UNIT 11

Astronomy

Chapter 30

What is Astronomy?

Frequently in the news we hear about discoveries that involve space. In fact, our knowledge of the solar system and beyond is expanding each year because of advancements in technology. In recent years, space probes have been sent to most of the planets in the solar system and we have seen them "up close" for the very first time. Long before the invention of the telescope, ancient civilizations made observations of the heavens that helped people keep track of time and the seasons. In this chapter, you will learn about tools and language of astronomy.

30.1 Cycles on Earth — *How do we keep track of time?*

In this Investigation, you will build a solar clock and discover the variables involved with using the sun to keep track of time. You will also observe the lunar cycle over the course of a month and construct a daily calendar based on changes in the moon's appearance.

30.2 Tools of Astronomy — *How does a telescope work?*

In this Investigation, you will build a simple telescope and use it to observe objects around your school. Through this exercise, you will find out how a telescope works. Next, you will use your telescope to observe the surface of the moon. Finally, you will try a more difficult task—observing the planet Jupiter and some of its moons.

Learning Goals

In this chapter, you will:

- ✔ Relate keeping track of time to astronomical cycles.
- ✔ Predict how the moon will appear based on its orbital position.
- ✔ Describe what causes the seasons.
- ✔ Describe what causes eclipses.
- ✔ Convert large numbers to scientific notation.
- ✔ Name the differences between stars, planets, galaxies, and the universe.
- ✔ Convert between kilometers and light years.
- ✔ Explain how refracting and reflecting telescopes work.
- ✔ Name some telescopes that examine other types of electromagnetic waves.
- ✔ Describe how satellites, space probes, and piloted spacecraft are used in astronomy.

Vocabulary

axis	lunar eclipse	revolution	solar eclipse
calendar	planet	rotation	star
galaxy	reflecting telescope	satellite	telescope
light year	refracting telescope	scientific notation	universe

30.1 Cycles on Earth

Did you know that two ancient cultures, the Chinese and the Mayans, independently determined that the length of a year is 365.25 days? They did this without even knowing that Earth revolves around the sun! The development of a calendar to keep track of time came from the need to be able to predict the seasons, annual floods, and other cyclical occurrences in communities' lives. In this section, you will learn where our calendar came from and why astronomical cycles on Earth occur.

Calendars

Astronomical cycles

Do you ever wonder where our calendar comes from? Or why there is a "leap year" every four years? The answers have to do with the position of Earth in space and its relationship to the sun and moon. Today we know that Earth both spins and revolves around the sun. We also know that the moon revolves around Earth. These movements cause the *astronomical cycles* that are the basis for our calendar.

What is a calendar?

A **calendar** is a means of keeping track of all the days in a year. For thousands of years, different cultures have struggled to come up with their own calendars. Ancient civilizations developed calendars based on their observations of the sun, moon, and stars without knowing of our planet's position in space. Many such civilizations independently invented almost identical calendars. Most of these were divided into weeks and months, and included important information such as amount of daylight, position of the sun in the sky, and the phases of the moon.

Ancient calendars

Stonehenge in Great Britain is thought to be an early example (1500 BC) of a calendar. This monument, made of giant stones arranged in a pattern, marks the direction in which the sun rises and sets on the longest period of daylight of the year. This may have helped its builders to keep track of the passage of a year. Chinese astronomers in 1300 BC were the first to calculate the correct length of a year (365.25 days). The Mayans also devised a calendar with 365.25 days. This Mayan civilization (located in what is now Mexico) had no knowledge of the calendars used by other peoples. The blue box at right shows a timeline of various calendars from around the world.

Calendars through human history

20,000 years ago. Ice-age hunters in Europe scratched lines in bones to mark the passage of days.

7,000 BC. Babylonians kept a calendar with 29- and 30-day months. They needed to add an extra month every eight years.

4,000 BC. The Egyptians adopted a solar calendar with 365 days in a year. This was divided into 12 months, each with 30 days, and an extra five days at the end.

2,000 BC. Mayans of Central America calculated that there were 365.25 days in a year.

700 BC. The Roman calendar consisted of 10 months in a year of 304 days. It ignored the remaining 61 days, which fell in the middle of winter.

46 BC. Romans adopted the Julian calendar, named after Julius Caesar. It is very close to the modern calendar we use today.

The lunar cycle

Phases of the moon

Have you ever noticed that the shape of the moon appears to change in a regular pattern (Figure 30.1)? This gradual change in the appearance of the moon, known as the *lunar cycle,* is one of the first discoveries that helped ancient civilizations divide the year into smaller parts. These *phases* of the moon occur because of the positions of Earth, the moon, and the sun.

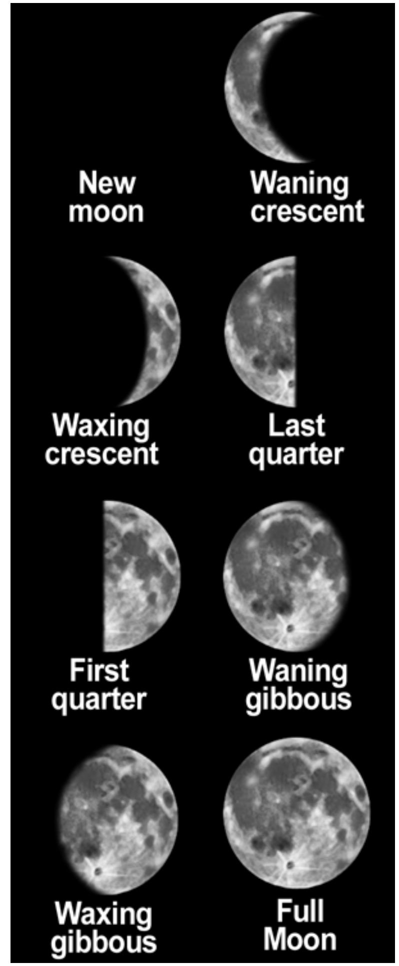
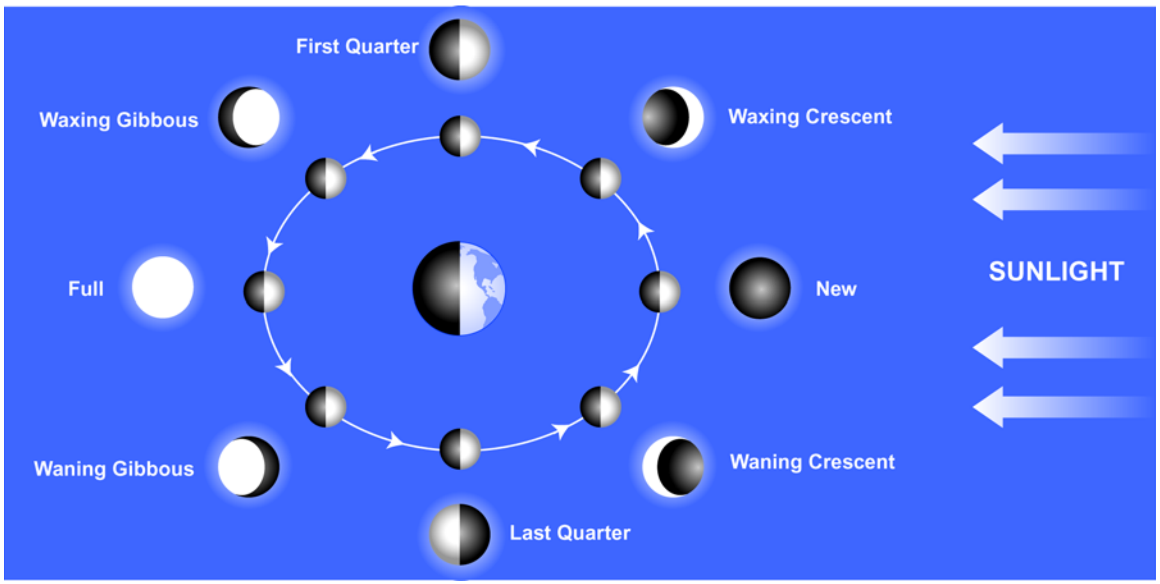


Figure 30.1: *How the moon appears from Earth in various phases.*

Orbits

The moon moves around Earth in a path called an *orbit*. The diagram below shows the positions of Earth and the sun in relation to the moon's orbit. Notice that the moon orbits in a counterclockwise direction. That is the same direction that Earth orbits the sun. How the moon appears to Earth dwellers at different positions in its orbit is shown in the diagram.



