TIMELINE

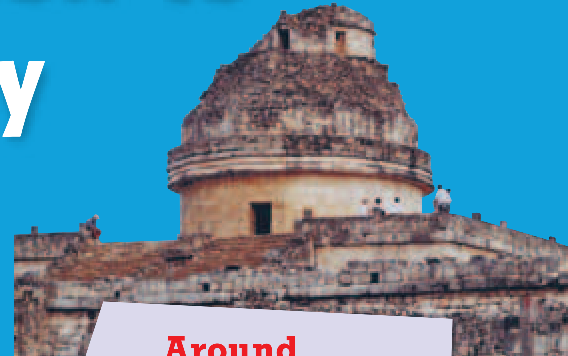
UNIT 6

Introduction to Astronomy

Have you ever looked up at the night sky and wondered, “What’s out there?” For thousands of years, people have asked about and studied the lights in the night sky. In this unit, you will learn about our closest neighbors—the moon, the sun, and the planets that make up our solar system—as well as about galaxies and stars. This timeline includes some of the events leading to our current understanding of our solar system and our universe.

125 B.C.

Hipparchus, a Greek astronomer, divides the stars he can see into categories according to their brightness.



Around 1000

El Caracol, an early observatory, is constructed in Chichén Itzá, Mexico. The Maya use it to study the motion of the planets and stars.

1974

An X-ray source is discovered in the constellation Cygnus. It is believed to be a black hole.

1981

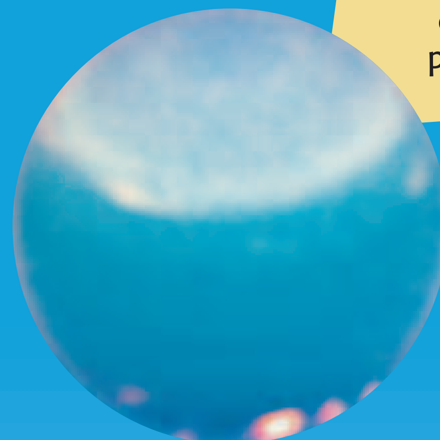
NASA successfully launches the first space shuttle, a manned space vehicle designed for reuse.

1610

Using the newly invented telescope, Galileo discovers the phases of Venus and four moons of Jupiter.

1781

William Herschel, an amateur astronomer, discovers the planet Uranus.



1961

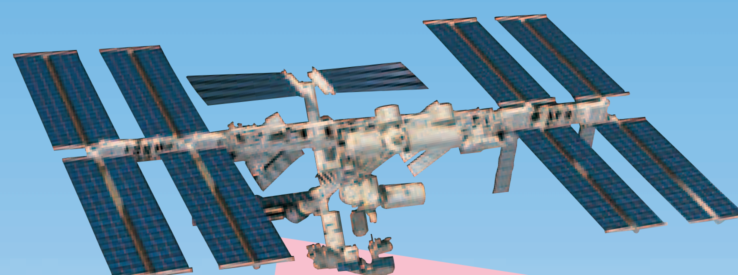
Soviet cosmonaut Yuri Gagarin becomes the first person to orbit Earth.

1801

An Italian astronomer named Giuseppe Piazzi discovers Ceres, the first known asteroid.

1991

A total eclipse of the sun is visible from Hawaii and from Mexico.



1994

Comet Shoemaker-Levy 9 crashes into Jupiter. The impact sites are visible to observers using telescopes and special imaging equipment.

1998

Russian cosmonauts and American astronauts begin construction of the International Space Station.

CHAPTER 17

Formation of the Solar System

Imagine . . .

Imagine you are in gym class. But this class has some really “far out” activities! You live inside a space station in orbit around the Earth. Unfortunately, you need gravity to get a good workout. The best the space station can offer is “artificial gravity” created by the station’s slow rotation around its axis. This isn’t really gravity, but it produces a force that is similar to the effect of the gravity you would feel on Earth’s surface.

Think of whirling a pail of water attached to a string. If the bottom of the pail breaks, the water will fly off in a straight line. In the same way, the space-station floor pushes against your feet, keeping you inside the station. You feel this force as artificial gravity. The faster the station spins or the farther you are from the center, the heavier you feel.

Running on the station’s track takes on a new meaning. To get a really good workout, you run in the direction of the station’s rotation. The faster you run, the heavier you feel because your speed is added to that of the station. Of course, you can always run in the opposite direction to feel lighter!

Things get really interesting when you start lifting weights. If you lift a barbell off the floor, you will be lifting it closer to the center of the spinning station. The higher you lift the barbell, the lighter it gets because the distance to the center is getting shorter!

Today your class is heading toward the central axis of the station, where the artificial gravity drops to zero! On the way there, you'll stop to practice "flying" in the reduced gravity.

In this chapter you will explore gravity and pressure, the forces controlling the birth of our solar system. You will also explore energy production in the sun and the shape and structure of the Earth.

What Do You Think?

In your ScienceLog, try to answer the following questions based on what you already know:

1. What keeps the planets in their orbits?
2. Why does the sun shine?
3. Why is the Earth round?

Investigate!

Strange Gravity

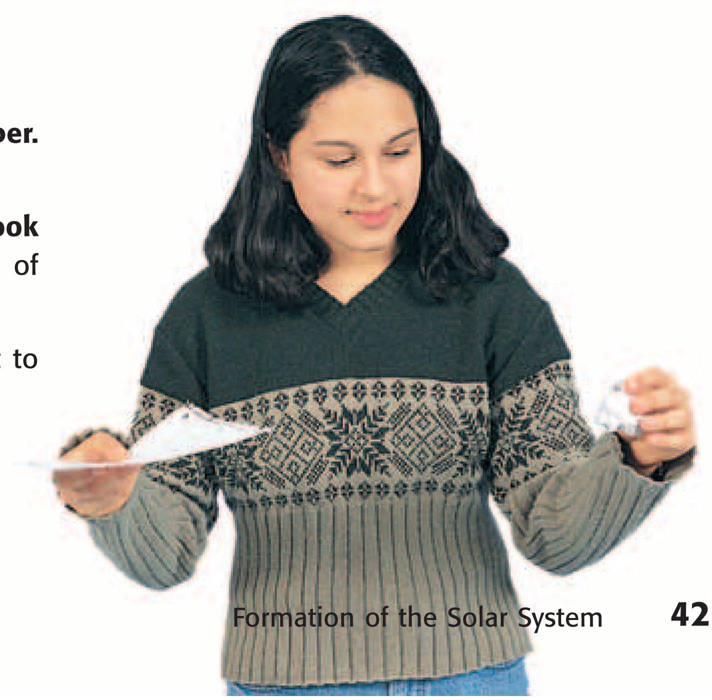
More than 2,000 years ago, early Greek philosophers formed new ideas by simply making assumptions. They didn't see any value in testing their ideas with experiments. This changed, however, in the early 1600s when the Italian scientist Galileo Galilei started performing clever experiments to try to figure out how the world worked. Galileo's experiments helped later scientists understand how gravity works. In this activity you will experiment with how different objects behave under the pull of Earth's gravity.

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

4. Which piece of paper reached the bottom first? Did either piece of paper fall slower than the book on which it rested? What does this mean about the way gravity pulls on objects of different mass? of equal mass? Record your observations in your ScienceLog.
5. 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. What do you observe? Does the result have anything to do with gravity? Why or why not? Record your observations in your ScienceLog, and share your ideas with your classmates.



Section 1

A Solar System Is Born

NEW TERMS

solar system	orbit
nebula	revolution
solar nebula	period of revolution
planetesimal	ellipse
rotation	astronomical unit

OBJECTIVES

- Explain the basic process of planet formation.
- Compare the inner planets with the outer planets.
- Describe the difference between rotation and revolution.
- Describe the shape of the orbits of the planets, and explain what keeps them in their orbits.

You probably know that Earth is not the only planet orbiting the sun. In fact, it has eight fellow travelers in its cosmic neighborhood. Together these nine planets and the sun are part of the solar system. The **solar system** is composed of the sun (a star) and the planets and other bodies that travel around the sun. (When talking about systems around other stars, the term *planetary system* is sometimes used.) But how did our solar system come to be?

The Solar Nebula

All the ingredients for building planets are found in the vast, seemingly empty regions between the stars. But these regions are not really empty. The "stuff between the stars" contains a mixture of gas and dust. The gas is mostly hydrogen and helium, while the dust is made up of tiny grains of elements such as carbon and iron. The dust and gas clump together in huge interstellar clouds called **nebulas** (or *nebulae*), which are so big that light takes many years to cross them! The nebulas are cold—only 10 Celsius degrees above absolute zero—and dark, as shown in **Figure 1.** Over time, light from nearby stars interacts with the dust and gas, and many new chemicals are formed. Chemicals, such as alcohol, and bits and pieces of complex molecules similar to those necessary for life are eventually formed deep within the nebulas. These clouds are the first ingredients of a new planetary system.

Figure 1 *The Horsehead nebula is a dark cloud of gas and dust as well as a possible site for future star formation.*

Gravity Pulls Matter Together Because these clouds of dust and gas consist of matter, they have mass. *Mass,* which is a measure of the amount of matter in an object, is affected by the force of gravity. But because the matter in a nebula is so spread out, the attraction between the dust and gas particles is very small. If a nebula's density were great enough, then the attraction between the particles might be strong enough to pull everything together into the center of the cloud. But even large clouds don't necessarily collapse toward the center because there is another effect, or force, that pushes in the opposite direction of gravity. You'll soon find out what that force is.

Pressure Pushes Matter Apart *Temperature* is a measure of how fast the particles in an object move around. If the gas molecules in a nebula move very slowly, the temperature is very low and the cloud is cold. If they move fast, the temperature is high and the cloud is warm. Because the cloud has a temperature that is above absolute zero, the gas molecules are moving. There is no particular structure in the cloud, and individual gas molecules can move in any direction. Sometimes they crash into each other. As shown in **Figure 2,** these collisions create a push, or *pressure,* away from the other gas particles. This pressure is what finally balances the gravity and keeps the cloud from collapsing.

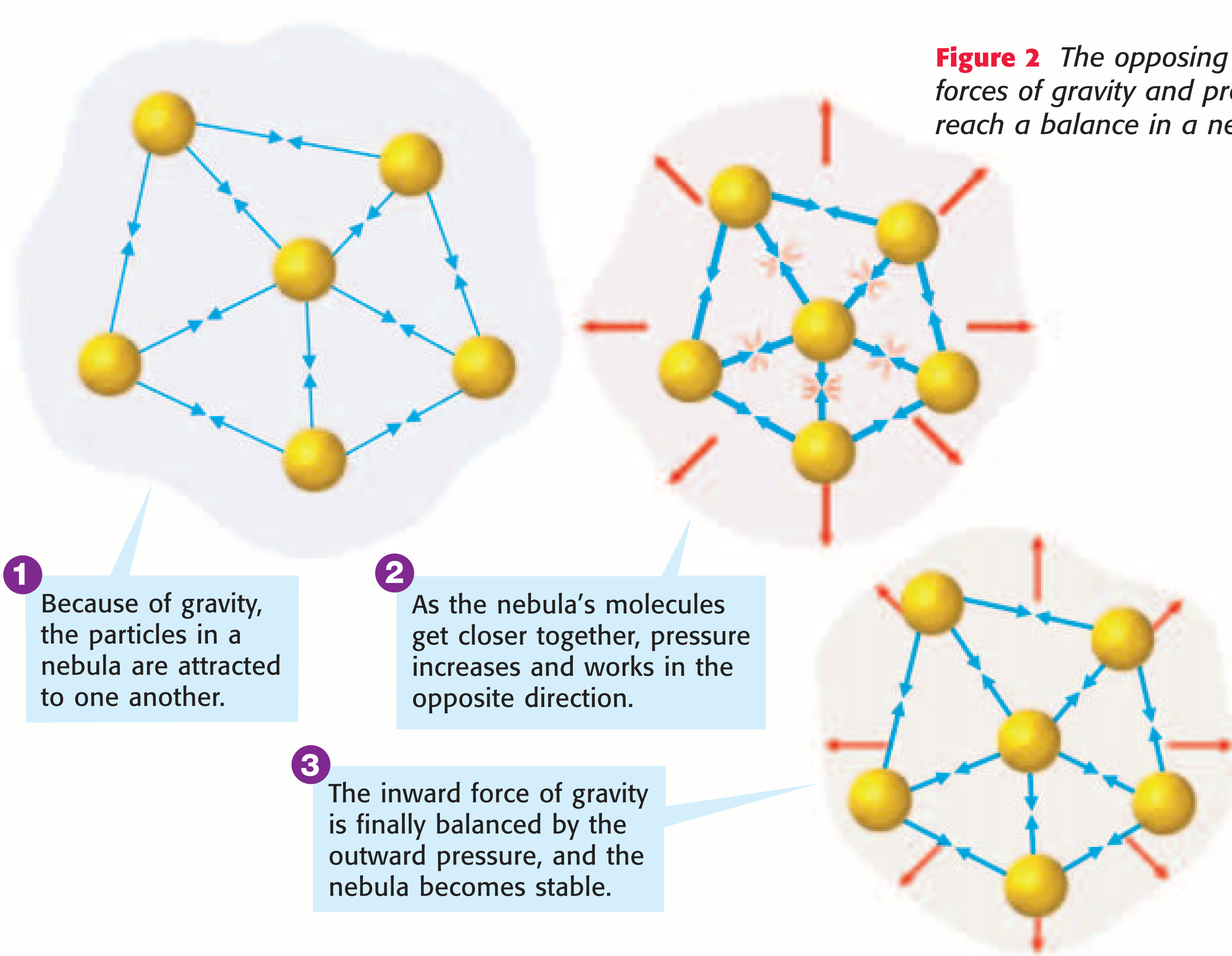


Figure 2 *The opposing forces of gravity and pressure reach a balance in a nebula.*

