. As a result, the hydrogen nuclei have enough energy to overcome the repulsive force, and hydrogen fuses into helium, as shown in **Figure 5.**

The energy produced in the center, or core of the sun takes millions of years to reach the sun's surface. The energy passes from the core through a very dense region called the *radiative zone*. The matter in the radiative zone is so crowded that the light and energy are blocked and sent in different directions. Eventually, the energy reaches the *convective zone*. Gases circulate in the convective zone, which is about 200,000 km thick. Hot gases in the convective zone carry the energy up to the *photosphere*, the visible surface of the sun. From there, the energy leaves the sun as light, which takes only 8.3 min to reach Earth.

Reading Check What causes the nuclei of hydrogen atoms to repel each other?

Figure 4 *Like charges repel just as similar poles on a pair of magnets do.*

Figure 5 **Fusion of Hydrogen in the Sun**



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*.

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

3 Helium-4 Two helium-3 atoms then combine to form ordinary helium-4, which releases more energy and a pair of hydrogen nuclei.

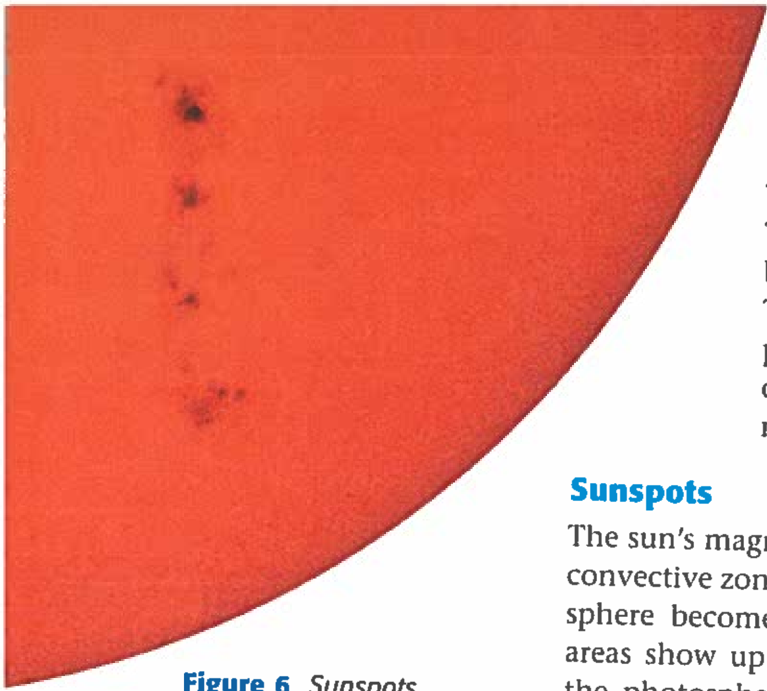


Figure 6 *Sunspots mark cooler areas on the sun's surface. They are related to changes in the magnetic properties of the sun.*

Solar Activity

The photosphere is an ever-changing place. Thermal energy moves from the sun's interior by the circulation of gases in the convective zone. This movement of energy causes the gas in the photosphere to boil and churn. This circulation, combined with the sun's rotation, creates magnetic fields that reach far out into space.

Sunspots

The sun's magnetic fields tend to slow down the activity in the convective zone. When activity slows down, areas of the photosphere become cooler than surrounding areas. These cooler areas show up as sunspots. **Sunspots** are cooler, dark spots of the photosphere of the sun, as shown in **Figure 6.** Sunspots can vary in shape and size. Some sunspots can be as large as 50,000 miles in diameter.

The numbers and locations of sunspots on the sun change in a regular cycle. Scientists have found that the sunspot cycle lasts about 11 years. Every 11 years, the amount of sunspot activity in the sun reaches a peak intensity and then decreases. **Figure 7** shows the sunspot cycle since 1610, excluding the years 1645–1715, which was a period of unusually low sunspot activity.

sunspot a dark area of the photosphere of the sun that is cooler than the surrounding areas and that has a strong magnetic field

Reading Check What are sunspots? What causes sunspots to occur?

Climate Confusion

Scientists have found that sunspot activity can affect the Earth. For example, some scientists have linked the period of low sunspot activity, 1645–1715, with the very low temperatures that Europe experienced during that time. This period is known as the "Little Ice Age." Most scientists, however, think that more research is needed to fully understand the possible connection between sunspots and Earth's climate.

Sunspot-Cycle History

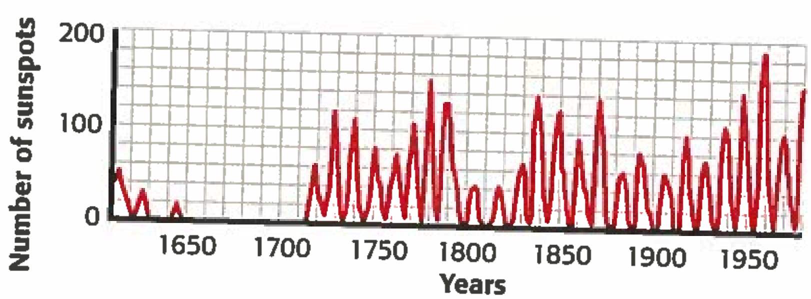


Figure 7 *This graph shows the number of sunspots that have occurred each year since Galileo's first observation in 1610.*

Solar Flares

The magnetic fields that cause sunspots also cause solar flares. *Solar flares,* as shown in **Figure 8,** are regions of extremely high temperature and brightness that develop on the sun's surface. When a solar flare erupts, it sends huge streams of electrically charged particles into the solar system. Solar flares can extend upward several thousand kilometers within minutes. Solar flares are usually associated with sunspots and can interrupt radio communications on Earth and in orbit. Scientists are trying to find ways to give advance warning of solar flares.

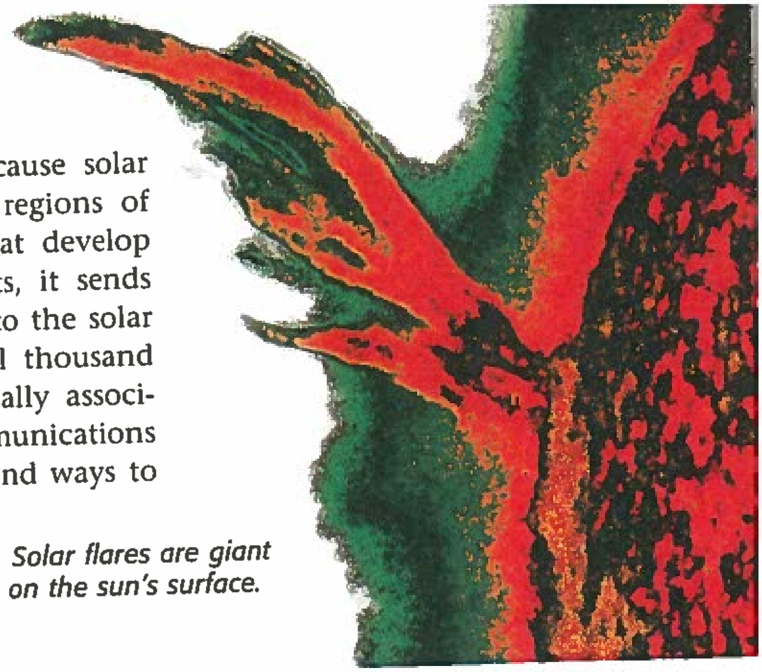


Figure 8 *Solar flares are giant eruptions on the sun's surface.*

SECTION Review

Summary

- The sun is a large ball of gas made mostly of hydrogen and helium. The sun consists of many layers.
- The sun's energy comes from nuclear fusion that takes place in the center of the sun.
- The visible surface of the sun, or the photosphere, is very active.
- Sunspots and solar flares are the result of the sun's magnetic fields that reach space.
- Sunspot activity may affect Earth's climate, and solar flares can interact with Earth's atmosphere.