The *new moon* occurs when the moon is between Earth and the sun. A new moon is not visible in the sky because the lit side is completely facing the sun. A *full moon* occurs when the moon is on the opposite side of Earth from the sun and appears fully lit in the night sky. One complete lunar cycle, from new moon to new moon, takes 29.5 days to complete.

Dividing the year into equal parts

Days Earth's **axis** is the imaginary line that passes through its center and connects the North and South poles. Earth's spinning on its axis is called **rotation** (Figure 30.2) and it brings about day and night. If you have ever watched the sun travel during the day, you know that it appears to travel toward the west. This is because Earth rotates towards the east. It is this rotation that causes day and night. One complete rotation is called a *day.*

Years As Earth rotates on its axis, it also travels around the sun. The movement of one object around another in space is called **revolution**. Earth's path as it revolves around the sun is called its *orbit*. One *year* is the amount of time it takes Earth to complete one revolution around the sun. This is equal to 365.25 days.

Months You have read that the lunar cycle—from new moon to new moon—takes 29.5 days to complete. Early civilizations tried to use the lunar cycle as a sort of calendar. However, this did not help them predict annual events accurately because a year of lunar cycles adds up to only 354 days, not 365.25, leaving a balance of 11.25 days each year. Calendars that were based on the lunar cycle soon got ahead of astronomical cycles.

Where are the extra days? Ancient Egyptians were among the first to realize that lunar cycles were not an accurate way to divide up a year. They determined that a star called Sirius rose next to the sun every 365 days. This number of days also corresponded to the beginning of the annual flood of the Nile River. To account for the extra days in a year, they developed a calendar that had 12 months, each with 30 days, with an extra 5 days that were not part of any month.

The modern calendar That ancient Egyptian calendar added up to 365 days and eventually evolved into the calendar we use today. However, because we know that one year is approximately 365.25 days long, our calendar adjusts for this. It has eleven months with 30 or 31 days each, and one month—February—with 28 days. In a so-called leap year, February has 29 days. The extra day every four years makes up for the extra 0.25 days that occur each year.

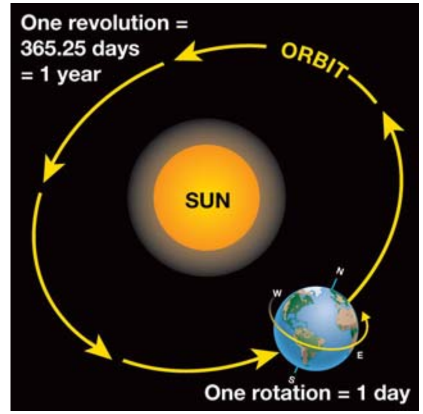


Figure 30.2: *Earth rotates on its axis.*

Counting the days in a year

Ancient cultures counted the number of days between celestial events to come up with the number of days in a year. For example, Egyptian astronomers counted the number of days between each first appearance of the star Sirius. The Mayans tracked the annual movements of the sun, moon, and planet Venus to determine the correct number of days in a year.

Dividing the day into equal parts

The time of day

A *clock* tells you the exact time of day and is used to mark the division of the day into equal parts. It may be hard to imagine, but there once was a time when humans did not need to keep track of the exact time of day. The rise and fall of the sun was the only "clock" that prehistoric humans needed to regulate their daily activities. It was not until about 5,000 years ago that ancient civilizations found the need to organize their time into units smaller than day and night.

Sundials

The ancient Egyptians were among the first to divide the day into parts that were similar to hours. As early as 3500 BC, monuments called *obelisks* were built to separate the day into parts. These monuments cast a shadow that moved during the day as the sun appeared to move across the sky. Markers were placed around the base of the monument to mark the subdivisions of time during the day (Figure 30.3). Obelisks evolved into *sundials* and these became more and more accurate. By 30 BC, different styles of sundials were in use in Greece, Asia, and Italy. However, sundials could only work during the day.

Water clocks

Water clocks were among the earliest timekeepers that could be used at night. One of the oldest was found in the tomb of an Egyptian pharaoh who died in 1500 BC. Early water clocks were stone containers with sloping sides that allowed water to drip at a constant rate through a small hole in the bottom. Markings on the inside surface of the container measured the passage of "hours." Greek water clocks divided the day into 12 hours and the night into 12 hours of unequal length to adjust for the change in the amount of daylight as the seasons changed.

Modern clocks

Today we divide each rotation of Earth into 24 equal parts called *hours*. Each hour is divided up into 60 parts called *minutes* and each minute into 60 parts called *seconds*. Like the water clock, modern clocks use a constant, repetitive action or process to keep track of equal increments of time. Where the water clock uses the constant dripping of water, modern clocks use a pendulum, vibrating crystal, balance wheel, electromagnetic waves, or even atoms to mark time. Quartz clocks and watches use the properties of a quartz crystal to provide very accurate vibrations. When electric current is applied to a quartz crystal, it vibrates at a regular frequency, depending on its shape and size.

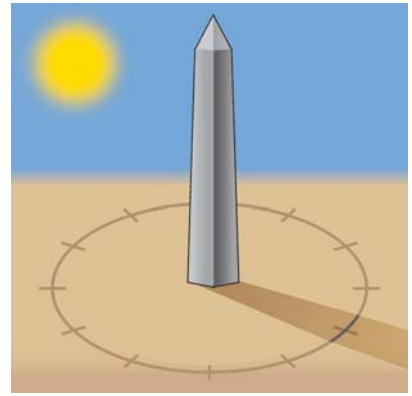


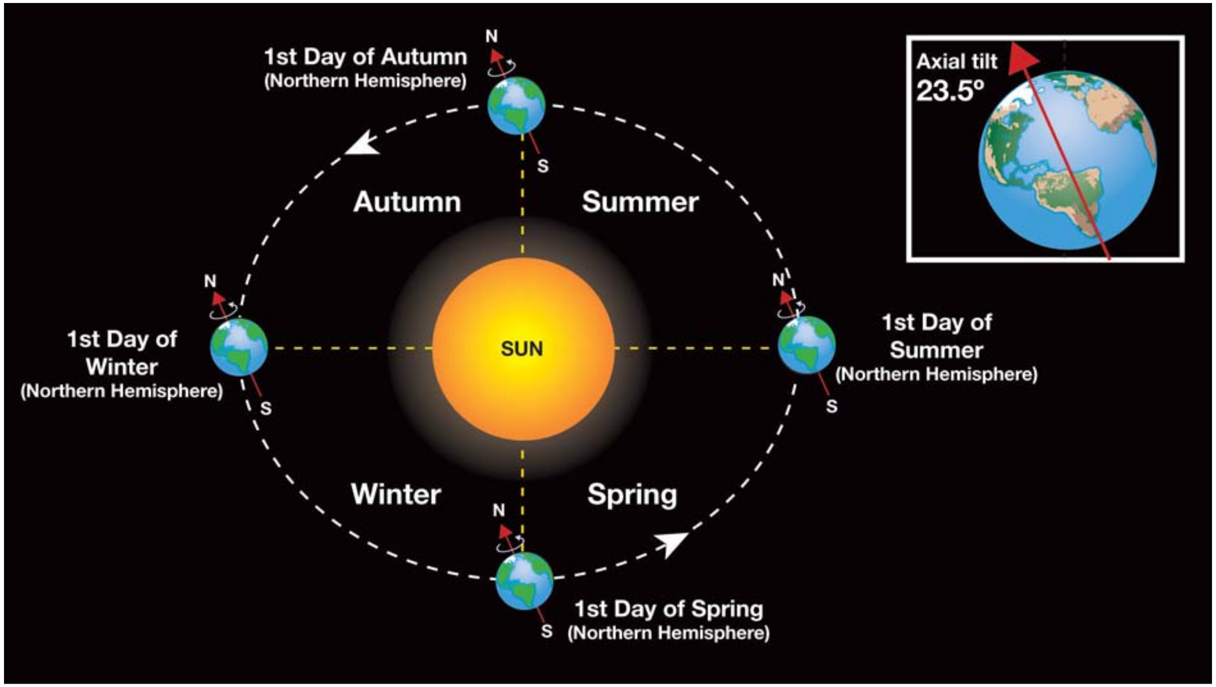
Figure 30.3: *An obelisk allowed ancient Egyptians to divide up the day into parts.*