The Solar Nebula Forms Sometimes something happens to upset this balance. Two nebulas can crash into each other, for example, or a nearby star can explode, causing material from the star to crash into the cloud. These events compress small regions of the cloud so that gravity overcomes the pressure. Gravity then causes the cloud to collapse inward. At this point, the stage is set for the formation of a star and, as in the case of our sun, its planets. The **solar nebula** is the name of the nebula that formed into our own solar system.

Self-Check

What keeps a nebula from collapsing? *(See page 596 to check your answer.)*

From Planetesimals to Planets

Once the solar nebula started to collapse, things happened quickly, at least on a cosmic time scale. As the dark cloud collapsed, matter in the cloud got closer and closer together. This made the attraction between particles even stronger because gravity is stronger when things are closer together. The stronger attraction pulled the cloud together, and the gas and dust particles moved at a faster rate, increasing the temperature at the center of the cloud.

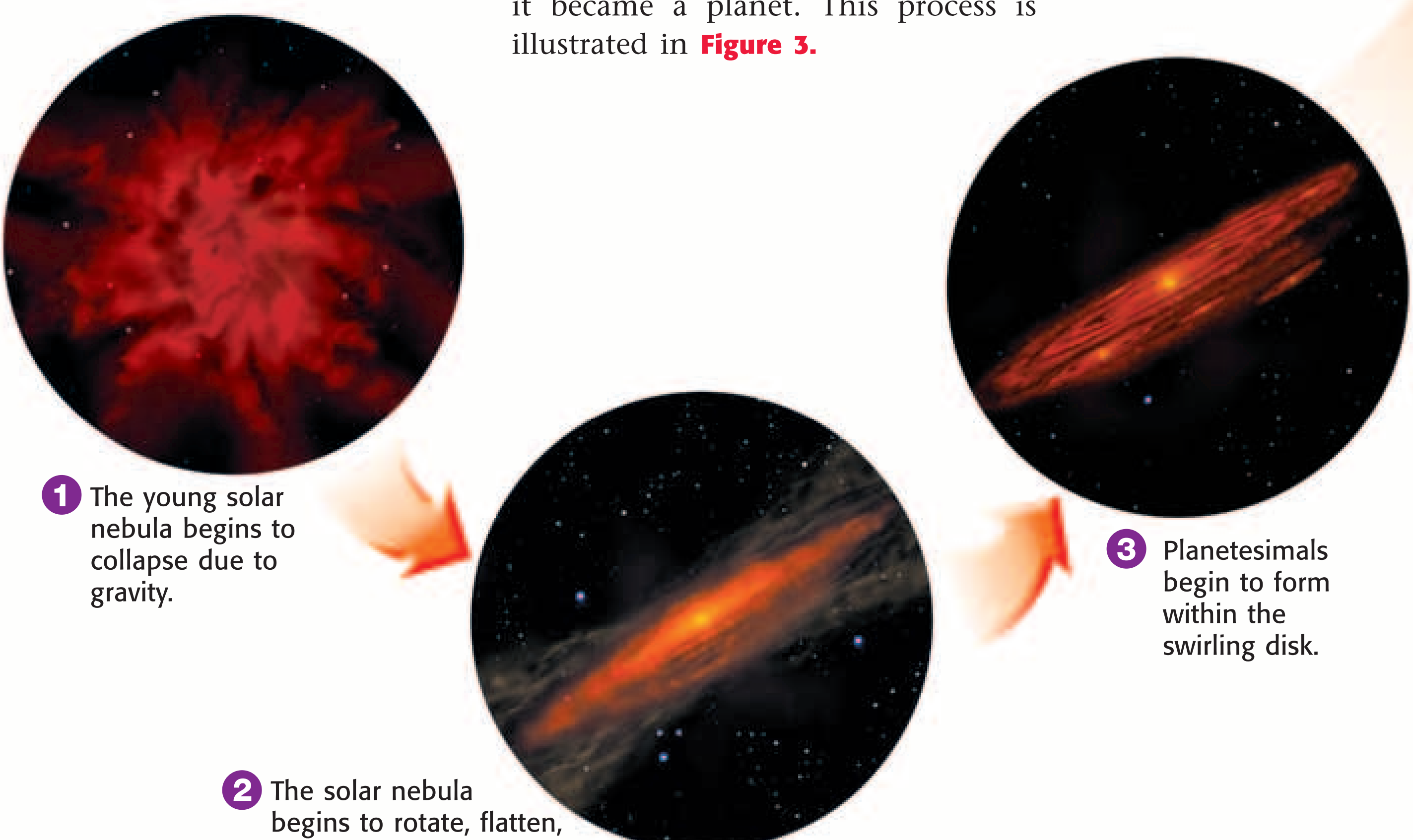
As things began to get crowded near the center of the solar nebula, particles of dust and gas in the cloud began to bump into other particles more often. Eventually much of the dust and gas began slowly rotating about the center of the cloud. The rotating solar nebula eventually flattened into a disk.

Planetesimals Sometimes bits of dust within the solar nebula stuck together when they collided. As more dust particles began to stick together and grow in size, they formed the tiny building blocks of the planets, called **planetesimals.** Within a few hundred thousand years, the planetesimals grew from microscopic sizes to boulder-sized, eventually measuring a kilometer across. The biggest planetesimal in each orbit started sweeping up most of the dust and debris in its path. Eventually it became a planet. This process is illustrated in **Figure 3.**

life science CONNECTION

Some of the complex molecules created in the cold, dark clouds that eventually form stars and planets contain amino acids. Amino acids are the building blocks of proteins and life. Scientists wonder if some of this material survives in the planetesimals that formed far from the sun—the comets. Could comets have brought life-forming molecules to Earth?

Figure 3 The Process of Solar System Formation

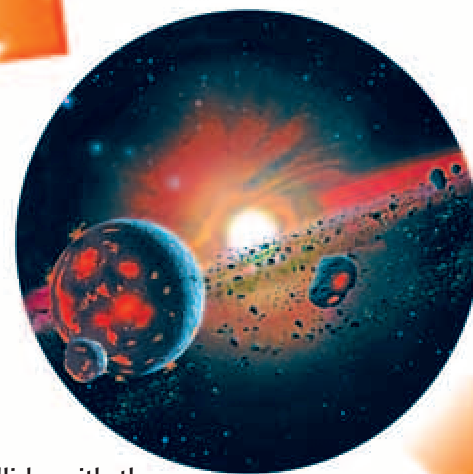


1 The young solar nebula begins to collapse due to gravity.

2 The solar nebula begins to rotate, flatten, and get warmer near its center.

3 Planetesimals begin to form within the swirling disk.

4 Because of their greater gravitational attraction, the largest planetesimals begin to sweep up more and more of the dust and gas of the solar nebula.



5 Smaller planetesimals collide with the larger ones, and planets begin to grow.

6 The remaining dust and gas are gradually removed from the solar nebula, leaving planets around the sun—a new solar system.

Planets The giant gas planets—Jupiter, Saturn, Uranus, and Neptune—were able to collect large amounts of dust in the cooler, outer solar nebula. Once they grew large enough, their gravity was strong enough to attract the nebula gases, hydrogen and helium. Far from the sun, it was cool enough for the giant planets to collect ices in addition to gases. Closer to the sun, it was too hot for the gases to remain, so these inner planets are made of rocky material.

Collisions with smaller planetesimals became more violent as pieces of debris became larger, leaving many craters on the surface of the rocky planets. We see evidence of this today particularly on Mercury and Mars as well as on our moon.

In the final steps of planet formation, the remaining planetesimals crashed down on the planets or got thrown to the outer edge of the solar nebula by the gravity of the larger planets—where they float in cold storage. Occasionally something, perhaps a passing star, sends them journeying toward the sun. If the planetesimal is icy, we see this visitor as a *comet*.

Self-Check

Why are the giant gas planets so large? *(See page 596 to check your answer.)*

Birth of a Star But what was happening at the middle of the solar nebula? The central part of the solar nebula contained so much mass and had become so hot—reaching temperatures of 10,000,000°C—that hydrogen fusion began. This created so much pressure at the center of the solar nebula that outward pressure balanced the inward force of gravity. At this point, the gas stopped collapsing.

As the sun was born, the remaining gas and dust of the nebula was blown into deep space by a strong solar wind, and the new solar system was complete. From the time the nebula first started to collapse, it took nearly 10 million years for the solar system to form.

Even though this was a fast process on a cosmic time scale, it is slow for us. So how do we know that our ideas of star and planet formation are correct? Powerful telescopes, such as the Hubble Space Telescope, are now able to show us some of the fine details inside distant nebulas. One such nebula is shown in **Figure 4.** For the first time, scientists can see disks of dust around stars that are in the process of forming.

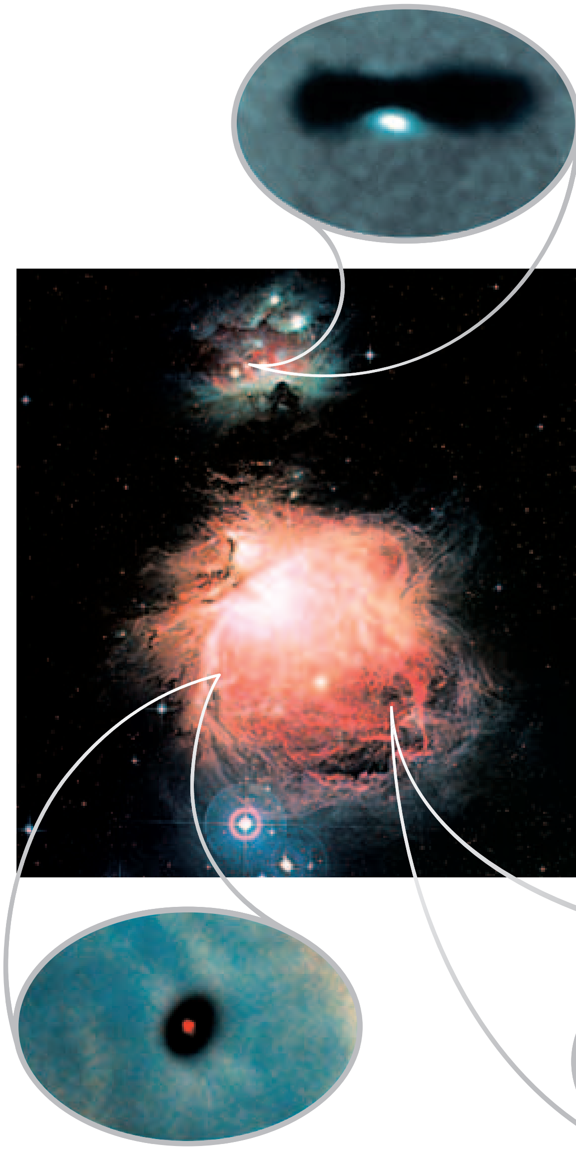
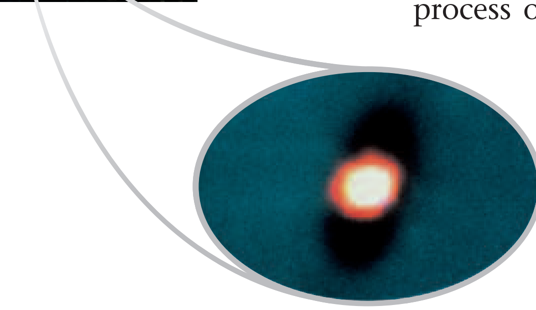



Figure 4 *The Orion nebula contains several disks of dust just beginning to form young stars.*

REVIEW

1. What two forces balance each other to keep a nebula of dust and gas from collapsing or flying apart?
2. Why does the composition of the giant gas planets differ from that of the rocky inner planets?
3. Explain why there is only one planet in each orbit around the sun.
4. **Making Inferences** Why do all the planets go around the sun in the same direction, and why do the planets all lie in a flat plane?