Using Key Terms

1. In your own words, write a definition for each of the following terms: *sunspot* and *nuclear fusion.*

Understanding Key Ideas

2. Which of the following statements describes how energy is produced in the sun?
   a. The sun burns fuels to generate energy.
   b. As hydrogen changes into helium deep inside the sun, a great deal of energy is made.
   c. Energy is released as the sun shrinks because of gravity.
   d. None of the above
3. Describe the composition of the sun.
4. Name and describe the layers of the sun.
5. In which area of the sun do sunspots appear?
6. Explain how sunspots form.
7. Describe how sunspots can affect the Earth.
8. What are solar flares, and how do they form?

Math Skills

9. If the equatorial diameter of the sun is 1.39 million kilometers, how many kilometers is the sun's radius?

Critical Thinking

10. **Applying Concepts** If nuclear fusion in the sun's core suddenly stopped today, would the sky be dark in the daytime tomorrow? Explain.
11. **Making Comparisons** Compare the theories that scientists proposed about the source of the sun's energy with the process of nuclear fusion in the sun.

SECTION 3

The Earth Takes Shape

In many ways, Earth seems to be a perfect place for life.

READING WARM-UP

Objectives

- Describe the formation of the solid Earth.
- Describe the structure of the Earth.
- Explain the development of Earth's atmosphere and the influence of early life on the atmosphere.
- Describe how the Earth's oceans and continents formed.

Terms to Learn

crust
mantle
core

READING STRATEGY

Discussion Read this section silently. Write down questions that you have about this section. Discuss your questions in a small group.

We live on the third planet from the sun. The Earth, shown in **Figure 1,** is mostly made of rock, and nearly three-fourths of its surface is covered with water. It is surrounded by a protective atmosphere of mostly nitrogen and oxygen and smaller amounts of other gases. But Earth has not always been such an oasis in the solar system.

Formation of the Solid Earth

The Earth formed as planetesimals in the solar system collided and combined. From what scientists can tell, the Earth formed within the first 10 million years of the collapse of the solar nebula!

The Effects of Gravity

When a young planet is still small, it can have an irregular shape, somewhat like a potato. But as the planet gains more matter, the force of gravity increases. When a rocky planet, such as Earth, reaches a diameter of about 350 km, the force of gravity becomes greater than the strength of the rock. As the Earth grew to this size, the rock at its center was crushed by gravity and the planet started to become round.

The Effects of Heat

As the Earth was changing shape, it was also heating up. Planetesimals continued to collide with the Earth, and the energy of their motion heated the planet. Radioactive material, which was present in the Earth as it formed, also heated the young planet. After Earth reached a certain size, the temperature rose faster than the interior could cool, and the rocky material inside began to melt. Today, the Earth is still cooling from the energy that was generated when it formed. Volcanoes, earthquakes, and hot springs are effects of this energy trapped inside the Earth. As you will learn later, the effects of heat and gravity also helped form the Earth's layers when the Earth was very young.

✓ *Reading Check* **What factors heated the Earth during its early formation?** (*See the Appendix for answers to Reading Checks.*)

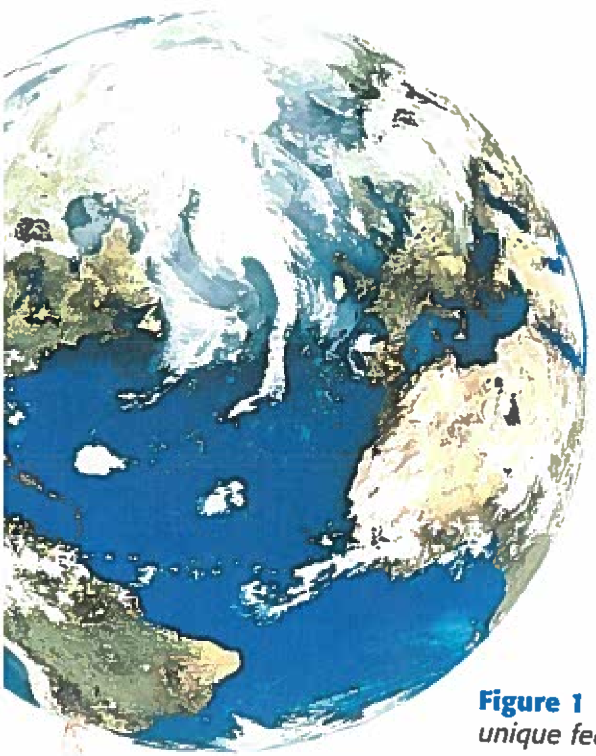


Figure 1 *When Earth is seen from space, one of its unique features—the presence of water—is apparent.*

How the Earth's Layers Formed

Have you ever watched the oil separate from vinegar in a bottle of salad dressing? The vinegar sinks because it is denser than oil. The Earth's layers formed in much the same way. As rocks melted, denser materials, such as nickel and iron, sank to the center of the Earth and formed the core. Less dense materials floated to the surface and became the crust. This process is shown in **Figure 2.**

The **crust** is the thin, outermost layer of the Earth. It is 5 to 100 km thick. Crustal rock is made of materials that have low densities, such as oxygen, silicon, and aluminum. The **mantle** is the layer of Earth beneath the crust. It extends 2,900 km below the surface. Mantle rock is made of materials such as magnesium and iron and is denser than crustal rock. The **core** is the central part of the Earth below the mantle. It contains the densest materials (nickel and iron) and extends to the center of the Earth—almost 6,400 km below the surface.