Atomic clocks

In the United States, the official time is regulated by an *atomic clock* located in Washington, D.C. Atomic clocks keep time better than the rotation of Earth or the movement of the stars. Without them, the Internet would not synchronize and the position of planets would not be known with enough accuracy for space probes to be launched and monitored. These clocks are called atomic because they use the vibrations of a cesium atom as a reference.

What causes seasons?

Seasons As Earth revolves around the sun, we experience different seasons. Ancient civilizations realized that as the seasons changed, so did the path of the sun in the sky (or so it seemed to them). As you have learned, seasons are caused by the 23.5° tilt of Earth's axis with respect to the plane of its orbit around the sun. As Earth rotates around the sun, its axial tilt remains fixed.



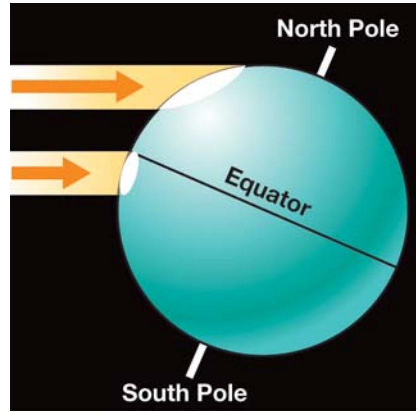


Figure 30.4: *During winter in the Northern Hemisphere, Earth's axial tilt is facing away from the sun. This means the sunlight in the Northern Hemisphere is be more spread out and less intense. Therefore, temperatures are lower in winter.*

The axial tilt causes the seasons During summer in the Northern Hemisphere, the north end of the axial tilt is facing *toward* the sun. This results in more direct sunlight and higher temperatures. Six months later, the north end of the axial tilt is facing *away* from the sun. The sunlight is spread more widely over the planet and thus is less intense, causing lower temperatures that bring winter to the Northern Hemisphere (Figure 30.4). The opposite happens in the Southern Hemisphere. The fact that Earth's axial tilt is fixed also explains why the position of the sun in the sky changes over the course of a year (Figure 30.5).

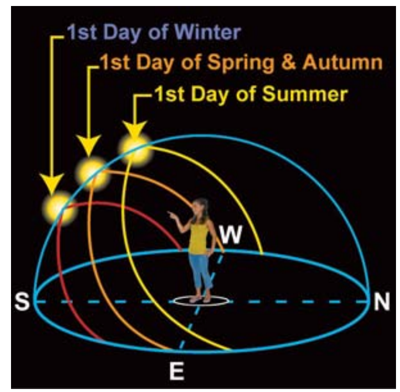


Figure 30.5: *The diagram shows the path of the sun across the sky during the year.*

What causes eclipses?

Eclipses When the sun shines on Earth or the moon, these objects cast shadows—just like you do when you stand in the sun. When Earth or the moon cross each other's shadow, an *eclipse* occurs. A **solar eclipse** occurs when the moon's shadow falls on Earth. A **lunar eclipse** occurs when Earth's shadow falls on the moon.

The moon's orbit is tilted If you look at the lunar cycle diagram on page 590, you may wonder why Earth's shadow doesn't cover the moon when it is between the moon and the sun. Instead, you get a full moon! The reason a lunar eclipse doesn't occur very often is that the moon's orbit is *tilted* at a 5° angle with respect to Earth's orbit around the sun as shown in Figure 30.6.

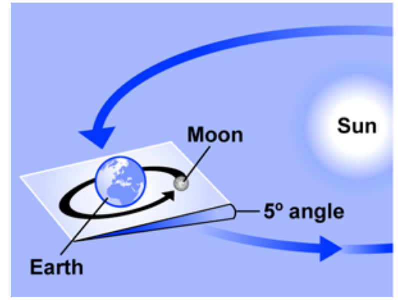
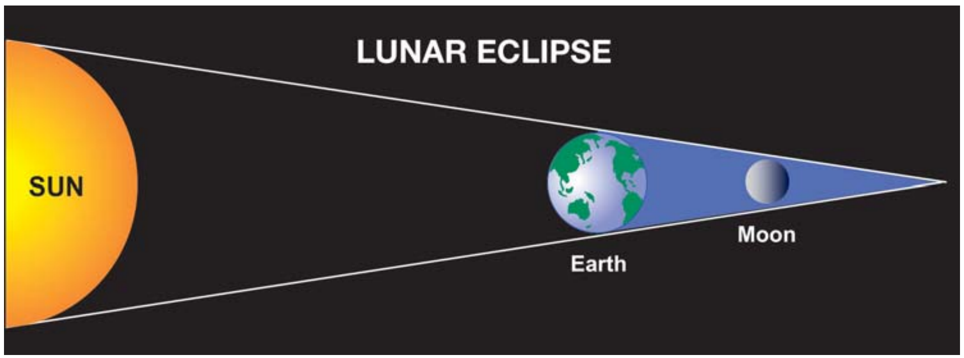


Figure 30.6: *The moon's orbit is tilted at a 5-degree angle with respect to Earth's orbit around the sun.*

Lunar eclipses Because of this tilted orbit, in most months, Earth's shadow does not block the sunlight from hitting the moon. However, sometimes the moon is perfectly aligned with Earth during a full moon. Because of this alignment, Earth's shadow temporarily blocks the sunlight from hitting the moon, causing a *lunar eclipse*. As the moon continues to move in its orbit, it gradually moves into a position where the sunlight hits it again.



Total and partial lunar eclipses A lunar eclipse can be total or partial and all observers on the dark side of Earth can see it at the same time. A partial eclipse occurs when only part of the moon falls in Earth's shadow. Also, during a lunar eclipse, the moon is still visible and appears reddish. Figure 30.7 shows an alignment for a partial eclipse.

Eclipses are a coincidence

The sun is 400 times larger in diameter than the moon. It is also 400 times farther away from Earth than the moon. Because of this coincidence, the sun and moon appear to be the same size in the sky. This is why total eclipses occur.