Planetary Motion

The solar system, which is now 4.6 billion years old, is not simply a collection of stationary planets and other bodies around the sun. Each one moves according to strict physical laws. The different ways these bodies move can have a variety of effects. The ways in which the Earth moves, for example, cause seasons and even day and night.

Rotation and Revolution How does the motion of the Earth cause day and night? The answer has to do with the Earth's spinning on its axis, or **rotation.** Only one-half of the Earth faces the sun at any given time. As the Earth rotates, different parts of the Earth receive sunlight. The half facing the sun is light (day), and the half facing away from the sun is dark (night).

In addition to rotating on its axis, the Earth also travels around the sun in a path called an **orbit.** This motion around the sun along its orbit is called **revolution.** The other planets in our solar system also revolve around, or orbit, the sun. The amount of time it takes for a single trip around the sun is called a **period of revolution.** The period for the Earth to revolve around the sun is 365 days. Mercury orbits the sun in 88 days.

BRAIN FOOD

All planets *revolve* around the sun in the same direction. If you could look down on the solar system from above the sun's north pole, you would see all the planets revolving in a counterclockwise direction. Not all planets *rotate* in the same direction, however. Venus, and Pluto rotate backward compared with the rest of the planets, and Uranus rotates on its side.

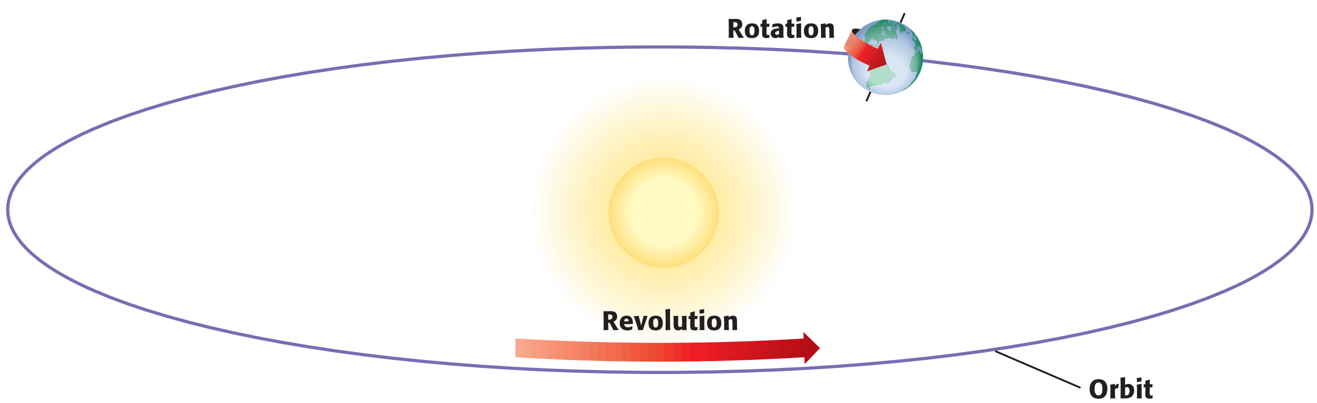


Figure 5 *A planet rotates on its own axis and revolves around the sun in a path called an orbit.*

Planetary Orbits But why do the planets continue to revolve around the sun? Does something hold them in their orbit? Why doesn't gravity pull the planets toward the sun? Or why don't they fly off into space? To answer these questions, we need to go back in time to look at the discoveries made by the scientists of the 1500s and 1600s.

Danish astronomer Tycho Brahe carefully observed the positions of the planets for over a quarter of a century. When he died, in 1601, a German astronomer named Johannes Kepler, inherited all of his records. Kepler set out to understand the motions of the planets and to make a simple description of the solar system.

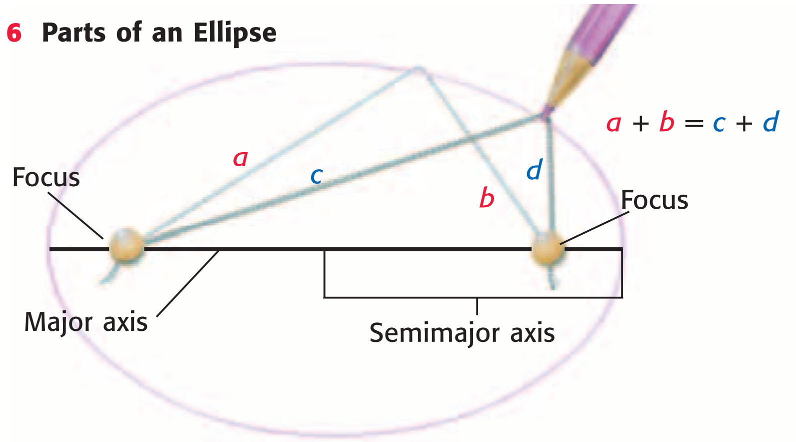
QuickLab

Staying in Focus

1. Take a short piece of **string,** and pin both ends to a **piece of paper** with two **thumbtacks.**
2. Keeping the string stretched tight at all times, use a **pencil** to trace out 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?

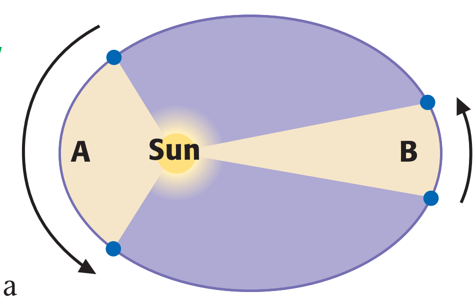
Kepler's First Law of Motion Kepler's first discovery, or *first law of motion,* came from his careful study of the movement of the planet Mars. He discovered that the planet did not move in a circle around the sun, but in an elongated circle called an *ellipse.* An **ellipse** is a closed curve in which the sum of the distances from the edge of the curve to two points (called *foci*) inside the ellipse is always the same, as shown in **Figure 6.**

Figure 6 **Parts of an Ellipse**



The maximum length of an ellipse is called its *major axis,* and half of this distance is the *semimajor axis*, which is usually used to give the size of an ellipse. The semimajor axis of Earth's orbit, for example, is 150 million kilometers. It represents the average distance between the Earth and the sun and is called one **astronomical unit,** or AU. Distances to other planets can be given in astronomical units rather than kilometers, saving a lot of zeros.

Kepler's Second Law Kepler also discovered that the planets seem to move faster when they are close to the sun and slower when they are farther away. To illustrate this, imagine that a planet is attached to the sun (which sits at one focus of the ellipse) by a string. The string will sweep out the same area in equal amounts of time. To keep the area of *A,* for example, equal to the area of *B,* the planet must move farther around its orbit in the same amount of time. This is Kepler's *second law of motion.*



Kepler's Third Law Kepler's *third law of motion* compares the period of a planet's revolution with its semimajor axis. By doing some mathematical calculations, Kepler was able to demonstrate that by knowing a planet's period of revolution, the planet's distance from the sun can be calculated.

MATH BREAK

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. Therefore, $1.88^2 = 1.523^3 = 3.53$. If astronomers know either the period or the distance, they can figure the other one out.

Newton's Law of Universal Gravitation

Kepler wondered if there was a reason that the planets closest to the sun move faster than the planets farther away, but he never got an answer. While his laws and the discoveries of other scientists formed the basis for understanding how the planets and the sun interact, it was Sir Isaac Newton (1642–1727) who finally put the puzzle together. He did this with his ideas about *gravity*. Newton didn't understand *why* gravity worked or what caused it. Even today, modern scientists do not fully understand gravity. But Newton was able to combine the work of earlier scientists to explain *how* the force of attraction between matter works.

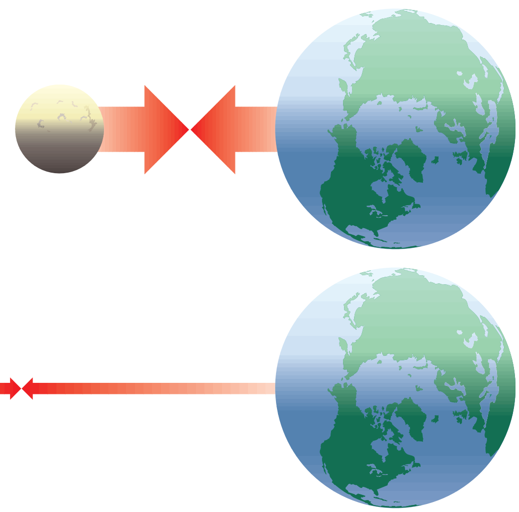
BRAIN FOOD

Legend has it that Newton got his ideas about gravity by watching an apple fall to the ground. Although it didn't hit him on the head, the apple may have inspired Newton to form his law of universal gravitation.

An Apple One Day Newton reasoned that small objects fall toward the Earth because they are attracted to each other by the force of gravity. But because the Earth has so much more mass than a small object, say an apple, only the object appears to move. Newton extended his idea to larger objects, realizing that the moon is also falling toward the Earth. But the moon is farther away from the Earth, so the effect is smaller.

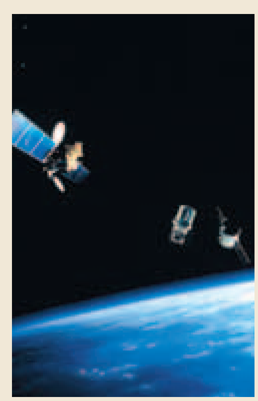
Newton thus developed his *law of universal gravitation*, which states that the force of gravity depends on the product of the masses of the objects divided by the square of the distance between them. In other words, if two objects are moved twice as far apart, the gravitational attraction between them will decrease by a factor of $2 \times 2 = 4$, as shown in **Figure 7.** If the objects are moved 10 times as far apart, the gravitational attraction will decrease by a factor of $10 \times 10 = 100$.

Figure 7 *If two objects are moved twice as far apart, the gravitational attraction between them will be four times less.*



APPLY

Space engineers that plan the paths of orbiting satellites must be able to calculate the height of the most appropriate orbit and the location of the satellite at each moment. To do this, they must take into account both Kepler's laws of motion and Newton's law of universal gravitation. Try this exercise: If the mass of the Earth were twice its actual mass, by how much would the gravity increase on a satellite in orbit around Earth? If the satellite were suddenly moved three times farther away, would Earth's gravitational pull on the satellite increase or decrease? By how much?



Explore

When the space shuttle is in orbit, we see the astronauts floating around as they work. Many people talk about this as a "zero-g" environment, meaning no gravity. Is this correct? Are shuttle astronauts affected by gravity? Do research to find out what happens when objects are in orbit around Earth.

Falling Down and Around How did Newton explain the orbit of the moon around the Earth? After all, according to gravity, the moon should come crashing into the Earth. And this is what the moon would do if it were not moving at a high velocity. In fact, if it were not for gravity, the moon would simply shoot off away from the Earth.