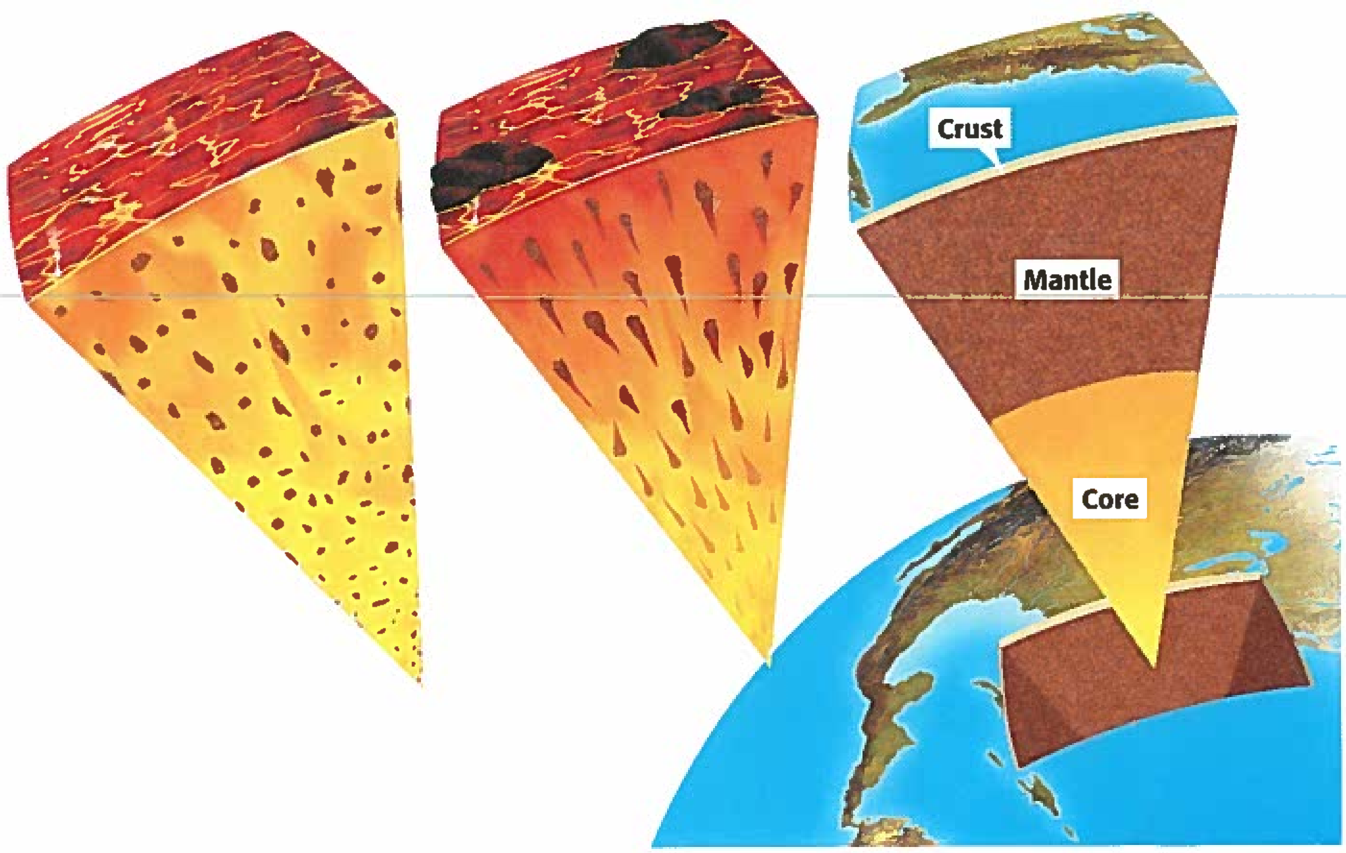
crust the thin and solid outermost layer of the Earth above the mantle

mantle the layer of rock between the Earth's crust and core

core the central part of the Earth below the mantle

Figure 2 The Formation of Earth's Layers

1. All materials in the early Earth are randomly mixed.
2. Rocks melt, and denser materials sink toward the center. Less dense elements rise and form layers.
3. According to composition, the Earth is divided into three layers: the crust, the mantle, and the core.



Formation of the Earth's Atmosphere

Today, Earth's atmosphere is 78% nitrogen, 21% oxygen, and about 1% argon. (There are tiny amounts of many other gases.) Did you know that the Earth's atmosphere did not always contain the oxygen that you need to live? The Earth's atmosphere is constantly changing. Scientists think that the Earth's earliest atmosphere was very different than it is today.

Earth's Early Atmosphere

Scientists think that Earth's early atmosphere was a mixture of gases that were released as Earth cooled. During the final stages of the Earth's formation, its surface was very hot—even molten in places—as shown in **Figure 3.** The molten rock released large amounts of carbon dioxide and water vapor. Therefore, scientists think that Earth's early atmosphere was a steamy mixture of carbon dioxide and water vapor.

Reading Check Describe Earth's early atmosphere.

CONNECTION TO Environmental Science

WRITING SKILL **The Greenhouse Effect** Carbon dioxide is a greenhouse gas. Greenhouse gases are gases that absorb thermal energy and radiate it back to Earth. This process is called the greenhouse effect because the gases function like the walls and roof of a greenhouse, which allow solar energy to enter but prevent thermal energy from escaping. Do research to find the percentage of carbon dioxide that is thought to make up Earth's early atmosphere. Write a report, and share your findings with your class.

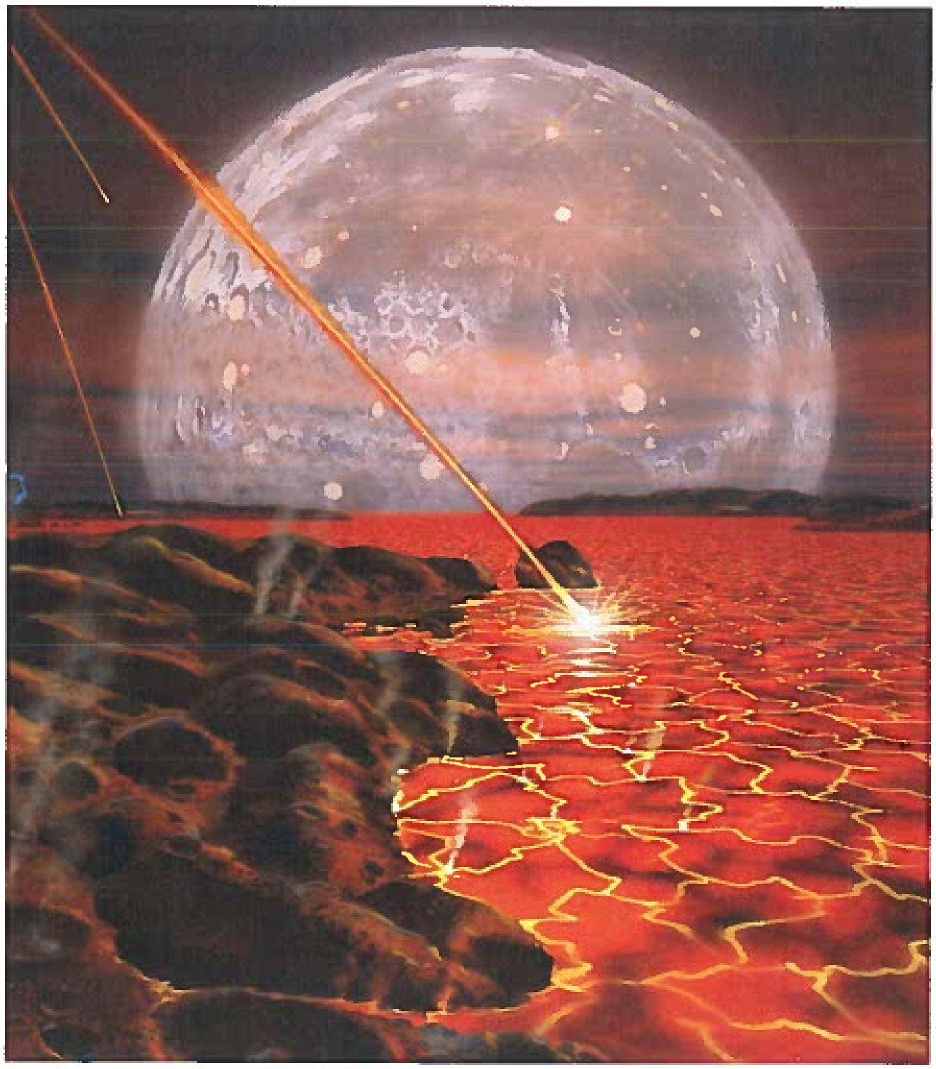


Figure 3 *This artwork is an artist's view of what Earth's surface may have looked like shortly after the Earth formed.*