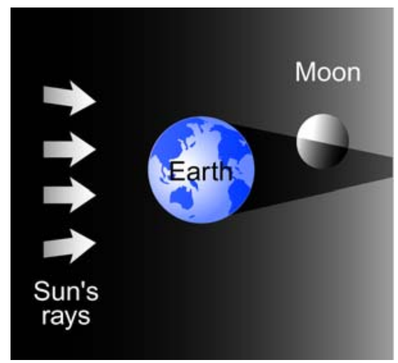
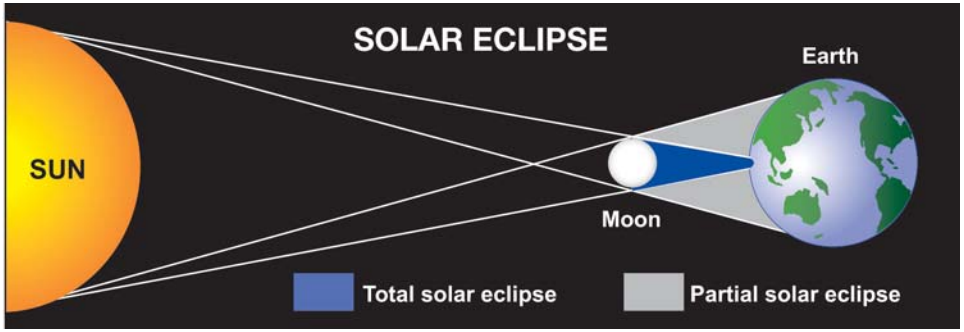


Figure 30.7: *A sun-Earth-moon alignment for a partial lunar eclipse.*

Solar eclipses

During a new moon (when the side of the moon that faces Earth is not lit by the sun), the moon is almost exactly between Earth and the sun. Most of the time, however, the moon travels just above or below the sun in the sky because of the 5° tilt of its orbit. During a *solar eclipse*, the new moon is directly between Earth and the sun and the moon's shadow hits part of Earth as shown below.



Total solar eclipse

The darkest part of the moon's shadow is cone-shaped and falls on only a small part of Earth's surface. Viewers in this region experience a total eclipse of the sun because the light is completely blocked by the moon. During a total eclipse, the sun gradually disappears behind the moon and then gradually reappears. This is because the moon revolves around Earth, so it gradually moves into the path of the sunlight, and then gradually moves out again. The sun is completely blocked by the moon's shadow for about two or three minutes.

Partial solar eclipse

In the diagram above, you can see that the moon casts a larger, lighter shadow on Earth's surface. Viewers in this region of the moon's shadow experience a partial eclipse. During this time, only part of the sun is blocked. You should NEVER look directly at the sun—even during a total or partial eclipse!

Benjamin Banneker

Benjamin Banneker was born in rural Maryland in 1731. His family owned a small farm. They were part of a group of about two hundred free men and women of African descent in Baltimore county.

Benjamin's grandmother taught him to read and write. He briefly attended a nearby Quaker school. Benjamin was especially fond of solving mathematical riddles and puzzles. Banneker sold produce at a nearby store owned by a man named George Ellicott. Ellicott loaned him books about mathematics and astronomy.

Banneker was soon recording detailed observations about the night sky. He performed complicated calculations to predict the position of planets and the timing of eclipses. From 1791-1797 he published his astronomical calculations along with weather and tide predictions. They were widely read across the eastern seaboard. Banneker served as an astronomer in surveying project and was appointed by President George Washington to assist in the layout of the District of Columbia.

30.2 Tools of Astronomy

You may think that astronomers spend most of their time looking at the sky through a telescope. While telescopes are an important part of the science, today's astronomers spend much of their time examining data and images on computer screens. In 1990, the Hubble Space Telescope was put into orbit around Earth. This powerful instrument constantly sends computerized images from space to Earth. Astronomers view these images on computer screens and then store the data for later use. Since the objects they observe are so far away, astronomers have developed their own units to measure them. What are the tools of astronomy? How do astronomers measure vast distances?

Figure 30.8: *The Hubble Space Telescope.*

Astronomical numbers

Scientific notation

When you look up at the night sky, do you ever think about how far away the stars are? The closest star to our sun, Alpha Centauri, is 41,000,000,000,000 kilometers away. As you can see, trying to write out such astronomical distances as 41 trillion requires a lot of zeros. **Scientific notation** is a mathematical abbreviation for writing very large (or very small) numbers. Using this method, numbers are written as a value between 1 and 10, multiplied times a power of 10. For example, the distance in the example above can be written as 4.1 x 10^{13} km. Here's a step-by-step example of how to write numbers in scientific notation. The steps are shown in Figure 30.9.

Example problem:

Earth is approximately 150,000,000 kilometers from the sun. Write this value using scientific notation:

Step 1: Move the decimal until you get a value that is between 1 and 10. Count the number of times you move the decimal.

Step 2: Write down the new number without all of the zeros.

Step 3: Write × 10 after the number.

Step 4: Write the number of times you moved the decimal as the power of 10 (the exponent). If you moved the decimal to the left, the exponent will be positive. If you moved the decimal to the right, the exponent will be negative.

Answer: Earth is approximately 1.5 × 10^8 km from the sun.

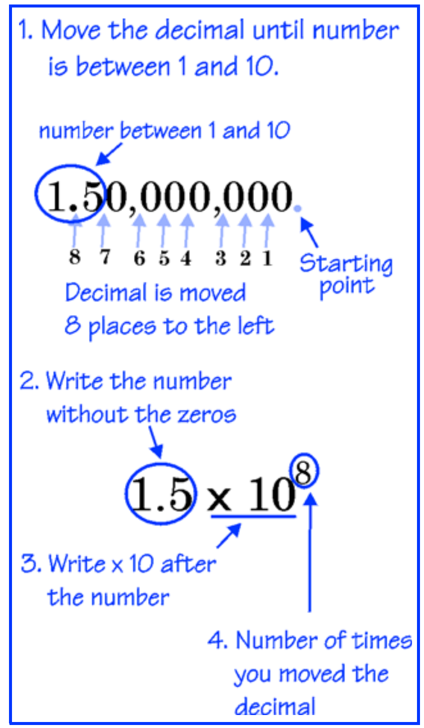


Figure 30.9: *Solving the example problem at left.*

How astronomers describe objects in space

What is the universe?

When you look up at the sky, what are some of the objects you see? You can see the sun and the moon and, on a clear night, many stars. If you watch the sky each night over a few months, you will notice that some of those "stars" change position over time and appear to wander in the sky. These are the planets that are part of our solar system—our own small corner of the *universe*. The **universe** is defined as everything that exists, including all matter and energy.

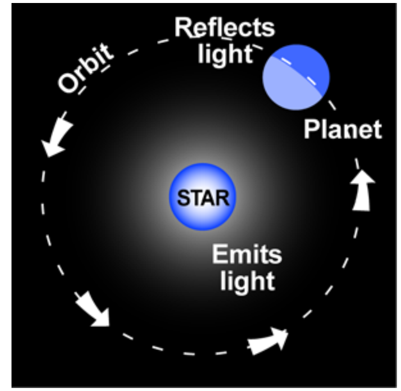


Figure 30.10: *A planet revolves around a star. Stars emit light and planets reflect light.*

Planets and stars

A **star** is a sphere of gas that undergoes a process called *fusion*. Because this process releases so much energy, stars give off a bright light. A **planet** is a large, spherical piece of matter that revolves around a star. On a clear night, you can see thousands of stars, but only five planets can be seen with the unaided eye. These are Mercury, Venus, Mars, Jupiter, and Saturn. If you look through a telescope, these planets appear larger than stars. Without a telescope, they give off a steady light, whereas stars appear to "twinkle." We can see the planets because they reflect light from the sun back to Earth. Unlike stars, they do not emit their *own* light. The table below compares planets and stars.

Table 30.1: ***How to tell the difference between a planet and a star***

Feature	Planet	Star
Distance from Earth	Relatively close	Very far (except for the sun)
Appearance in the sky	Gives off a steady light	Appears to "twinkle"
Long-term movement	Slowly wanders in the sky alone	Appears to move in a group
Source of light	Reflects light from the sun	Emits its own light

Galaxies

A **galaxy** is a huge collection of gas, dust, and billions of stars. These stars are attracted to each other by the force of gravity and are constantly in motion. If you look at the sky on a clear night, you can see what appears to be a milky-white trail across the stars. You are looking at part of the Milky Way—the galaxy to which we belong. Our galaxy contains at least 200 billion stars! Our location in the Milky Way galaxy is shown in Figure 30.11. The only way to observe other galaxies in the universe is with a very powerful telescope. Many galaxies have a spiral shape much like the Milky Way's.