To understand this better, 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. But instead of a hand holding a string, gravity is keeping the moon from flying off in a straight path. **Figure 8** shows how this works. This same principle holds true for all bodies in orbit, including the Earth and other planets in our solar system.

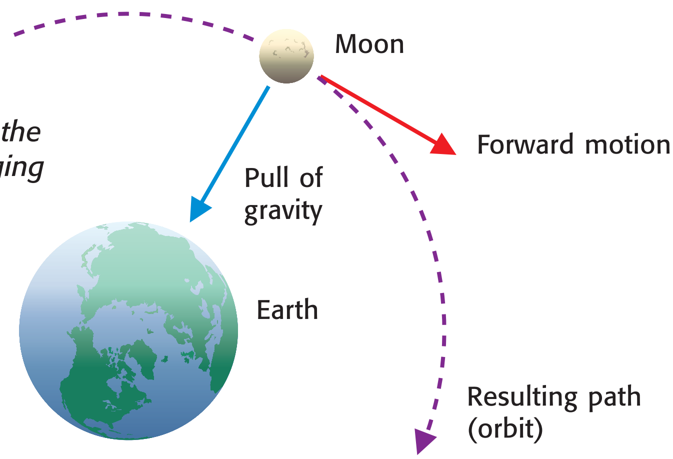
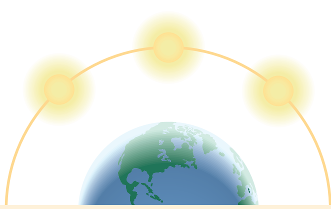


Figure 8 *Gravity is actually causing the moon to fall toward the Earth, changing what would be a straight-line path. The resulting path is a curved orbit.*



The Russians are planning to bounce sunlight from orbit to Earth. What's the scoop? Turn to page 449 to find out.

REVIEW

1. On what properties does the force of gravity between two objects depend?
2. Will a planet or comet be moving faster in its orbit when it is farther from or closer to the sun? Explain.
3. How does gravity keep a planet moving in an orbit around the sun?
4. **Applying Concepts** Suppose a certain planet had two moons, one of which was twice as far from the planet as the other. Which moon would complete one revolution of the planet first? Explain.

Section 2

The Sun: Our Very Own Star

NEW TERMS

corona	radiative zone
chromosphere	core
photosphere	nuclear fusion
convective zone	sunspot

OBJECTIVES

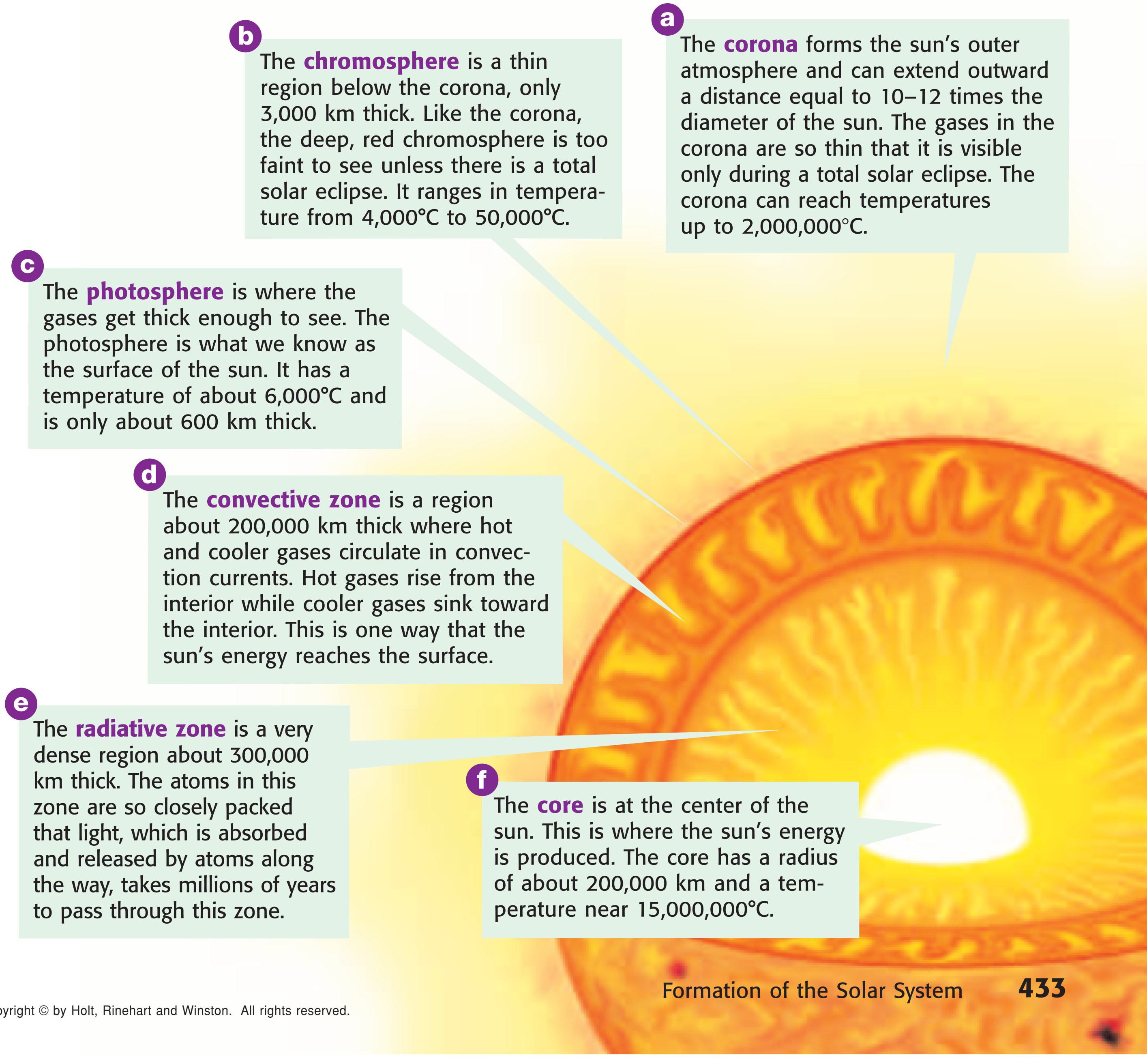
- Describe the basic structure and composition of the sun.
- Explain how the sun produces energy.
- Describe the surface activity of the sun, and name some of its effects on Earth.

There is nothing special about our sun, other than the fact that it is close enough to the Earth to give us light and warmth. Otherwise, the sun is similar to most of the other stars in our galaxy. It is basically a large ball of gas made mostly of hydrogen and helium held together by gravity. But let's take a closer look.

The Structure of the Sun

Although it may look like the sun has a solid surface, it does not. When we see a picture of the sun, we are really seeing through the sun's outer atmosphere, down to the point where the gas becomes so thick we cannot see through it anymore. As shown in **Figure 9,** the sun is composed of several layers.

Figure 9 **Structure of the Sun and Its Atmosphere**



Energy Production in the Sun

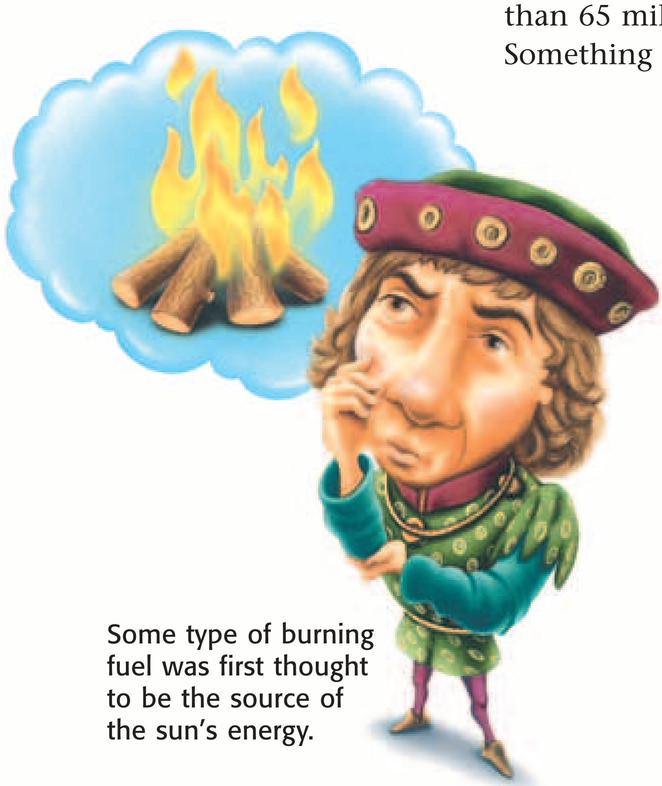
The sun has been shining on the Earth for about 4.6 billion years. How can it stay hot for so long? And what makes it shine? Over the years, several theories have been proposed to answer these questions. Because the sun is so bright and hot, many people thought that it was burning fuel to create the heat. But the amount of energy that is released during burning would not be enough to power the sun. If all of the matter in the sun were simply burned, the sun would last for only 10,000 years.

It eventually became clear that burning wouldn't last long enough to keep the sun shining. Scientists began to think that the sun was slowly shrinking due to gravity and that perhaps this would release enough energy to heat the sun. While the release of gravitational energy is more powerful than burning, it is still 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. We know that dinosaurs roamed the Earth more than 65 million years ago, so this couldn't be the explanation. Something even more powerful was needed.

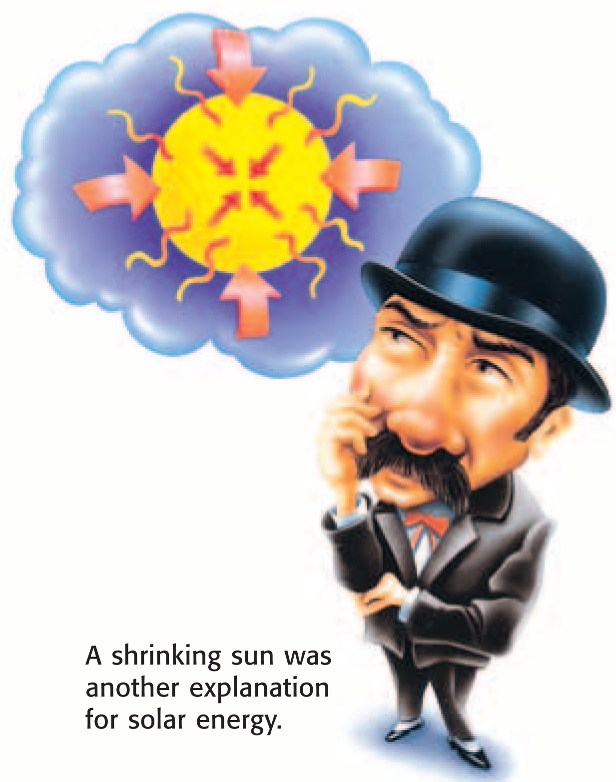
BRAIN FOOD

Despite the large size of Jupiter and Saturn, the sun itself contains over 99 percent of all the matter in the solar system.

Figure 10 *Ideas about the source of the sun's energy have changed over time.*



Some type of burning fuel was first thought to be the source of the sun's energy.

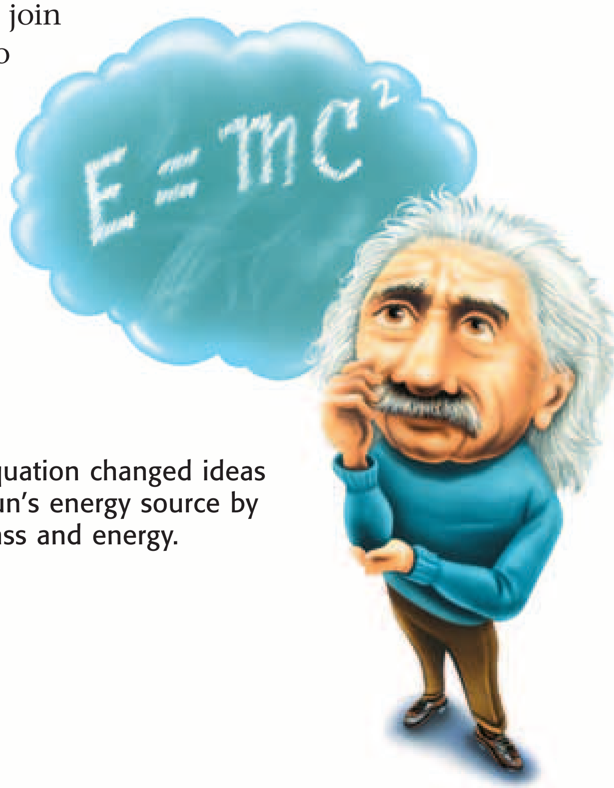


A shrinking sun was another explanation for solar energy.