Figure 4 *As this volcano in Hawaii shows, a large amount of gas is released during an eruption.*

Earth's Changing Atmosphere

As the Earth cooled and its layers formed, the Earth's atmosphere changed again. This atmosphere probably formed from volcanic gases. Volcanoes, such as the one in **Figure 4,** released chlorine, nitrogen, and sulfur in addition to large amounts of carbon dioxide and water vapor. Some of this water vapor may have condensed to form the Earth's first oceans.

Comets, which are planetesimals made of ice, also may have contributed to this change of Earth's atmosphere. As comets crashed into the Earth, they brought in a range of elements, such as carbon, hydrogen, oxygen, and nitrogen. Comets also may have brought some of the water that helped form the oceans.

The Role of Life

How did this change of Earth's atmosphere become the air you are breathing right now? The answer is related to the appearance of life on Earth.

Ultraviolet Radiation

Scientists think that ultraviolet (UV) radiation, the same radiation that causes sunburns, helped produce the conditions necessary for life. Because UV light has a lot of energy, it can break apart molecules in your skin and in the air. Today, we are shielded from most of the sun's UV rays by Earth's protective ozone layer. But Earth's early atmosphere probably did not have ozone, so many molecules in the air and at Earth's surface were broken apart. Over time, this material collected in the Earth's waters. Water offered protection from the effects of UV radiation. In these sheltered pools of water, chemicals may have combined to form the complex molecules that made life possible. The first life-forms were very simple and did not need oxygen to live.

SCHOOL to HOME

Comets and Meteors

What is the difference between a comet and a meteor? With a parent, research the difference between comets and meteors. Then, find out if you can view meteor showers in your area!

ACTIVITY

The Source of Oxygen

Sometime before 3.4 billion years ago, organisms that produced food by photosynthesis appeared. *Photosynthesis* is the process of absorbing energy from the sun and carbon dioxide from the atmosphere to make food. During the process of making food, these organisms released oxygen—a gas that was not abundant in the atmosphere at that time. Scientists think that the descendants of these early life-forms are still around today, as shown in **Figure 5.**

Photosynthetic organisms played a major role in changing Earth's atmosphere to become the mixture of gases you breathe today. Over the next hundreds of millions of years, more and more oxygen was added to the atmosphere. At the same time, carbon dioxide was removed. As oxygen levels increased, some of the oxygen formed a layer of ozone in the upper atmosphere. This ozone blocked most of the UV radiation and made it possible for life, in the form of simple plants, to move onto land about 2.2 billion years ago.

Reading Check **How did photosynthesis contribute to Earth's current atmosphere?**

Formation of Oceans and Continents

Scientists think that the oceans probably formed during Earth's second atmosphere, when the Earth was cool enough for rain to fall and remain on the surface. After millions of years of rainfall, water began to cover the Earth. By 4 billion years ago, a global ocean covered the planet.

For the first few hundred million years of Earth's history, there may not have been any continents. Given the composition of the rocks that make up the continents, scientists know that these rocks have melted and cooled many times in the past. Each time the rocks melted, the heavier elements sank and the lighter ones rose to the surface.

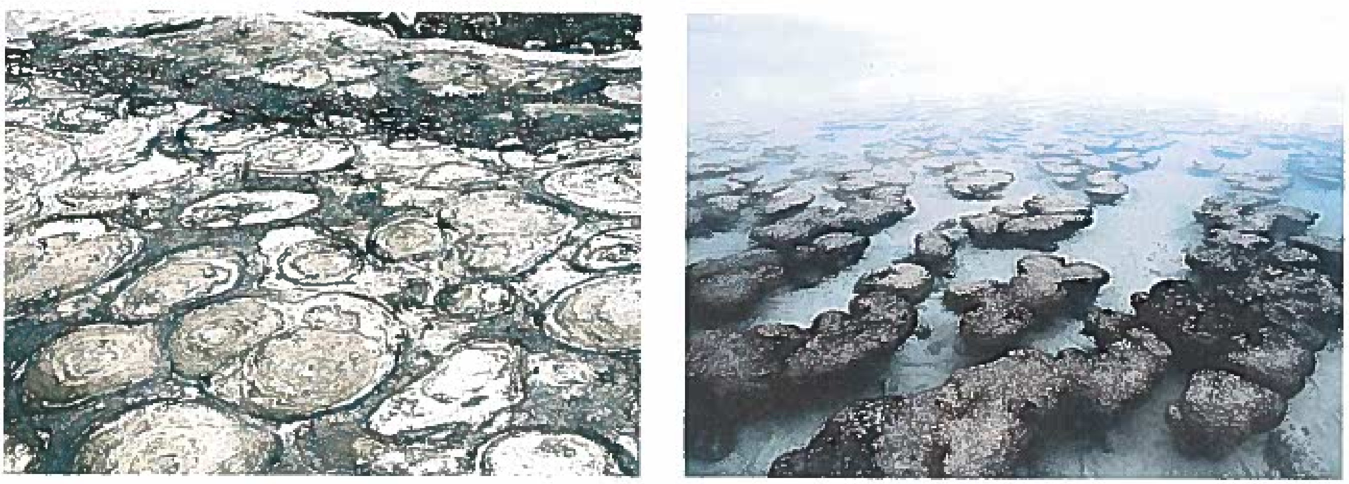


Figure 5 *Stromatolites, mats of fossilized algae (left), are among the earliest evidence of life. Blue-green algae (right) living today are thought to be similar to the first life-forms on Earth.*

The Growth of Continents

After a while, some of the rocks were light enough to pile up on the surface. These rocks were the beginning of the earliest continents. The continents gradually thickened and slowly rose above the surface of the ocean. These scattered young continents did not stay in the same place, however. The slow transfer of thermal energy in the mantle pushed them around. Approximately 2.5 billion years ago, continents really started to grow. And by 1.5 billion years ago, the upper mantle had cooled and had become denser and heavier. At this time, it was easier for the cooler parts of the mantle to sink. These conditions made it easier for the continents to move in the same way that they do today.

INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HZ5SOLW.**

SECTION Review

Summary

- The effects of gravity and heat created the shape and structure of Earth.
- The Earth is divided into three main layers based on composition: the crust, mantle, and core.
- The presence of life dramatically changed Earth's atmosphere by adding free oxygen.
- Earth's oceans formed shortly after the Earth did, when it had cooled off enough for rain to fall. Continents formed when lighter materials gathered on the surface and rose above sea level.

Using Key Terms

1. Use each of the following terms in a separate sentence: *crust*, *mantle*, and *core*.

Understanding Key Ideas

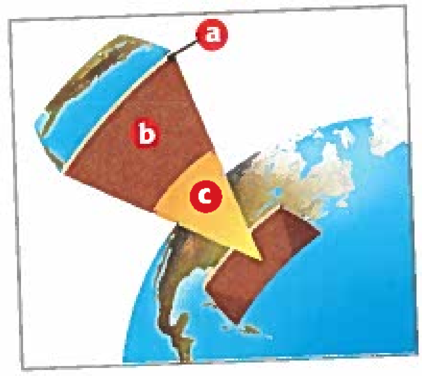
2. Earth's first atmosphere was mostly made of
   - **a.** nitrogen and oxygen.
   - **b.** chlorine, nitrogen, and sulfur.
   - **c.** carbon dioxide and water vapor.
   - **d.** water vapor and oxygen.
3. Describe the structure of the Earth.
4. Why did the Earth separate into distinct layers?
5. Describe the development of Earth's atmosphere. How did life affect Earth's atmosphere?
6. Explain how Earth's oceans and continents formed.

Critical Thinking

7. **Applying Concepts** How did the effects of gravity help shape the Earth?
8. **Making Inferences** How would the removal of forests affect the Earth's atmosphere?

Interpreting Graphics

Use the illustration below to answer the questions that follow.



9. Which of the layers is composed mostly of the elements magnesium and iron?
10. Which of the layers is composed mostly of the elements iron and nickel?

SECTION 4

Planetary Motion

Why do the planets revolve around the sun? Why don't they fly off into space? Does something hold them in their paths?

READING WARM-UP

Objectives

- Explain the difference between rotation and revolution.
- Describe three laws of planetary motion.
- Describe how distance and mass affect gravitational attraction.

Terms to Learn

rotation
orbit
revolution

READING STRATEGY

Paired Summarizing Read this section silently. In pairs, take turns summarizing the material. Stop to discuss ideas that seem confusing.

To answer these questions, you need to go back in time to look at the discoveries made by the scientists of the 1500s and 1600s. Danish astronomer Tycho Brahe (TIE koh BRAH uh) carefully observed the positions of planets for more than 25 years. When Brahe died in 1601, a German astronomer named Johannes Kepler (yoh HAHN uhs KEP luhr) continued Brahe's work. Kepler set out to understand the motions of planets and to describe the solar system.

A Revolution in Astronomy

Each planet spins on its axis. The spinning of a body, such as a planet, on its axis is called **rotation.** As the Earth rotates, only one-half of the Earth faces the sun. The half facing the sun is light (day). The half that faces away from the sun is dark (night).

The path that a body follows as it travels around another body in space is called the **orbit.** One complete trip along an orbit is called a **revolution.** The amount of time a planet takes to complete a single trip around the sun is called a *period of revolution*. Each planet takes a different amount of time to circle the sun. Earth's period of revolution is about 365.25 days (a year), but Mercury orbits the sun in only 88 days. **Figure 1** illustrates the orbit and revolution of the Earth around the sun as well as the rotation of the Earth on its axis.

rotation the spin of a body on its axis

orbit the path that a body follows as it travels around another body in space

revolution the motion of a body that travels around another body in space; one complete trip along an orbit

Figure 1 *A planet rotates on its own axis and revolves around the sun in a path called an orbit.*

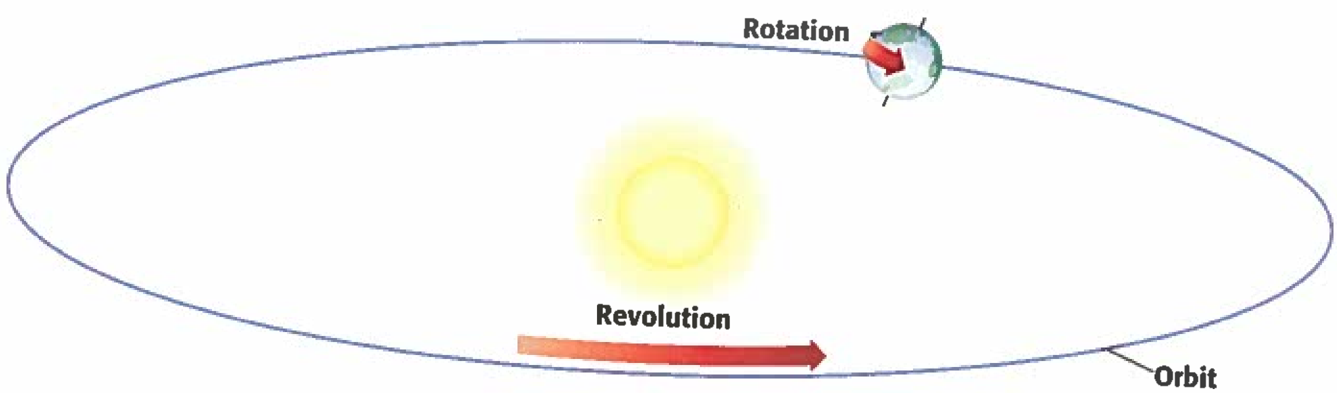
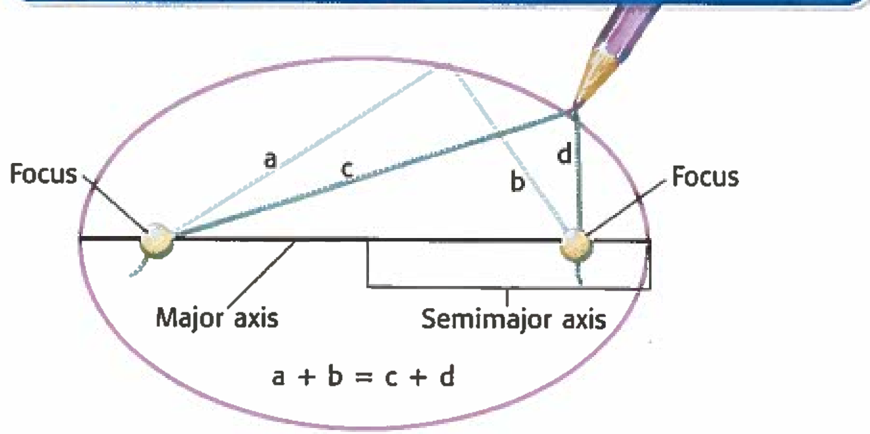


Figure 2 Parts of an Ellipse



Kepler's First Law of Motion

Kepler's first discovery came from his careful study of Mars. Kepler discovered that Mars did not move in a circle around the sun but moved in an elongated circle called an *ellipse.* This finding became Kepler's first law of motion. An ellipse is a closed curve in which the sum of the distances from the edge of the curve to two points inside the ellipse is always the same, as shown in **Figure 2.** An ellipse's maximum length is called its *major axis.* Half of this distance is the *semimajor axis,* which is usually used to describe the size of an ellipse. The semimajor axis of Earth's orbit—the maximum distance between Earth and the sun—is about 150 million kilometers.