Figure 30.11: *Our location in the Milky Way galaxy.*

Units of distance in space

What is a light year? As you have read, distances in space are huge. Because of this, scientists have developed units other than kilometers or meters to measure them. You may have heard of *light years* (ly), one of the most common astronomical terms. Even though the name may sound like it, this unit does not measure time. One light year is equal to the *distance* that light travels through space in one year.

Calculating a light year In space, light travels at the amazing speed of 300,000 kilometers per second. How far will it travel in one year? Recall that *speed* = distance ÷ time. This means we can calculate the distance light travels in one year by multiplying the speed of light by time (by rearranging the variables). However, to get the correct value, we must also convert seconds into years since the value for the speed of light contains seconds. Here's how to solve this problem:

$$\begin{aligned}
\text{1 light year (ly)} &= \text{speed of light} \times \text{time} \\
&= (300{,}000\ \text{km/sec}) \times \left(1\ \text{year} \times \frac{365\ \text{days}}{1\ \text{year}} \times \frac{24\ \text{hours}}{1\ \text{day}} \times \frac{3600\ \text{sec}}{1\ \text{hour}}\right) \\
&= (300{,}000\ \text{km/sec}) \times (31{,}536{,}000\ \text{sec}) \\
&= 9{,}460{,}000{,}000{,}000\ \text{km} \quad \text{or} \quad 9.46 \times 10^{12}\ \text{km}
\end{aligned}$$

A light year is the distance light travels in one year through space (9.46 × 10^{12} kilometers).

Unit conversion How many light years away is Alpha Centauri, the closest star to our sun? We already know that it is 4.1 x 10^{13} km away. We also know that one light year is equal to 9.46 × 10^{12} km. Using unit conversion, we get:

$$4.1 \times 10^{13}\ \cancel{\text{km}} \times \frac{1.0\ \text{ly}}{9.46 \times 10^{12}\ \cancel{\text{km}}} = 4.3\ \text{ly}$$

Can you see why light years are more useful to astronomers than kilometers?

Object	Distance from Earth (light years)
Sirius (brightest star in the sky)	8.8
Betelgeuse (appears as a red star in the sky)	700
Crab Nebula (remnant of an exploded star)	4,000
Andromeda galaxy	2.3 million

Figure 30.12: *Distance from Earth (in light years) of some well-known objects in the universe.*

Think about it...

When you look at Alpha Centauri in the night sky, how "old" is the light you are seeing? In other words, how long did it take that light to get to Earth? The answer is easy if you use your head. Think about the definition of a light year and you'll figure out the answer! HINT: This star is 4.3 light years away.

Observing distant objects

Light years and time

The blue box on the previous page points out an interesting phenomenon about observing distant objects. Since most objects in space are hundreds, even billions of light years away, the light we see is as old as the number of light years the object is from Earth. For example, the light we see from Alpha Centauri left that star 4.3 years ago. This means that when we look at the light from stars or other objects in space, we are actually looking back in time. When astronomers use a powerful telescope to view the Andromeda galaxy, they are looking back in time 2.3 million years (Figure 30.13)!

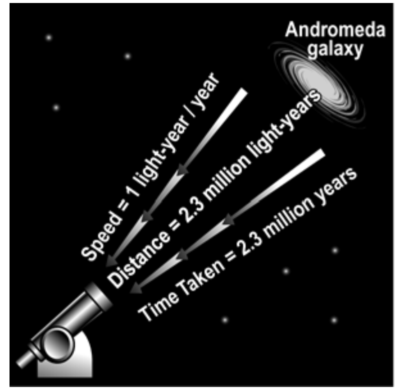


Figure 30.13: *When astronomers use a powerful telescope to look at the Andromeda galaxy, they are looking back in time 2.3 million years.*

Time as a tool of astronomy

As astronomers view distant objects in space, they are actually studying ancient history. The farther away the object they are viewing, the further back in time they are looking. This fact has become an important tool that astronomers use to piece together how the universe began, and how it has changed over time. For example, by comparing stars that are relatively near with stars that are very far away, astronomers can develop theories about the life cycle of stars, including how they begin, how long they "live," and what happens when they "die."

Problem: Communication delays in space

The problem

In 1969, Neil Armstrong and Buzz Aldrin were first to land a lunar module on the moon, 384,400 kilometers from Earth. You may have heard Armstrong's famous phrase, spoken when he stepped out of the module onto the moon's surface: "That's one small step for man, one giant leap for mankind." When he spoke, he was not heard immediately on Earth because of the moon's distance. How long did it take the radio waves to travel to Earth so that those words could be heard by millions of viewers? (HINT: Radio waves travel at the speed of light.)

What do you know?

You know that the *distance* from the moon to Earth is 384,400 kilometers. The *speed* of light is 300,000 kilometers per second. Since speed is distance divided by *time*, you can rearrange the variables to solve for this quantity. Figure 30.14 shows the solution to the problem.

1. Equation

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

2. Rearrange variables to solve for time

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

3. Plug in the numbers and solve

$$\text{time} = \frac{384{,}400 \text{ km}}{300{,}000 \text{ km/sec}}$$

$$= 1.28 \text{ seconds}$$

Figure 30.14: *Solving the problem.*

Telescopes

History of the telescope

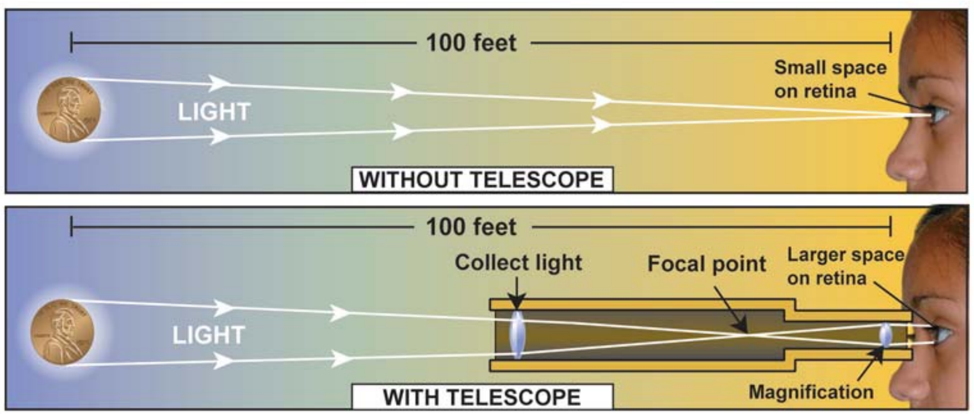
Before the invention of the telescope, the human eye was the primary instrument for observing the night sky. In the 1600s, Galileo was the first to use a telescope for astronomical observations. He observed craters on the moon, tiny moons around Jupiter, and the rings of Saturn (which he thought looked like "ears"). Since then, astronomers have developed increasingly powerful telescopes that continue to add to our knowledge of the universe.

What is a telescope?

A **telescope** is a device that makes objects that are far away appear closer. Telescopes come in many different shapes and sizes, from a small tube weighing less than a pound, to the Hubble Space Telescope, weighing several tons. Most of the telescopes used today are of two types; **refracting telescopes** use *lenses* and **reflecting telescopes** use *mirrors*. Both types accomplish the same thing, but in different ways.

How does a telescope work?

Have you ever tried to read the writing on a penny from 100 feet away? The reason you cannot read it with your naked eye is that the image of a penny from 100 feet away does not take up much space on your retina (the screen of your eye). Telescopes work by collecting the light from a distant object with a lens or mirror and bringing that light into a concentrated point, called the *focal point*. The bright light from the focal point is then magnified by another lens so that it takes up more space on your retina. This makes the object appear much larger and closer.