LabBook

The sun is difficult to study because it is far away from Earth. Just how far? You might be able to figure it out by turning to page 586 in the LabBook.

Nuclear Fusion At the beginning of the twentieth century, Albert Einstein demonstrated that matter and energy are interchangeable. Matter can be converted to energy according to his famous formula: $E = mc^2$, where E is energy, m is mass, and c is the speed of light. Because the speed of light is so large, even a small amount of matter can produce a large amount of energy. This idea paved the way for an understanding of a very powerful source of energy. **Nuclear fusion** is the process by which two or more nuclei with small masses (such as hydrogen) join together, or fuse, to form a larger, more massive nucleus (such as helium). During the process, energy is produced—a lot of it!



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

life science CONNECTION

At the time Darwin introduced his theory of evolution, scientists thought that the sun was a few million years old at most. Some scientists argued that evolution—which takes place over billions of years—was therefore impossible because the sun could not have been shining that long. The nuclear fusion that fuels the sun, however, gives it a lifespan of about 10 billion years!

Atomic Review

Let's do a little review. *Atoms* are the smallest particles of matter that keep their chemical identity. A hydrogen atom and a helium atom are illustrated here. Notice that an atom consists of a *nucleus* surrounded by one or more *electrons,* which have a negative charge. A nucleus is made up of two types of smaller particles—a *proton,* with a positive charge, and a *neutron,* with no charge. The positively charged protons in the nucleus are balanced by an equal number of negatively charged electrons. The number of protons and electrons gives the atom its chemical identity.

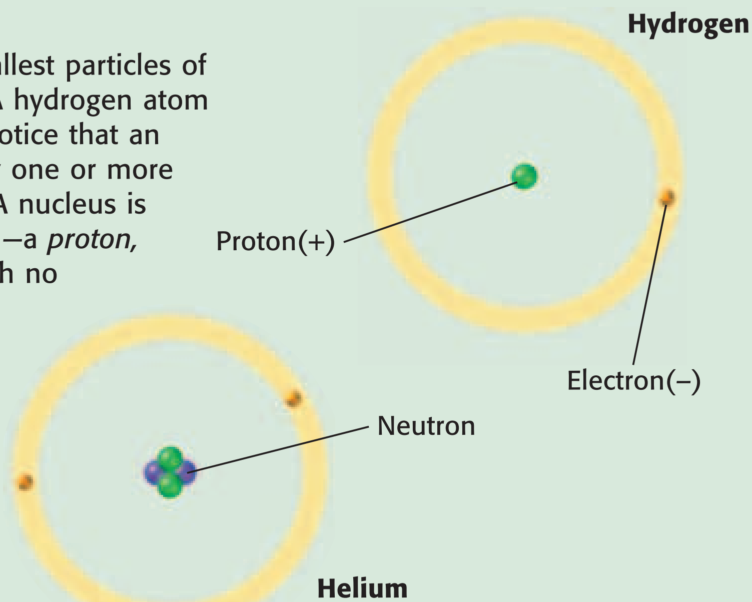
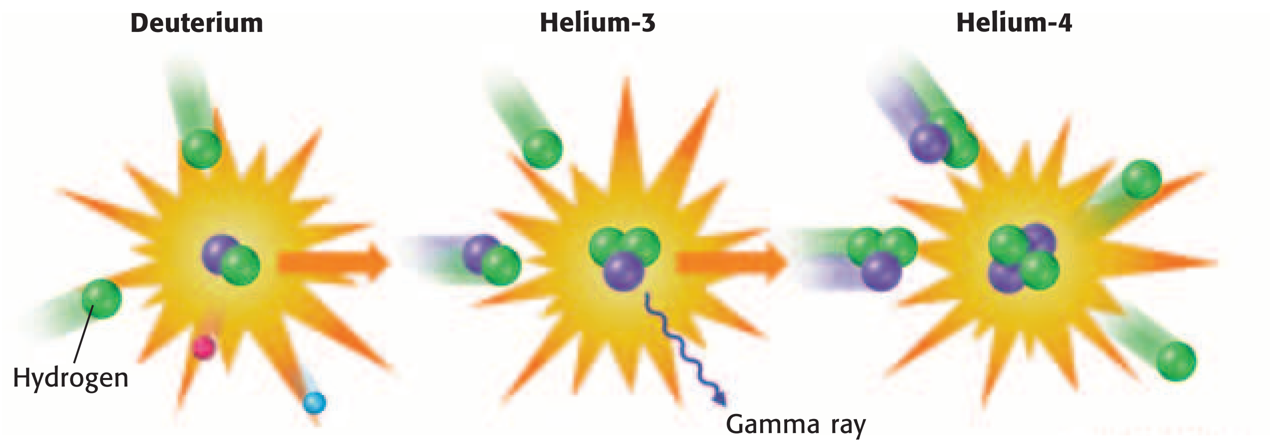


Figure 11 *Like charges repel, just like similar poles on a pair of magnets.*

Under normal conditions, the nuclei of hydrogen atoms would never get close enough to combine because they are positively charged, and like charges repel each other, as shown in **Figure 11.** In the center of the sun, however, the temperature and pressure are very high because of the huge amount of matter within the core. This gives the hydrogen nuclei enough energy to overcome the repulsive force, allowing the conversion of hydrogen to helium. The conversion to helium occurs in three steps, as shown in **Figure 12.**

Figure 12 Fusion of Hydrogen in the Sun



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

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

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

The energy produced in the core of the sun takes millions of years to reach the sun's surface. In the radiative zone just outside the core, the matter is so crowded that the light and energy keep getting blocked and sent off in different directions. Eventually the energy reaches the less crowded region of the convective zone, where hot gases carry it up to the photosphere relatively quickly. From there the energy leaves the sun as light, taking only 8.3 minutes to reach Earth.

The energy released during the nuclear fusion of 1 g of hydrogen is equal to about 100 tons of TNT! Each second, the sun converts about 5 million tons of matter into pure energy.

Activity on the Sun's Surface

The photosphere, or the visible surface of the sun, is a very dynamic place. As heat from the sun's interior reaches the surface, it causes the gas to boil and churn, a result of the rising and sinking of gases in the convective zone below. The surface, therefore, has a grainy appearance, though it can be seen only through special telescopes.

The circulation of the gases within the sun, in addition to the sun's own rotation, produces magnetic fields that reach out into space. But these magnetic fields also tend to slow down the activity in the convective zone. This causes areas on the photosphere above to be slightly cooler than surrounding areas. These cooler areas, which do not shine as brightly, show up as sunspots. **Sunspots** are cooler, dark spots on the sun, as shown in **Figure 13.**

The number of sunspots and their location on the sun change on a regular cycle. Records of the number of sunspots have been kept ever since the invention of the telescope. There may also be a connection between sunspot activity and Earth's long-term climate. In **Figure 14,** the cycle of sunspot numbers is shown, with the exception of the years 1645–1715, when sunspots were not observed. These years marked a much colder than average period for Europe and have been called the Little Ice Age.

The magnetic fields that cause sunspots also cause disturbances in the solar atmosphere. Giant storms on the surface of the sun, called *solar flares,* have temperatures of up to 5 million degrees Celsius. Solar flares send out huge streams of particles from the sun. These particles interact with the Earth's upper atmosphere, causing spectacular light shows called *auroras.*

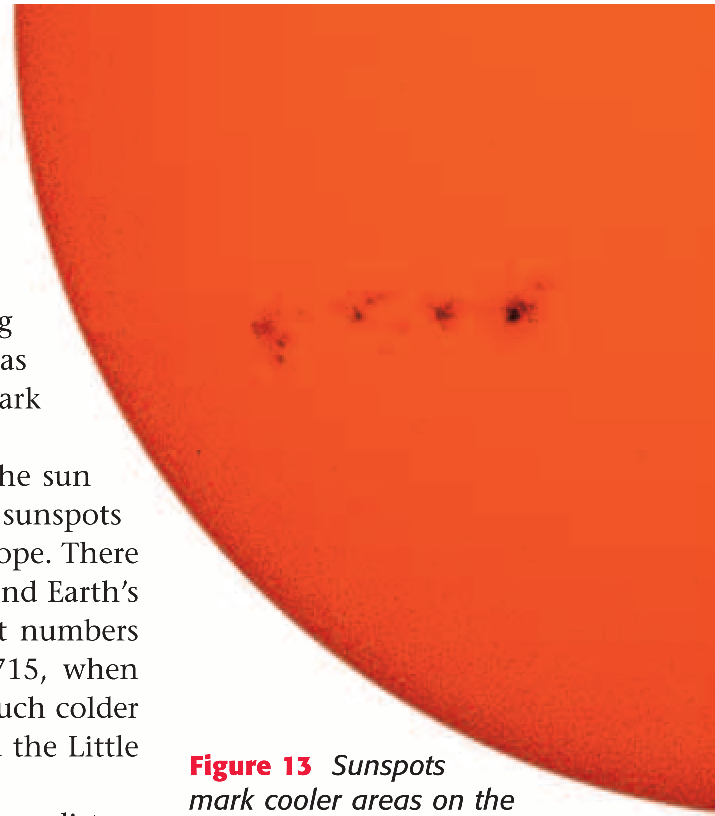


Figure 13 *Sunspots mark cooler areas on the sun's surface. They are related to changes in the magnetic properties of the sun.*

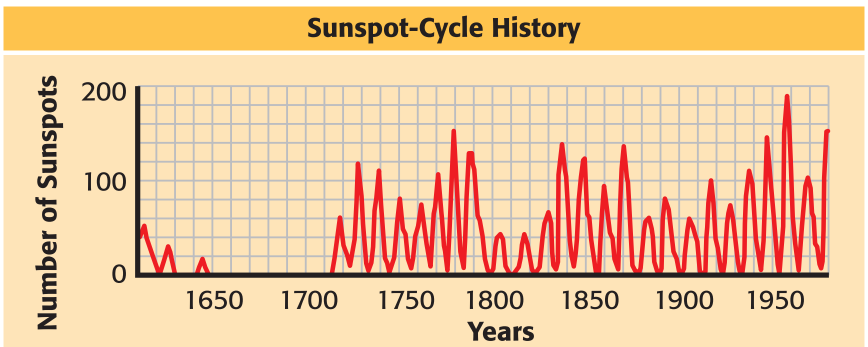


Figure 14 *This graph shows the number of sunspots that have occurred each year since Galileo's first observations, in 1610.*

REVIEW

1. According to modern understanding, what is the source of the sun's energy?
2. If nuclear fusion in the sun's core suddenly stopped today, would the sky be dark in the daytime tomorrow? Why?
3. **Interpreting Illustrations** In Figure 12, the nuclear fusion process ends up with one helium-4 nucleus and two free protons. What might happen to the two protons next?

physical science CONNECTION

Solar flares can interrupt radio communications on Earth. They can also affect satellites in orbit. The particles released during a solar flare can cause electronic circuits to fail. Scientists are trying to find ways to predict solar activity and give advanced warning of such events.

Section 3

The Earth Takes Shape

NEW TERMS

crust
mantle
core

OBJECTIVES

- Describe the shape and structure of the Earth.
- Explain how the Earth got its layered structure and how this process affects the appearance of Earth's surface.
- Explain the development of Earth's atmosphere and the influence of early life on the atmosphere.
- Describe how the Earth's oceans and continents were formed.

Investigating the early history of the Earth is not easy because no one was there to study it directly. Figuring out what the early Earth was like is similar to having a huge jigsaw puzzle with most of the pieces missing. Scientists develop ideas about what happened based on their knowledge of chemistry, biology, physics, geology, and other sciences. Astronomers are also gathering evidence from other stars where planets are forming to better understand how our own solar system formed. When new pieces of information come in, however, the pieces of the puzzle may have to be rearranged to make the new pieces fit.