Kepler's Second Law of Motion

Kepler's second discovery, or second law of motion, was that the planets seemed to move faster when they are close to the sun and slower when they are farther away. To understand this idea, imagine that a planet is attached to the sun by a string, as modeled in **Figure 3.** When the string is shorter, the planet must move faster to cover the same area.

Kepler's Third Law of Motion

Kepler noticed that planets that are more distant from the sun, such as Saturn, take longer to orbit the sun. This finding was Kepler's third law of motion, which explains the relationship between the period of a planet's revolution and its semimajor axis. Knowing how long a planet takes to orbit the sun, Kepler was able to calculate the planet's distance from the sun.

Reading Check Describe Kepler's third law of motion. (*See the Appendix for answers to Reading Checks.*)

MATH PRACTICE

Kepler's Formula

Kepler's third law can be expressed with the formula

$$P^2 = a^3$$

where P is the period of revolution and a is the semimajor axis of an orbiting body. For example, Mars's period is 1.88 years, and its semimajor axis is 1.523 AU. Thus, $1.88^2 = 1.523^3 = 3.53$. Calculate a planet's period of revolution if the semimajor axis is 5.74 AU.

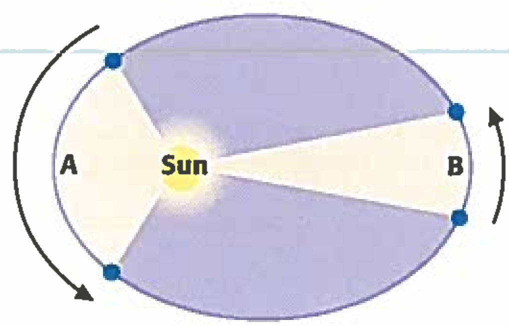


Figure 3 *According to Kepler's second law, to keep the area of A equal to the area of B, the planet must move faster in its orbit when it is closer to the sun.*

Newton to the Rescue!

Kepler wondered what caused the planets closest to the sun to move faster than the planets farther away. However, he never found an answer. Sir Isaac Newton finally put the puzzle together when he described the force of gravity. Newton didn't understand why gravity worked or what caused it. Even today, scientists do not fully understand gravity. But Newton combined the work of earlier scientists and used mathematics to explain the effects of gravity.

The Law of Universal Gravitation

Newton reasoned that an object falls toward Earth because Earth and the object are attracted to each other by gravity. He discovered that this attraction depends on the masses of the objects and the distance between the objects.

Newton's *law of universal gravitation* states that the force of gravity depends on the product of the masses of the objects divided by the square of the distance between the objects. The larger the masses of two objects and the closer together the objects are, the greater the force of gravity between the objects. For example, if two objects are moved twice as far apart, the gravitational attraction between them will decrease by 2 × 2 (a factor of 4), as shown in **Figure 4.** If two objects are moved 10 times as far apart, the gravitational attraction between them will decrease by 10 × 10 (a factor of 100).

Both Earth and the moon are attracted to each other. Although it may seem as if Earth does not orbit the moon, Earth and the moon actually orbit each other.

Reading Check **Explain Newton's law of universal gravitation.**

Quick Lab

Staying in Focus

1. Take a **short piece of string,** and pin both ends to a **piece of paper** by using **two thumbtacks.**
2. Keeping the string stretched tight at all times, use a **pencil** to trace the path of an ellipse.
3. Change the distance between the thumbtacks to change the shape of the ellipse.
4. How does the position of the thumbtacks (foci) affect the ellipse?

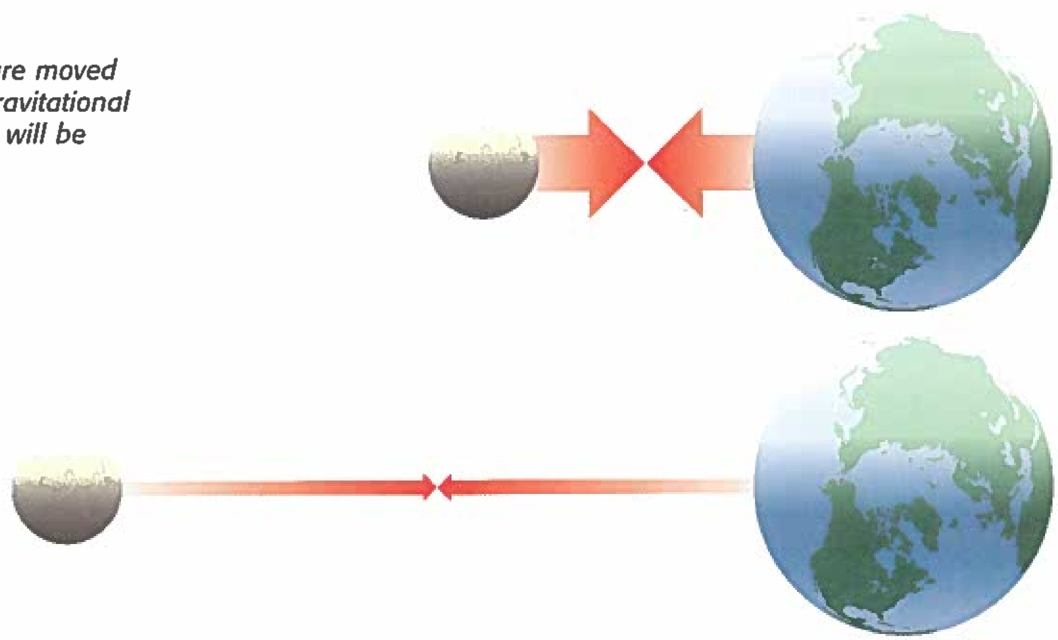


Figure 4 *If two objects are moved twice as far apart, the gravitational attraction between them will be 4 times less.*

Orbits Falling Down and Around

If you drop a rock, it falls to the ground. So, why doesn't the moon come crashing into the Earth? The answer has to do with the moon's inertia. *Inertia* is an object's resistance in speed or direction until an outside force acts on the object. In space, there isn't any air to cause resistance and slow down the moving moon. Therefore, the moon continues to move, but gravity keeps the moon in orbit, as **Figure 5** shows.

Imagine twirling a ball on the end of a string. As long as you hold the string, the ball will orbit your hand. As soon as you let go of the string, the ball will fly off in a straight path. This same principle applies to the moon. Gravity keeps the moon from flying off in a straight path. This principle holds true for all bodies in orbit, including the Earth and other planets in our solar system.