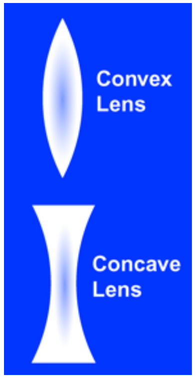


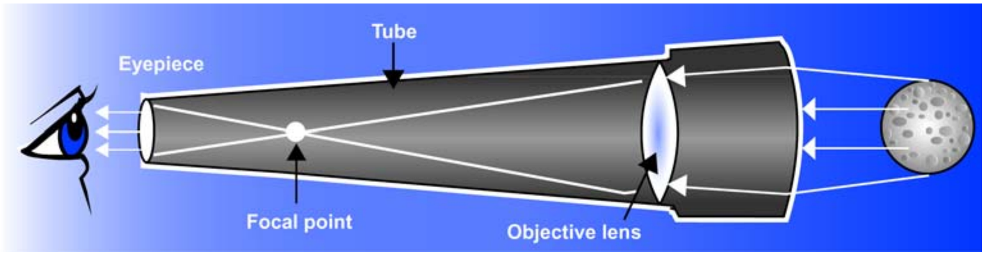
Telescope milestones

3500 BC Phoenicians discover glass while cooking on sand.
1350 Craftsmen in Venice begin making lenses for spectacles.
1608 Hans Lippershey applies for a patent for the refracting telescope.
1609 Galileo is the first to use a telescope to view craters on the moon.
1704 Newton invents the reflecting telescope.
1897 World's largest refracting telescope built and housed in Yerkes Observatory, Wisconsin.
1990 The Hubble Space Telescope is launched from the space shuttle Discovery.

Refracting telescopes

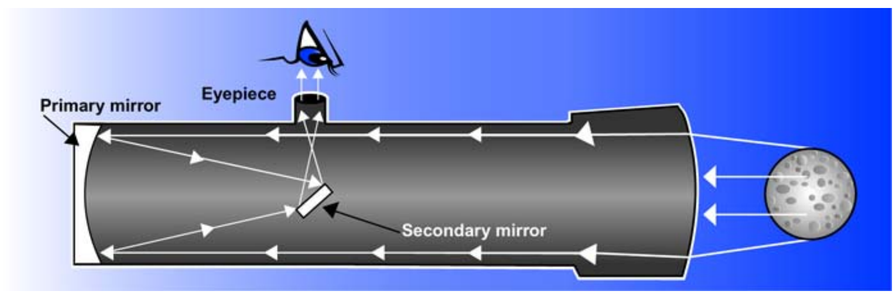
Refracting telescopes use lenses to bend, or refract light, making objects look bigger. They are made from a long *tube*, a glass *objective lens* that you point toward the sky, and an *eyepiece*—another glass lens that magnifies the object. The tube holds the two lenses the correct distance from one another. The objective lens is *convex*, that is, wider in the middle than at the edges. This lens gathers light from an object, and bends it to a focal point near the back of the tube. The eyepiece lens can be either convex or *concave* (thinner in the middle and wider at the edges). The picture below shows how light rays travel through a refracting telescope to your eye.





Reflecting telescopes

Reflecting telescopes use mirrors instead of lenses to gather and focus light. Isaac Newton developed this type of telescope in 1680. A mirror is made by coating the surface of a concave lens with a reflecting material. This mirror (called the primary mirror) is placed at the back of a tube. Light rays enter the tube and are reflected off the primary mirror to a focal point. Another small, flat mirror (the secondary mirror) is placed in the path of the focal point at an angle that deflects the light rays to an eyepiece, located at the side of the tube. The eyepiece performs the magnification of the image, just like in a refracting telescope. Because the secondary mirror is so small compared with the primary mirror, it only blocks a small fraction of light entering the telescope.



Arthur Walker

Arthur Walker was born in 1936. Arthur was an excellent student. He decided to take the entrance exam for the Bronx High School of Science. Arthur passed the exam, but when he entered the school a teacher told him that the prospects for an African-American scientist were bleak. Arthur's mother visited the school and told them her son would pursue whatever course of study he wished.

Walker went on to earn a Ph.D. in physics from the University of Illinois. He spent three years in the Air force, designing a rocket probe and satellite experiment to measure radiation that affects satellite operation. Later, Walker worked to develop the first X-ray spectrometer used aboard a satellite. It helped determine the temperature and composition of the sun's corona.

In 1974, Walker joined the faculty at Stanford University. There he used a new multilayer mirror technology to develop telescopes that were launched into space on rockets. The telescopes produced detailed pictures of the sun and its corona, bringing about significant changes in our understanding of them.

Other types of telescopes

Electromagnetic waves

So far, the telescopes you have read about collect and focus visible light. Visible light is a type of *electromagnetic wave*. Objects in the universe give off many other types of electromagnetic waves that we cannot detect with our eyes, including radio waves, infrared waves, and X rays. These waves all travel at the speed of light in space and have energies (frequencies) that increase as their wavelengths become smaller. Astronomers use different types of telescopes to view the different types of waves emitted by objects in space.

Radio telescopes

A *radio telescope* works like an extremely powerful receiver that picks up radio waves from space. Astronomers aim these telescopes toward an object such as a star and tune them until they receive waves in the correct frequency. The information is analyzed by a computer which draws an image of the source of radio waves. Astronomers use radio telescopes to produce images of stars and galaxies, analyze the chemical composition of objects, and map the surfaces of planets. Figure 30.15 shows an image of the Crab Nebula (the remnants of an exploded star) taken by a radio telescope (*Photo courtesy Very Large Array/ National Radio Astronomy Observatory)*.

Infrared telescopes

Another type of telescope looks at infrared waves. Since this type of wave is mostly absorbed by Earth's atmosphere, *infrared telescopes* are often placed on satellites that orbit above Earth. In 1983, the Infrared Astronomical Satellite (IRAS) was launched to map the entire sky at infrared wavelengths. It discovered a new comet, found evidence of another solar system, and discovered a new type of galaxy. Figure 30.16 shows an image of the Crab Nebula captured by an infrared telescope (*Photo courtesy NASA/IRAS*).

X-ray telescopes

X-ray telescopes are designed to detect high-energy radiation (X rays) from space. Since these waves cannot penetrate our atmosphere, x-ray telescopes are always placed on satellites. One of the most powerful, NASA's Chandra X-ray Observatory, was launched on the space shuttle Columbia in 1999. Its mission is to observe X rays that are emitted by high-energy objects in the universe such as stars that have exploded. Figure 30.17 shows an image of the Crab Nebula captured by an x-ray telescope (*Photo courtesy NASA/Chandra*).

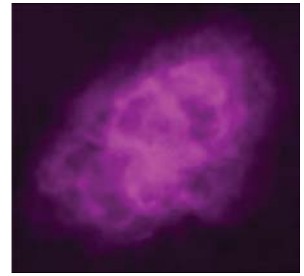


Figure 30.15: *An image of the Crab Nebula taken by a radio telescope.*

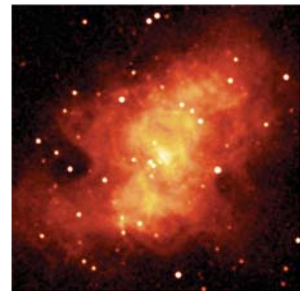


Figure 30.16: *An image of the Crab Nebula taken by an infrared telescope.*

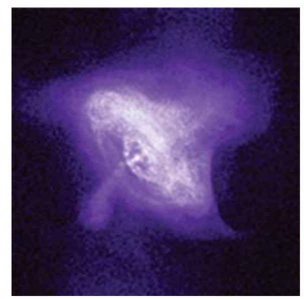


Figure 30.17: *An image of the Crab Nebula, taken by an x-ray telescope.*

Satellites and other spacecraft

Satellites

A **satellite** is an object that travels in orbit around another object. The moon is a natural satellite that orbits Earth. On Oct. 4, 1957, the former Soviet Union launched Sputnik I, the first *artificial* satellite to orbit Earth. Since then, hundreds of satellites have been launched. These important tools of astronomy (and many other sciences) continuously send data back to computers on Earth for analysis.