The Solid Earth Takes Form

As scientists now understand it, the Earth was formed from the accumulation of planetesimals. The addition of planetesimals kept the Earth growing until it reached its present size. This happened within the first 10 million years of the collapse of the solar nebula.

When a young planet is still small, it can have an irregular shape. Bits can get broken off during collisions with planetesimals, and new material doesn't always collect on the surface evenly. As more matter builds up on the young planet, the gravity increases and the material pushing toward the center of the planet gets heavier. When a rocky planet, such as Earth, reaches a diameter of about 350 km, pressure from all this material becomes greater than the strength of the rocks in the center of the planet. At this point, the planet starts to become spherical in shape as the rocks in the center are crushed.

As planetesimals fell to Earth, the energy of their motion was changed into heat. This energy made the Earth warmer. Once the Earth reached a certain size, the interior could not cool off as fast as its temperature rose, and the rocky material inside began to melt.

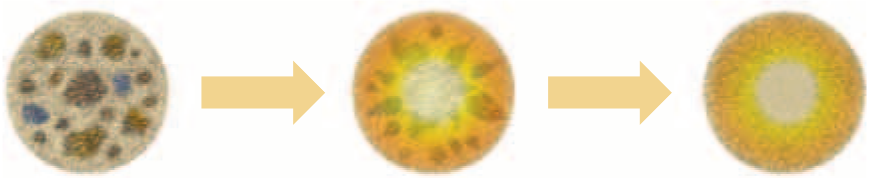
Figure 15 *The Earth has not always looked as inviting as it does today.*

Self-Check

Why is the Earth spherical in shape, while most asteroids and comets are not? *(See page 596 to check your answer.)*

The Earth and Its Layers Have you ever dropped pebbles into water or tried mixing oil and vinegar together for a salad? What happens? The heavier material (either solid or liquid) sinks, and the lighter material floats to the top. This is because of gravity. The material with a higher density experiences a stronger attraction and falls to the bottom. The same thing happened in the young Earth. As its rocks melted, the heavy elements, such as nickel and iron, sank to the center of the Earth, forming what we call the *core*. Lighter materials floated to the surface. This process is illustrated in **Figure 16.**

Figure 16 Earth's Materials Separate into Layers



All materials in the early Earth are randomly mixed.

Rocks melt, and dense materials separate and sink.

Less-dense materials rise, and layers are formed.

The formation of the core started while the Earth was growing, and heat was added by the planetesimals and other material that fell to Earth. A second source of energy for heating the Earth was radioactive material, which was present in the solar nebula. Radioactive material radiates energy, and as it collected within the Earth, it also heated the planet.

The Earth's Interior The Earth is divided into three distinct layers according to the composition of its materials. These layers are shown in **Figure 17.** Geologists can map the interior of the Earth by measuring how sound waves pass through the planet during earthquakes and underground explosions.

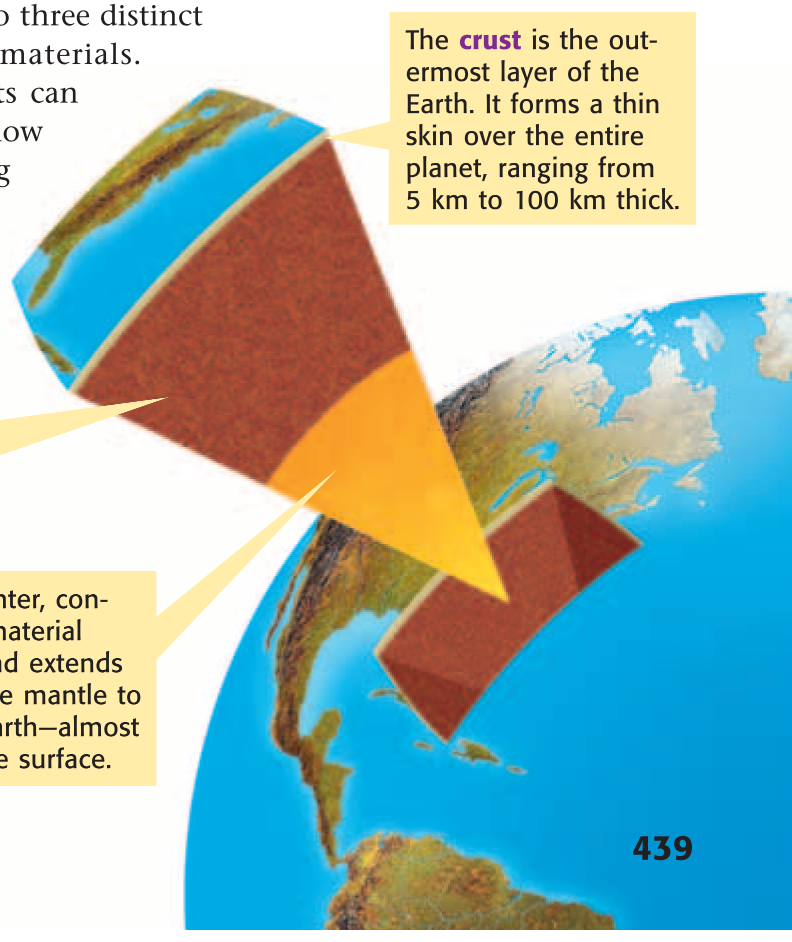


Figure 17 *The interior of the Earth consists of three layers.*

QuickLab

Mixing It Up

Have you ever mixed oil and water and watched what happened? Try this.

1. Pour 50 mL of **water** into a 150 mL **beaker.**
2. Add 50 mL of **cooking oil** to the water. Stir vigorously.
3. Let the mixture stand undisturbed for a few minutes.
4. What happens to the oil and water?
5. How does this relate to the interior of the early Earth?

The Atmosphere Evolves

chemistry CONNECTION

The Cassini Mission to Saturn (launched in October 1997) will study the chemistry of Saturn's moon Titan. Titan's atmosphere, like Earth's, is composed mostly of nitrogen, but it also contains many hydrogen-rich compounds. Scientists want to study how molecules essential to life may be formed in this atmosphere.

Other than the presence of life, one of the biggest differences between the Earth of today and the Earth of 4.6 billion years ago is the character of its atmosphere. Earth's atmosphere today is composed of 21 percent oxygen, 78 percent nitrogen, and about 1 percent argon (with tiny amounts of many other gases). But it has not always been this way. Read on to discover how the Earth's atmosphere has changed through time.

Earth's First Atmosphere Earth's early atmosphere was very different from the atmosphere of today. In the 1950s, laboratory experiments on the origins of life were based on the hypothesis that Earth's early atmosphere was largely made up of methane, ammonia, and water. And since the solar nebula was rich in hydrogen, many scientists thought that Earth's first atmosphere also contained a lot of hydrogen compounds.

New evidence is changing the way we think about Earth's first atmosphere. For one thing, 85 percent of the Earth's matter probably came from material similar to the *meteorites*—planetesimals made of rock. The other 15 percent probably came from the outer solar system in the form of *comets*—planetesimals made of ice.

During the final stages of formation, the Earth was hit many times by planetesimals, and the surface was very hot, even molten in places, as illustrated in **Figure 18.** The ground would have been venting large amounts of gas released from the heated minerals. The composition of meteorites tells us that much of that gas would have been water vapor and carbon dioxide. These two gases are also commonly released during volcanic eruptions when rocks turn to lava. Earth's first atmosphere was probably a steamy atmosphere made of water vapor and carbon dioxide.

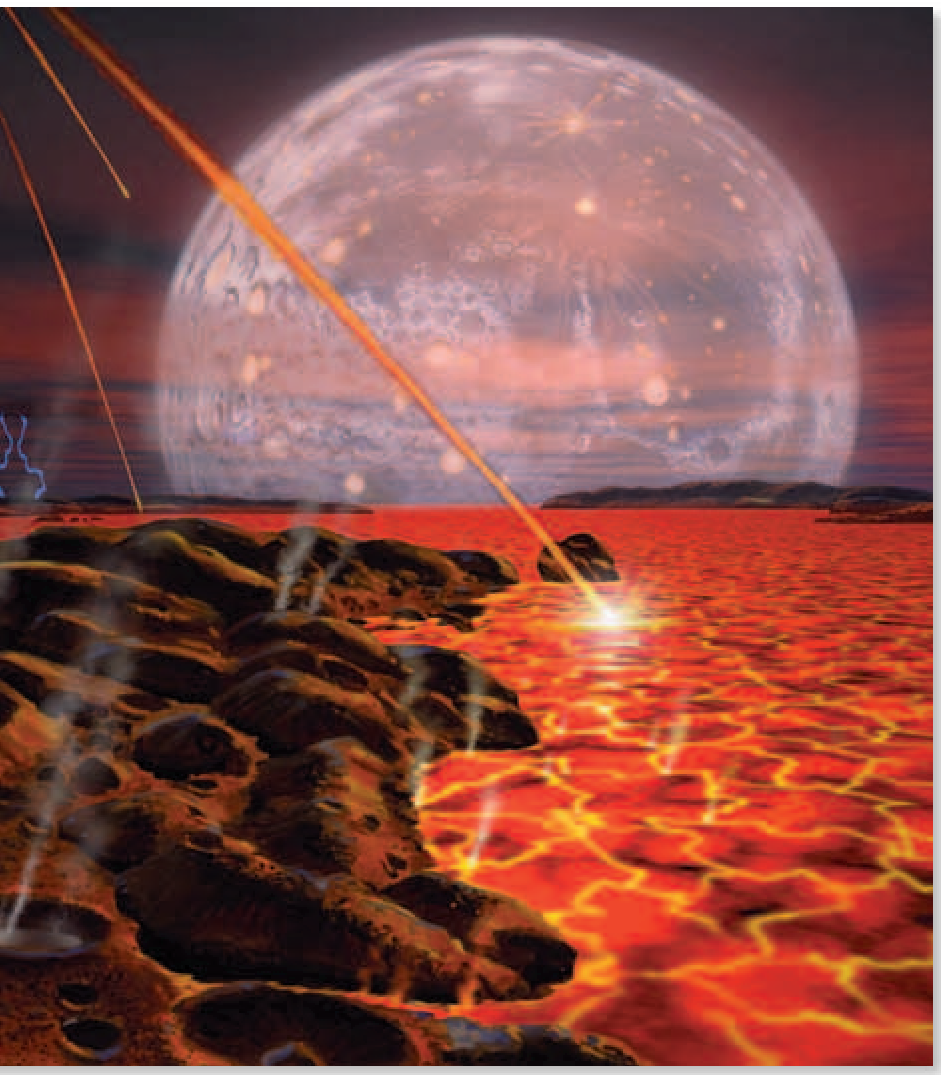


Figure 18 *This is an artist's view of what Earth's surface may have looked like shortly after Earth's formation.*

Even though there was a lot of water vapor in the atmosphere, it probably didn't create our oceans right away. Planetesimal impacts may have helped release gases from the Earth, but they also helped to knock some of those gases back into space. Because planetesimals travel very fast, their impacts speed up the gas molecules in the atmosphere enough for them to overcome gravity and escape into space.

Heavier elements, such as iron, that were on the surface of the Earth also reacted chemically with water and gave off hydrogen—the lightest element. And because the early Earth was very warm, this hydrogen also had enough energy to escape.

Comets brought in a range of elements, such as carbon, hydrogen, oxygen, and nitrogen. They may also have brought water that eventually formed the oceans, as shown in **Figure 19.**

Figure 19 *Comets may have brought some of the water that formed the early Earth's oceans.*

Earth's Second Atmosphere After the Earth cooled off and the core formed, it was possible for the Earth's second atmosphere to take shape. This atmosphere was formed by gases contributed by both comets and volcanoes. Eruptions from Hawaiian volcanoes, like the one in **Figure 20,** show that a large amount of water vapor is produced, along with chlorine, nitrogen, sulfur, and large amounts of carbon dioxide. This carbon dioxide kept the planet much warmer than it is today.