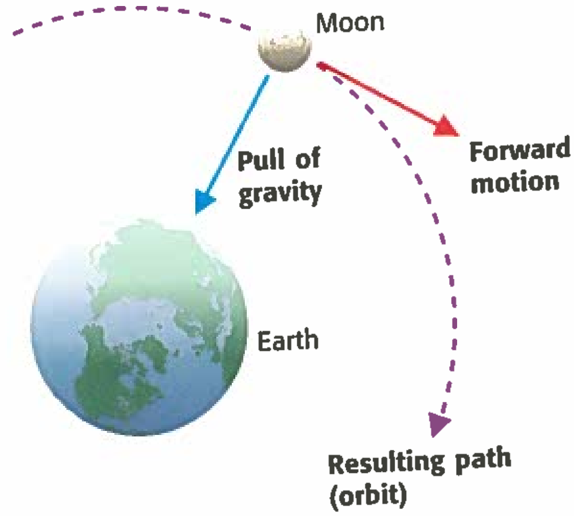


Figure 5 *Gravity causes the moon to fall toward the Earth and changes a straight-line path into a curved orbit.*

SECTION Review

Summary

- Rotation is the spinning of a planet on its axis, and revolution is one complete trip along an orbit.
- Planets move in an ellipse around the sun. The closer they are to the sun, the faster they move. The period of a planet's revolution depends on the planet's semimajor axis.
- Gravitational attraction decreases as distance increases and as mass decreases.

Using Key Terms

1. In your own words, write a definition for each of the following terms: *revolution* and *rotation*.

Understanding Key Ideas

2. Kepler discovered that planets move faster when they
   a. are farther from the sun.
   b. are closer to the sun.
   c. have more mass.
   d. rotate faster.
3. On what properties does the force of gravity between two objects depend?
4. How does gravity keep a planet moving in an orbit around the sun?

Math Skills

5. The Earth's period of revolution is 365.25 days. Convert this period of revolution into hours.

Critical Thinking

6. **Applying Concepts** If a planet had two moons and one moon was twice as far from the planet as the other, which moon would complete a revolution of the planet first? Explain your answer.
7. **Making Comparisons** Describe the three laws of planetary motion. How is each law related to the other laws?

Using Scientific Methods

Skills Practice Lab

How Far Is the Sun?

OBJECTIVES

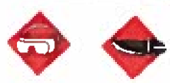
Create a solar-distance measuring device.

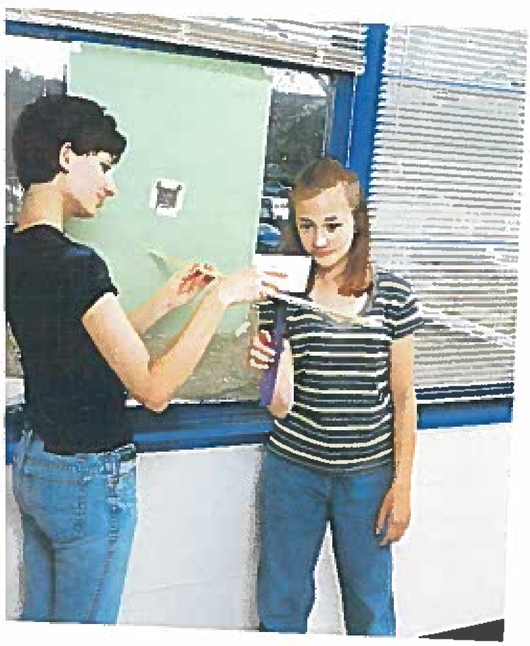
Calculate the Earth's distance from the sun.

MATERIALS

- aluminum foil, 5 cm × 5 cm
- card, index
- meterstick
- poster board
- ruler, metric
- scissors
- tape, masking
- thumbtack

SAFETY





It doesn't slice, it doesn't dice, but it can give you an idea of how big our universe is! You can build your very own solar-distance measuring device from household items. Amaze your friends by figuring out how many metersticks can be placed between the Earth and the sun.

Ask a Question

1. How many metersticks could I place between the Earth and the sun?

Form a Hypothesis

2. Write a hypothesis that answers the question above.

Test the Hypothesis

3. Measure and cut a 4 cm × 4 cm square from the middle of the poster board. Tape the foil square over the hole in the center of the poster board.
4. Using a thumbtack, carefully prick the foil to form a tiny hole in the center. Congratulations! You have just constructed your very own solar-distance measuring device!
5. Tape the device to a window facing the sun so that sunlight shines directly through the pinhole. **Caution:** Do not look directly into the sun.
6. Place one end of the meterstick against the window and beneath the foil square. Steady the meterstick with one hand.
7. With the other hand, hold the index card close to the pinhole. You should be able to see a circular image on the card. This image is an image of the sun.
8. Move the card back until the image is large enough to measure. Be sure to keep the image on the card sharply focused. Reposition the meterstick so that it touches the bottom of the card.

9. Ask your partner to measure the diameter of the image on the card by using the metric ruler. Record the diameter of the image in millimeters.

10. Record the distance between the window and the index card by reading the point at which the card rests on the meterstick.

11. Calculate the distance between Earth and the sun by using the following formula:

$$\text{distance between the sun and Earth} = \text{sun's diameter} \times \frac{\text{distance to the image}}{\text{image's diameter}}$$

1 cm = 10 mm
1 m = 100 cm
1 km = 1,000 m

(Hint: The sun's diameter is 1,392,000,000 m.)

Analyze the Results

1. **Analyzing Results** According to your calculations, how far from the Earth is the sun? Don't forget to convert your measurements to meters.

Draw Conclusions

2. **Evaluating Data** You could put 150 billion metersticks between the Earth and the sun. Compare this information with your result in step 11. Do you think that this activity was a good way to measure the Earth's distance from the sun? Support your answer.

Chapter Review

USING KEY TERMS

Complete each of the following sentences by choosing the correct term from the word bank.

nebula	crust
mantle	solar nebula

1. A ___ is a large cloud of gas and dust in interstellar space.

2. The ___ lies between the core and the crust of the Earth.

For each pair of terms, explain how the meanings of the terms differ.

3. *nebula* and *solar nebula*

4. *crust* and *mantle*

5. *rotation* and *revolution*

6. *nuclear fusion* and *sunspot*

UNDERSTANDING KEY IDEAS

Multiple Choice

7. To determine a planet's period of revolution, you must know its
   - **a.** size.
   - **b.** mass.
   - **c.** orbit.
   - **d.** All of the above

8. During Earth's formation, materials such as nickel and iron sank to the
   - **a.** mantle.
   - **b.** core.
   - **c.** crust.
   - **d.** All of the above

9. Planetary orbits are shaped like
   - **a.** orbits.
   - **b.** spirals.
   - **c.** ellipses.
   - **d.** periods of revolution.

10. Impacts in the early solar system
    - **a.** brought new materials to the planets.
    - **b.** released energy.
    - **c.** dug craters.
    - **d.** All of the above

11. Organisms that photosynthesize get their energy from
    - **a.** nitrogen.
    - **b.** oxygen.
    - **c.** the sun.
    - **d.** water.