The Hubble Space Telescope

The Hubble Space Telescope (or HST) is a satellite that orbits Earth. This powerful telescope, placed out of reach of "light pollution," constantly sends images from deep space to computers back on Earth. A NASA image captured by the HST is shown below. Most of the objects in the image are not stars, which appear to have "spikes"—but galaxies, most of them *billions* of light years away! Since this image shows only a tiny fraction of the sky, what does it tell you about the number of galaxies that may be found in the universe?

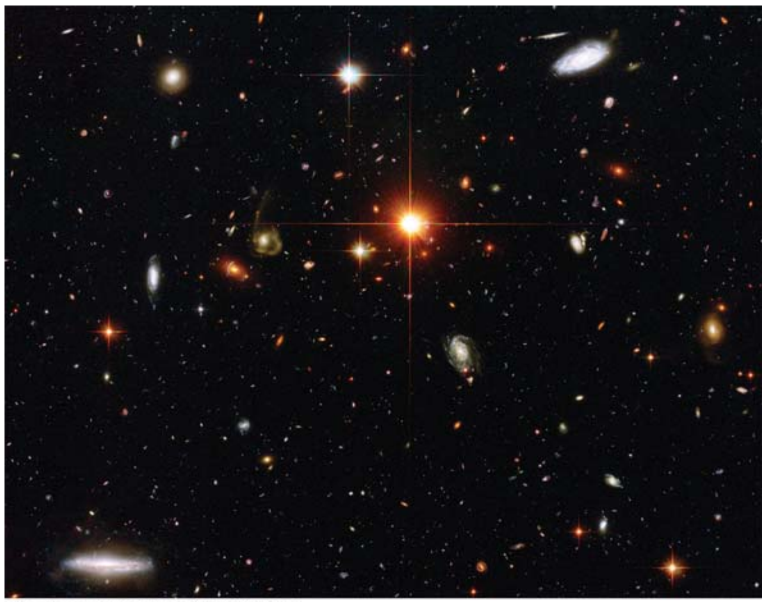


Photo courtesy of NASA/HST

Remote sensing

Many satellites are designed for low Earth orbit, at altitudes between 200 and 1,000 kilometers. One of the chief functions of these satellites is remote sensing, or making observations from a distance. Images of Earth's atmosphere and surface are created from different types of electro-magnetic waves. For example, radio waves can pass through clouds so images can be made of events that may be otherwise hidden. Infrared waves can be used to monitor vegetation or temperature differences in air and water. Weather forecasters rely on satellite images of clouds in order to predict the weather and warn of approaching storms. Many of these satellites travel at speeds of 28,000 kilometers per hour and orbit Earth in about 90 minutes!

Space probes

Space probes are unmanned spacecraft that carry scientific instruments on board. Since the early 1970s, they have helped astronomers make many discoveries about our solar system. Space probes are not designed to return to Earth, but many have landed on other planets. Others have flown past planets, taking pictures as they go. Still others have remained in orbit around a planet for long periods of time to study them in great detail. Space probes have landed on—or at least flown near—every planet but Pluto. Table 30.2 lists some NASA probes and their missions.

Table 30.2: ***Some NASA planetary space probes and their missions***

Planet	Probe and launch year	Primary mission and year(s)
Mercury	Mariner 10 (1973)	Mercury flyby (1974-75)
Venus	Magellan (1989)	Radar mapping of the planet surface (1990-94)
Mars	2001 Mars Odyssey (2001)	Map chemical makeup of Mars' surface (2002-04)
Jupiter	Galileo (1989)	Orbit Jupiter and some of its moons (1995-97)
Saturn	Cassini (1997)	Orbit Saturn and send a probe to its moon Titan (2004)
Uranus	Voyager 2 (1977)	Uranus flyby (1986)
Neptune	Voyager 2 (1977)	Neptune flyby (1989)
Pluto	New Horizons (future mission)	Pluto flyby (estimated 2006)

Piloted spacecraft

In April 1961, Yuri Gagarin of the former Soviet Union was the first human to travel in space, followed on May 5 by Alan Shepard of the United States. This led to the NASA Manned Lunar Program known as *Apollo* from 1963-72 in which humans successfully landed on the moon. Since Apollo, we have not sent humans back to the moon, or to any other bodies in space, mainly because of the cost of such missions. However, piloted spacecraft are still useful tools of astronomy.

Space shuttles and stations

Space shuttles are piloted spacecraft that launch from rocket "boosters" and can land back on Earth like an airplane. Developed by NASA, they are used to conduct experiments in space, to launch and repair satellites, and to transport people to and from *space stations*, such as the International Space Station (or ISS). The ISS is a joint project of six nations that orbits 450 kilometers above Earth's surface. On board, scientists conduct numerous experiments, many of which depend on constant freefall (microgravity) conditions provided by the space station.

Voyager 1 and 2

Launched in 1977, the NASA Voyager 1 and 2 probes have traveled farther from Earth than any other man-made object. Both have completed their missions and are currently headed toward the boundary where the sun's gravitational force is no longer dominant. They travel at an amazing speed of 17 kilometers per second (38,000 miles per hour)! Voyager 1 is now more than twice as far from Earth as Pluto. Both Voyagers are still sending information back to Earth via radio waves. These signals are picked up by a powerful array of radio telescopes called the Deep Space Network.

Figure 30.18: *The International Space Station (or ISS).*

How does a space shuttle work?

What is a space shuttle? The first space shuttle, *Columbia*, was launched on April 12, 1981, in Florida. After a space flight lasting more than 36 hours, it made a perfect landing in California. Before the shuttles, manned spacecraft were not reusable. Space shuttles have the ability to be launched like a rocket, orbit Earth like a satellite while performing missions, and land on a runway like an airplane.

Shuttle components A space shuttle consists of three big components: two *solid rocket boosters* (SRBs), an *external fuel tank*, and an *orbiter* (Figure 30.19). The orbiter looks similar to an airplane and contains a flight deck, living quarters, and a cargo bay for transporting objects such as satellites to and from space.

Launching a shuttle The SRBs provide most of the force required to lift the 4.5-million-pound shuttle off the launch pad. In addition, the orbiter has three main engines that burn the liquid hydrogen and oxygen fuel stored in the external fuel tank. Two minutes after launch, the SRBs separate from the orbiter and fall back to Earth on parachutes. These can be reused. After eight minutes, the external fuel tank drops away and the orbiter's main engines stop firing.

Why does a shuttle orbit? At this point, the orbiter is 250 kilometers above Earth and is moving at a speed of 28,000 kilometers per hour. Because its engines are no longer thrusting, it does not continue to travel *away* from Earth. To do this would require higher speeds. Instead, the orbiter is pulled toward Earth by the force of gravity as it moves forward at a constant speed. The combination of the pull of gravity downward and the forward motion at a constant speed, causes it to fall *around* Earth, not into it. Because there is no friction in space, the orbiter requires no fuel to maintain its orbit speed. This follows Newton's first law of motion.

Returning to Earth When the crew is ready to return to Earth, the orbiter is turned around to face the opposite direction. Small engines are fired in the rear of the orbiter to slow it down so that it begins to fall back *toward* Earth instead of around it. As the orbiter enters the atmosphere, thick tiles protect it from the heat generated by air friction. The air resistance slows the orbiter down as it glides down to Earth's surface. The orbiter uses wheels to land on a runway just like a plane. The space shuttle orbiter can be reused about 100 times before it is retired.