Figure 20 *As this volcano in Hawaii shows, a large amount of gas is released during an eruption.*

environmental science CONNECTION

Because carbon dioxide is a very good *greenhouse gas*—one that traps heat—scientists have tried to estimate how much carbon dioxide the Earth must have had in its second atmosphere in order to keep it as warm as it was. For example, if all of the carbon dioxide that is now tied up in rocks and minerals of the ocean floor were released, it would make an atmosphere of carbon dioxide 60 times as thick as our present atmosphere.

Earth's Current Atmosphere How did this early atmosphere change to become the atmosphere we know today? It happened with the help of solar ultraviolet (UV) radiation, the very thing that we worry about now for its cancer-causing ability. Solar UV light is dangerous because it has a lot of energy and can break apart molecules in the air or in your skin. Today we are shielded from most of the sun's ultraviolet rays by Earth's protective ozone layer. But Earth's early atmosphere had no ozone, and many molecules were broken apart in the atmosphere. The pieces were later washed out into shallow seas and tide pools by rain. Eventually a rich supply of these pieces of molecules collected in protected areas, forming a rich organic solution that has sometimes been called a "primordial soup."

Although there was no ozone, a layer of water offers protection from the effects of ultraviolet radiation, and life is thought to have originated beneath the sea. The earliest forms of life may have been a primitive type of bacteria that lives near hydrothermal vents on the ocean floor. These primitive bacteria may have evolved into more-complex organisms such as blue-green algae, which were capable of photosynthesis and produced oxygen as a byproduct. These early life-forms are still around today, as shown in **Figure 21.**

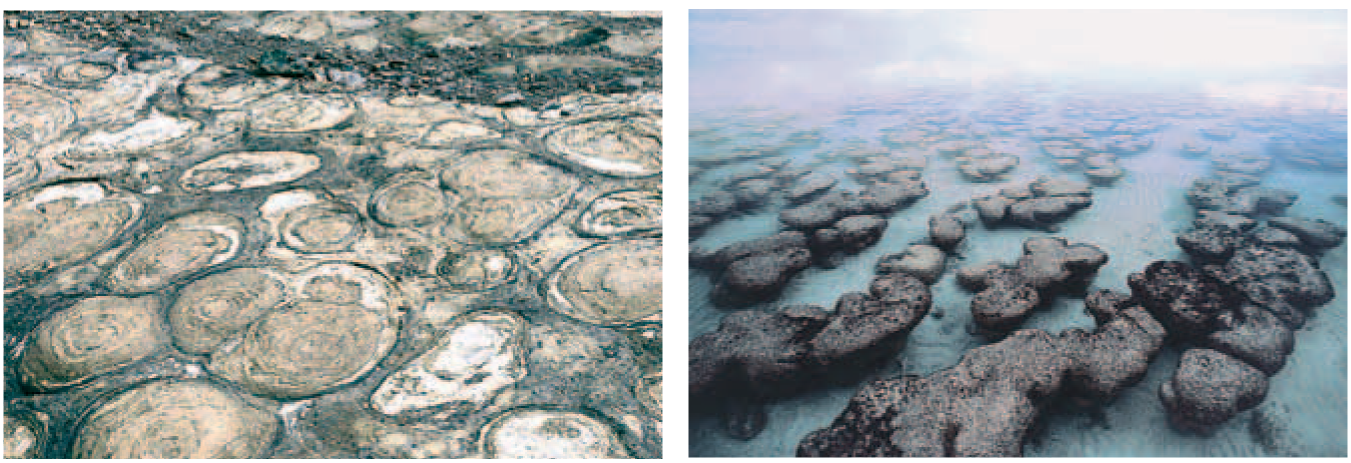


Figure 21 *Fossilized algae (left) are among the earliest signs of life discovered. Today's stromatolites (right) are mats of bacteria thought to be similar to the first life on Earth.*

Oxygen didn't immediately build up in the atmosphere because it would have combined readily with minerals on the surface of the Earth such as iron. Evidence suggests that oxygen levels remained very low until about 2 billion years ago and then began to increase. The rate of this increase, however, is a subject of debate.

As plants began to cover the land, oxygen levels increased because plants produce oxygen during photosynthesis. Therefore, it was the emergence of life that completely changed our atmosphere into the one we have today.

Oceans and Continents

It is hard to say exactly when the first oceans appeared on Earth, but they probably formed early, as soon as the Earth was cool enough for rain to fall and remain on the surface. We know that Earth's secondary atmosphere had plenty of water vapor. After millions of years of rainfall, water began to cover the Earth, and by 4 billion years ago, a giant global ocean may have covered the planet. For the first few hundred million years of the Earth's history, there were probably no continents.

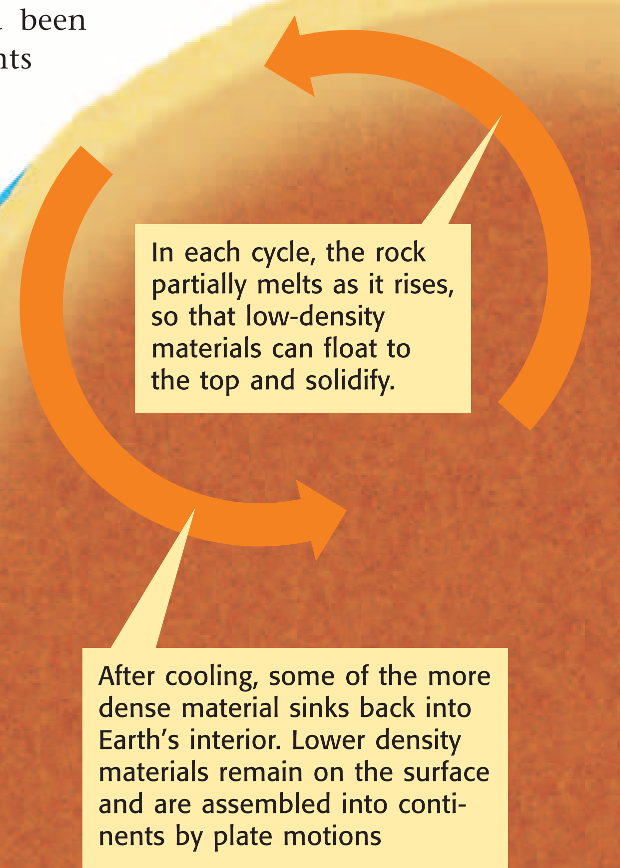
So how and when did the continents appear? Continental crust material is very light compared with material in the mantle. The composition of the granite and other rocks making up the continents tells geologists that the rocks of the crust have melted and cooled many times in the past. Each time the rocks melted, the heavier elements sank, leaving the lighter ones to rise to the surface. This process is illustrated in **Figure 22.**

After a while, some of the rocks were light enough that they no longer sank, and they began to pile up on the surface. This marked the beginning of the earliest continents. After gradually thickening, the continents slowly rose above the level of the seas. These scattered young continents didn't stay in the same place, however, because the slow convection in the mantle pushed the continents around. By about 3.5 billion years ago, less than 10 percent of the continents had been formed, but around 2.5 billion years ago, continents really started to grow. By 1.5 billion years ago, the upper mantle had cooled and become denser and heavier, so it was easier for the colder parts of it to sink. Then the real continental action, or *plate tectonics,* began.

life science CONNECTION

Oxygen combines very quickly with other chemicals. Therefore, we would not expect to see oxygen in an atmosphere unless there were living organisms to keep making it. The discovery of oxygen in the atmosphere of another planet or moon would signal the presence of extraterrestrial life!

Figure 22 *The slow convective motion in the Earth's mantle causes rock to rise and sink.*



REVIEW

1. Why did the Earth separate into distinct layers?
2. How did the Earth's atmosphere change composition to become today's nitrogen and oxygen atmosphere?
3. Which are older, oceans or continents? Explain.
4. **Drawing Conclusions** If the Earth were not hot inside, would we have moving continents (plate tectonics)? Explain.

Chapter Highlights

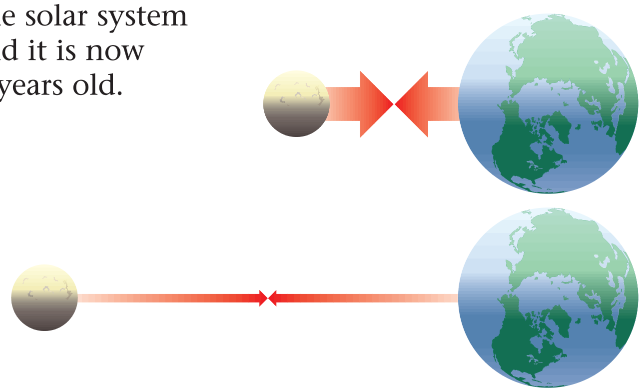
SECTION 1

Vocabulary

solar system *(p. 424)*
nebula *(p. 424)*
solar nebula *(p. 425)*
planetesimal *(p. 426)*
rotation *(p. 429)*
orbit *(p. 429)*
revolution *(p. 429)*
period of revolution *(p. 429)*
ellipse *(p. 430)*
astronomical unit *(p. 430)*

Section Notes

- The solar system formed out of a vast cloud of cold gas and dust called a nebula.
- Gravity and pressure were balanced, keeping the cloud unchanging until something upset the balance. Then the nebula began to collapse.
- Collapse of the solar nebula caused heating in the center. As material crowded closer together, planetesimals began to form.
- The central mass of the nebula became the sun. Planets formed from the surrounding disk of material.
- It took about 10 million years for the solar system to form, and it is now 4.6 billion years old.
- The orbit of one body around another has the shape of an ellipse.
- Planets move faster in their orbits when they are closer to the sun.
- The square of the period of revolution of the planet is equal to the cube of its semimajor axis.
- Gravity depends on the masses of the interacting objects and the square of the distance between them.



Skills Check

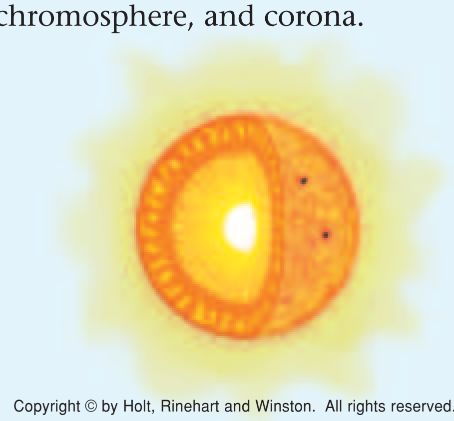
Math Concepts

SQUARES AND CUBES Let's take another look at Kepler's third law of motion. Expanding the formula $P^2 = a^3$ to $P \times P = a \times a \times a$ may be an easier way to consider the calculation. The period of Venus, for example, is 0.61 years, and its semimajor axis is 0.72 AU. Thus,

$$P^2 = a^3$$
$$P \times P = a \times a \times a$$
$$0.61 \times 0.61 = 0.72 \times 0.72 \times 0.72$$
$$0.37 = 0.37$$

Visual Understanding

LIKE AN ONION The sun is formed of six different layers of gas. From the inside out, the layers are the core, radiative zone, convective zone, photosphere, chromosphere, and corona. Look back at Figure 9 on page 433 to review the characteristics of each layer.



SECTION 2

Vocabulary

corona *(p. 433)*
chromosphere *(p. 433)*
photosphere *(p. 433)*
convective zone *(p. 433)*
radiative zone *(p. 433)*
core *(p. 433)*
nuclear fusion *(p. 435)*
sunspot *(p. 437)*

Section Notes

- The sun is a gaseous sphere made primarily of hydrogen and helium.
- The sun produces energy in its core by a process called nuclear fusion.
- Magnetic changes within the sun cause sunspots and solar flares.