12. Which of the following planets has the shortest period of revolution?
    - **a.** Pluto
    - **b.** Earth
    - **c.** Mercury
    - **d.** Jupiter

13. Which gas in Earth's atmosphere suggests that there is life on Earth?
    - **a.** hydrogen
    - **b.** oxygen
    - **c.** carbon dioxide
    - **d.** nitrogen

14. Which layer of the Earth has the lowest density?
    - **a.** the core
    - **b.** the mantle
    - **c.** the crust
    - **d.** None of the above

15. What is the measure of the average kinetic energy of particles in an object?
    - **a.** temperature
    - **b.** pressure
    - **c.** gravity
    - **d.** force

Short Answer

16 Compare a sunspot with a solar flare.

17 Describe how the Earth's oceans and continents formed.

18 Explain how pressure and gravity may have become unbalanced in the solar nebula.

19 Define *nuclear fusion* in your own words. Describe how nuclear fusion generates the sun's energy.

CRITICAL THINKING

20 **Concept Mapping** Use the following terms to create a concept map: *solar nebula, solar system, planetesimals, sun, photosphere, core, nuclear fusion, planets,* and *Earth.*

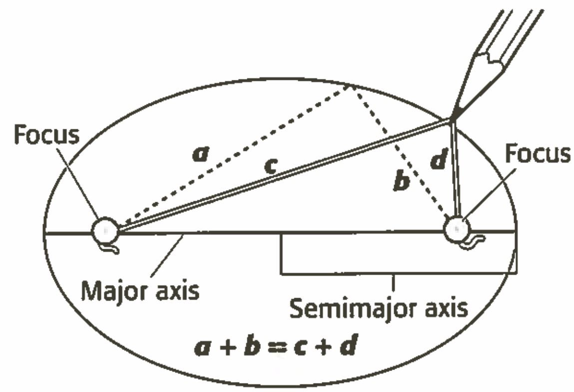
21 **Making Comparisons** How did Newton's law of universal gravitation help explain the work of Johannes Kepler?

22 **Predicting Consequences** Using what you know about the relationship between living things and the development of Earth's atmosphere, explain how the formation of ozone holes in Earth's atmosphere could affect living things.

23 **Identifying Relationships** Describe Kepler's three laws of motion in your own words. Describe how each law relates to either the revolution, rotation, or orbit of a planetary body.

INTERPRETING GRAPHICS

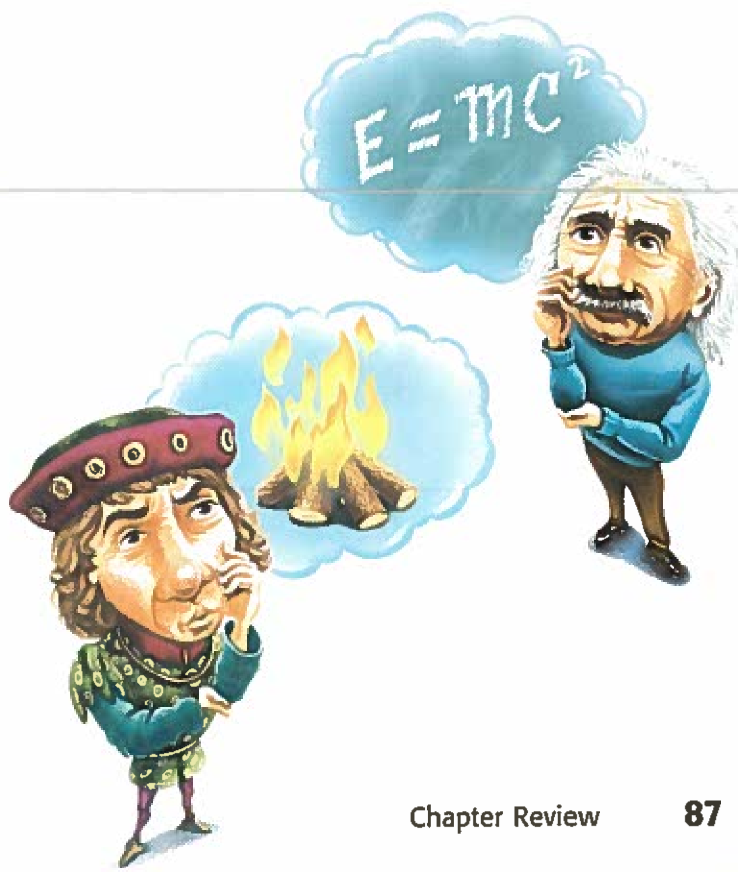
Use the illustration below to answer the questions that follow.



24 Which of Kepler's laws of motion does the illustration represent?

25 How does the equation shown above support the law?

26 What is an ellipse's maximum length called?



Standardized Test Preparation

READING

Read each of the passages below. Then, answer the questions that follow each passage.

Passage 1 You know that you should not look at the sun, right? But how can we learn anything about the sun if we can't look at it? We can use a solar telescope! About 70 km southwest of Tucson, Arizona, is Kitt Peak National Observatory, where you will find three solar telescopes. In 1958, Kitt Peak was chosen from more than 150 mountain sites to be the site for a national observatory. Located in the Sonoran Desert, Kitt Peak is on land belonging to the Tohono O'odham Indian nation. On this site, the McMath-Pierce Facility houses the three largest solar telescopes in the world. Astronomers come from around the globe to use these telescopes. The largest of the three, the McMath-Pierce solar telescope, produces an image of the sun that is almost 1 m wide!

1. Which of the following is the largest telescope in the world?

A Kitt Peak
B Tohono O'odham
C McMath-Pierce
D Tucson

2. According to the passage, how can you learn about the sun?

F You can look at it.
G You can study it by using a solar telescope.
H You can go to Kitt Peak National Observatory.
I You can study to be an astronomer.

3. Which of the following is a fact in the passage?

A One hundred fifty mountain sites contain solar telescopes.
B Kitt Peak is the location of the smallest solar telescope in the world.
C In 1958, Tucson, Arizona, was chosen for a national observatory.
D Kitt Peak is the location of the largest solar telescope in the world.

Passage 2 Sunlight that has been focused can produce a great amount of thermal energy—enough to start a fire. Now, imagine focusing the sun's rays by using a magnifying glass that is 1.6 m in diameter. The resulting heat could melt metal. If a conventional telescope were pointed directly at the sun, it would melt. To avoid a meltdown, the McMath-Pierce solar telescope uses a mirror that produces a large image of the sun. This mirror directs the sun's rays down a diagonal shaft to another mirror, which is 50 m underground. This mirror is adjustable to focus the sunlight. The sunlight is then directed to a third mirror, which directs the light to an observing room and instrument shaft.

1. In this passage, what does the word *conventional* mean?

A special
B solar
C unusual
D ordinary

2. What can you infer from reading the passage?

F Focused sunlight can avoid a meltdown.
G Unfocused sunlight produces little energy.
H A magnifying glass can focus sunlight to produce a great amount of thermal energy.
I Mirrors increase the intensity of sunlight.

3. According to the passage, which of the following statements about solar telescopes is true?

A Solar telescopes make it safe for scientists to observe the sun.
B Solar telescopes don't need to use mirrors.
C Solar telescopes are built 50 m underground.
D Solar telescopes are 1.6 m in diameter.