Labs

How Far Is the Sun? *(p. 586)*

SECTION 3

Vocabulary

crust *(p. 439)*
mantle *(p. 439)*
core *(p. 439)*

Section Notes

- The Earth is divided into three main layers—crust, mantle, and core.
- Materials with different densities separarted because of melting inside Earth. Heavy elements sank to the center because of Earth's gravity.
- Earth's original atmosphere formed from the release of gases brought to Earth by meteorites and comets.
- Earth's second atmosphere arose from impacts by comets and volcanic eruptions. The composition was largely water and carbon dioxide.
- The presence of life dramatically changed Earth's atmosphere, adding free oxygen.
- Earth's oceans formed shortly after the Earth did, when it had cooled off enough for rain to fall.
- Continents were formed when lighter materials gathered on the surface and rose above sea level.

internetconnect

GO TO: go.hrw.com

Visit the **HRW** Web site for a variety of learning tools related to this chapter. Just type in the keyword:

KEYWORD: HSTSOL

GO TO: www.scilinks.org

Visit the **National Science Teachers Association** on-line Web site for Internet resources related to this chapter. Just type in the ***sci*LINKS** number for more information about the topic:

TOPIC: The Planets	***sci*LINKS NUMBER:** HSTP580
TOPIC: Kepler's Laws	***sci*LINKS NUMBER:** HSTP585
TOPIC: The Sun	***sci*LINKS NUMBER:** HSTP590
TOPIC: The Layers of the Earth	***sci*LINKS NUMBER:** HSTP595
TOPIC: The Oceans	***sci*LINKS NUMBER:** HSTP600

Chapter Review

USING VOCABULARY

For each pair of terms, explain the difference in their meanings.

1. rotation/revolution
2. ellipse/circle
3. solar system/solar nebula
4. planetesimal/planet
5. temperature/pressure
6. photosphere/corona

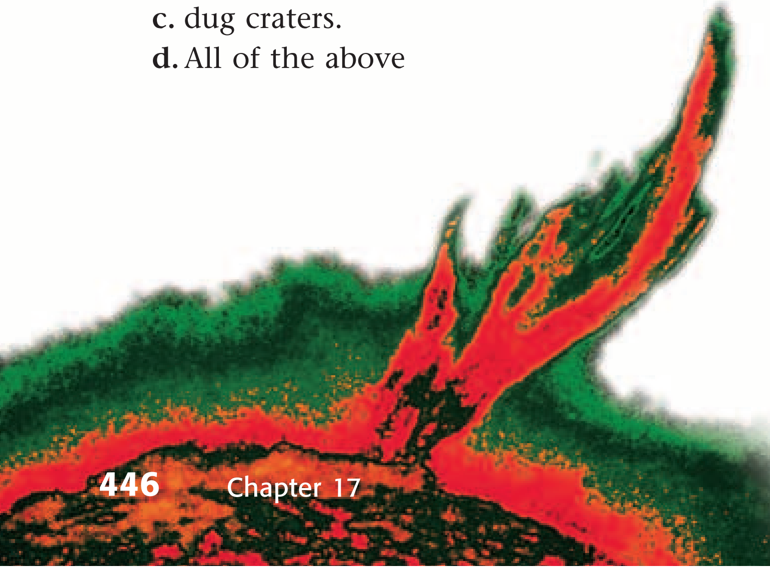
To complete the following sentences, choose the correct term from each pair of terms below.

7. It takes millions of years for light energy to travel through the sun's __?__. *(radiative zone* or *convective zone).*
8. __?__ of the Earth causes night and day. *(Rotation* or *Revolution)*
9. Convection in Earth's mantle causes __?__. *(plate tectonics* or *nuclear fusion)*

UNDERSTANDING CONCEPTS

Multiple Choice

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. Which type of planet will have a higher overall density?
    a. one that forms close to the sun
    b. one that forms far from the sun
12. Which process releases the most energy?
    a. nuclear fusion
    b. burning
    c. shrinking due to gravity
13. Which of the following planets has the shortest period of revolution?
    a. Pluto **c.** Mercury
    b. Earth **d.** Jupiter
14. Which gas in Earth's atmosphere tells us that there is life on Earth?
    a. hydrogen **c.** carbon dioxide
    b. oxygen **d.** nitrogen
15. Which layer of the Earth has the lowest density?
    a. the core
    b. the mantle
    c. the crust
16. What is the term for the speed of gas molecules?
    a. temperature **c.** gravity
    b. pressure **d.** force
17. Which of the following objects is least likely to have a spherical shape?
    a. a comet **c.** the sun
    b. Venus **d.** Jupiter

Short Answer

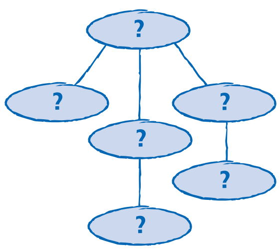
18. Why did the solar nebula begin to collapse to form the sun and planets if the forces of pressure and gravity were balanced?

19. How is the period of revolution related to the semimajor axis of an orbit? Draw an ellipse and label the semimajor axis.

20. How did our understanding of the sun's energy change over time?

Concept Mapping

21. Use the following terms to create a concept map: solar nebula, solar system, planetesimals, sun, photosphere, core, nuclear fusion, planets, Earth.



CRITICAL THINKING AND PROBLEM SOLVING

22. Explain why nuclear fusion works inside the sun but not inside Jupiter, which is also made mostly of hydrogen and helium.

23. Why is it less expensive to launch an interplanetary spacecraft from the international space station in Earth's orbit than from Earth itself?

24. Soon after the formation of the universe, there was only hydrogen and helium. Heavier elements, such as carbon, oxygen, silicon, and all the matter that makes up the heavier minerals and rocks in the solar system, were made inside an earlier generation of stars. Do you think the first generation of stars had any planets like Earth, Venus, Mercury, and Mars? Explain.

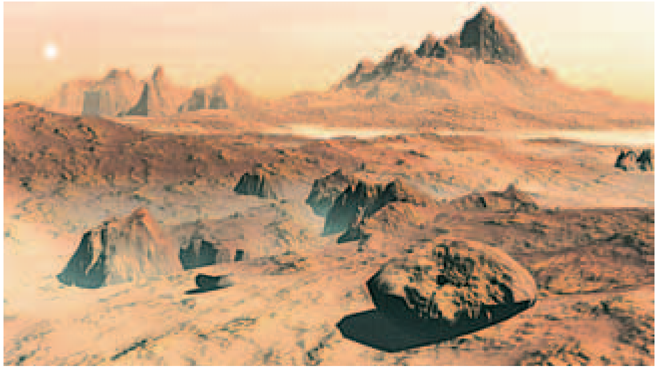
MATH IN SCIENCE

25. Suppose astronomers discover a new planet orbiting our sun. The orbit has a semimajor axis of 2.52 AU. What is the planet's period of revolution?

26. If the planet in the previous question is twice as massive as the Earth but is the same size, how much would a person who weighs 100 lb on Earth weigh on this planet?

INTERPRETING GRAPHICS

Examine the illustration below, and answer the questions that follow.



27. Do you think this is a rocky, inner planet or a gas giant?

28. Did this planet form close to the sun or far from the sun? Explain.

29. Does this planet have an atmosphere? Why or why not?

NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 423. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

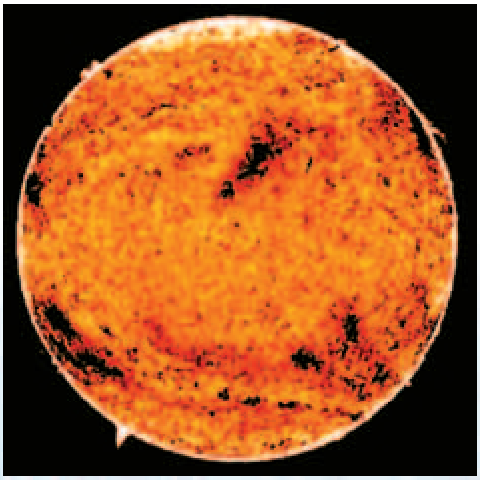
Science, Technology, and Society

Don't Look at the Sun!

You know you are not supposed to look at the sun, right? But how can we learn anything about the sun if we can't look at it? By using a solar telescope, of course! Where would you find one of these, you ask? Well, if you travel about 70 km southwest of Tucson, Arizona, you will arrive at Kitt Peak National Observatory, where you will find three of them. One telescope in particular has gone to great lengths to give astronomers extraordinary views of the sun!

Top Selection

In 1958, Kitt Peak was chosen from more than 150 mountain ranges to be the site for a national observatory. Located in the Sonoran Desert, Kitt Peak is a part of lands belonging to the Tohono O'odham nation. 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, called the McMath-Pierce telescope, creates an image of the sun that is almost 1 m wide!

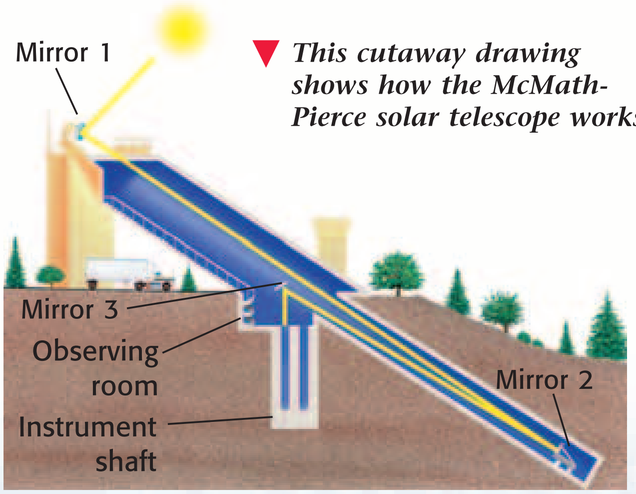


▲ *This is an image of the sun as viewed through the McMath-Pierce solar telescope.*

Too Hot to Handle

Have you ever caught a piece of paper on fire using only a magnifying glass and the rays from the sun? Sunlight that has been focused can produce a great amount of thermal energy—enough to start a fire. Now imagine a magnifying glass 1.6 m in diameter focusing the sun's rays. The resulting heat could melt metal. This is what would happen to a conventional telescope if it were pointed directly at the sun.

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 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.



▼ *This cutaway drawing shows how the McMath-Pierce solar telescope works.*

Scope It Out

► Kitt Peak Observatory also has optical telescopes, which differ from solar telescopes. Do some research to find out how optical telescopes work and what the ones at Kitt Peak are used for.

SCIENTIFIC DEBATE

Mirrors in Space

People who live in areas that do not get much sunshine are more prone to health problems such as depression and alcoholism. The people of Siberia, Russia, experience a shortage of sunshine during the winter, when the sun shines only 6 hours on certain days. Could there be a solution to this problem?

A Mirror From *Mir*

In February 1999, the crew of the space station *Mir* was scheduled to launch a large, umbrella-like mirror into orbit. The mirror was designed to reflect sunlight to Siberia. Once placed into orbit, however, problems arose and the crew was unable to unfold the mirror. Had things gone as planned, the beam of reflected sunlight was expected to be 5 to 10 times brighter than the light from the moon. If the first mirror had worked, this would have opened the door for Russia to build many more mirrors that are larger in diameter. These larger mirrors would have been launched into space to lengthen winter days, provide additional heat, and even reduce the amount of electricity used for lighting. The idea of placing mirrors in space, however, caused some serious concerns about the effects it could have.

▲ *The end of a winter day in Siberia*

Overcrowding

The first mirror was about 30 m in diameter. Because it was launched in the Low Earth Orbit (LEO), the light beam would be obstructed by the Earth's horizon as the mirror made its orbit. As a result, it would only reflect light on a single area for about 30 seconds. In order to shine light on Siberia on a large scale, hundreds of larger mirrors would have to be used. But using this many mirrors could result in collisions with satellites that share the LEO.

Damage to Ecosystems

It is very difficult to determine what effects extra daylight would have on Siberian ecosystems. Many plants and animals have cycles for various biological functions, such as feeding, sleeping, moving, and reproducing. Extra light and increased temperatures could adversely affect these cycles. Birds might migrate so late that they wouldn't survive the trip across the colder climates because food would be scarce. Plants might sprout too soon and freeze. Arctic ice might melt and cause flooding.

Light Pollution

Astronomers may also be affected by orbiting mirrors. Already astronomers must plan their viewing times to avoid the passing of bright planets and satellites. More sunlight directed toward the Earth would increase light pollution and could make seeing into space more difficult. A string of several hundred mirrors shining light toward the Earth would likely cause additional light pollution in certain locations as the mirrors passed overhead.

What's the Current Status?

▶ Find out more about the Russian project and where it stands now. If you had to decide whether to pursue this project, what would you decide? Why?