SHUTTLE PARTS

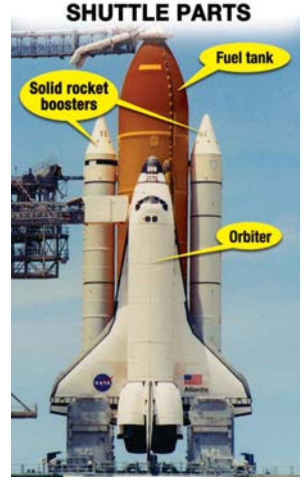


Figure 30.19: *Anatomy of a space shuttle.*

Figure 30.20: *A complete shuttle mission, from launch to landing.*

Chapter 30 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. orbit
2. rotation
3. revolution
4. light year
5. eclipse

a. device that divides the day into equal parts
b. causes day and night to occur on Earth
c. the movement of one object around another in space
d. the path followed by an object as it revolves around another object
e. the distance light travels in one year
f. when the moon's shadow falls on Earth or Earth's shadow falls on the moon

Set Two

1. galaxy
2. refracting telescope
3. universe
4. star
5. reflecting telescope

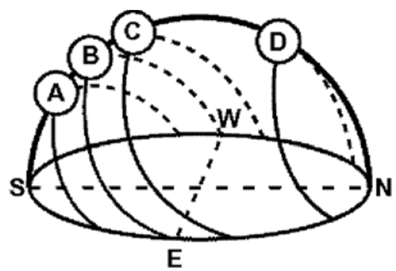
a. a single body that emits enormous amounts of energy
b. everything that exists including all matter and energy
c. a large, spherical piece of matter that revolves around a star
d. a device that uses only lenses to focus and magnify light rays from an object
e. a huge collection of gas, dust, and billions of stars
f. a device that uses mirrors and lenses to focus and magnify light rays from an object

Concept review

1. Name two examples of astronomical cycles. For each, describe an event that is directly related to it. *Example: Moon revolves around Earth, resulting in the phases of the moon.*
2. What is a leap year? Why does a leap year occur every four years?
3. Since the moon does not produce its own light, how can you see it?
4. The lunar cycle is closely related to which part of our calendar—a year, a month, or a day?
5. Explain how you could use the shadow of a lamp post to track the time of day on a sunny day.
6. Explain the difference between solar and lunar eclipses.
7. Why is scientific notation often used in astronomy?
8. Name three differences between planets and stars.
9. Why are light years used to measure distances to stars instead of kilometers?
10. What is the difference between a refracting telescope and a reflecting telescope?
11. Explain the difference between a radio telescope and an infrared telescope.
12. What are the advantages to placing a telescope on a satellite?

Problems

1. During one revolution around the sun, how many rotations of Earth occur?
2. How long does it take Earth to revolve around the sun in *seconds*? Show all of your math.
3. The Romans used a calendar with 365 days in a year (instead of the actual 365.25 days). How many days off would their calendar be after four years? Eight years? 300 years?
4. Match the letters on the diagram with the correct terms. You may use a letter more than once



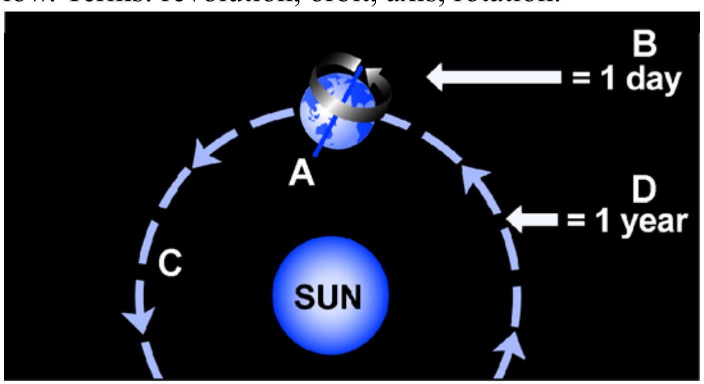
_____First day of summer

_____First day of winter

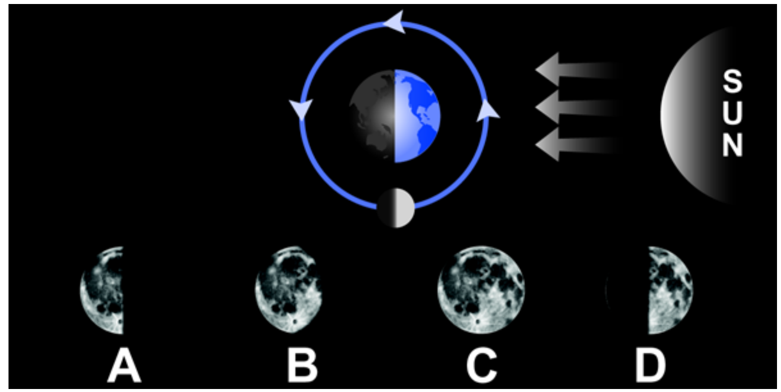
_____First day of spring

_____First day of autumn

5. Match each term with its corresponding letter on the diagram below. Terms: revolution, orbit, axis, rotation.



6. How would the moon appear from Earth if it were in the position shown in the diagram below?



7. Write the following values using scientific notation:
   a. 156,000,000,000 kilometers
   b. 18.5 pounds
   c. 0.0000000000000000000000025 centimeter
   d. 47,000,000,000,000 kilometers
   e. .0027 seconds
   f. 1.5 kilogram
   g. 93,000,000 miles
   h. 17,000 light years

8. Complete the table below by converting the distances to kilometers. You should use scientific notation in your answers:

Object	Distance from Earth (light years)	Distance from Earth (km)
Sirius (a star)	8.8	
Betelgeuse (a star)	700	
Crab Nebula (exploded star)	4,000	
Andromeda galaxy	2.3 million	

9. Suppose the sun suddenly burned out. How long would it take, in minutes, before we noticed this had occurred? (HINT: The speed of light is 300,000 km/sec and the distance of Earth from the sun is 150 million km).

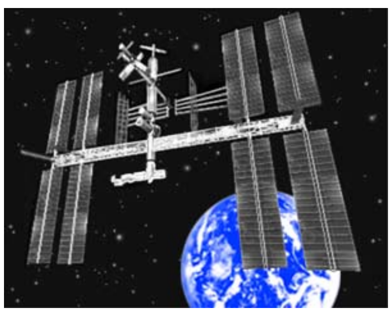
10. In 1989, the space probe Voyager II reached the planet Neptune and began sending images of the planet back to Earth. Assuming these radio waves had to travel about 4.0×10^9 km, how long did it take, in minutes, before astronomers received the signals from Voyager 2? (HINT: Radio waves travel at the speed of light—300,000 km/sec.)

Applying your knowledge

1. You have read that scientists conduct experiments on board the International Space Station that depend on the constant freefall (microgravity) conditions that this environment provides. Use the Internet to find out about one of these experiments. Identify the research question, hypothesis, procedures, and results of the experiment. Develop a poster presentation about the experiment for your class. Some good Web sites include:

   www.nasa.gov

   spaceflight.nasa.gov



2. Our ancestors used their observations of the sky to explain many aspects of their lives including religion, philosophy, science, and architecture. For example, many different Native American tribes planned and arranged buildings to correlate directly with the alignment of Earth, the moon, and the sun. Choose an ancient culture, and prepare a short paper that describes how astronomy influenced the lives of its people. Some cultures include: Mayan, Aztec, and the Navajo tribe.

3. Search the Internet for satellite images of your community. Find an image taken by each of the following types of electromagnetic radiation: visible light, radio waves, and infrared. What kinds of information does each type of image provide? What are the scientific uses for each type of image? Some good Web sites include:

   www.ghcc.msfc.nasa.gov

   www.ssec.wisc.edu/data

   mapping.usgs.gov

UNIT 11 Astronomy

Chapter 31

The Solar System

Introduction to Chapter 31

The solar system is our own little neighborhood in the universe. It consists of the sun surrounded by nine planets and numerous other objects. This chapter is about relationships between planets, their moons, and the sun. Why do planets and moons stay in orbit? How do Earth and the moon interact? What is the sun and how does it create so much energy?

31.1	**Earth and Moon**	*What does the length of a year have to do with Earth's distance from the sun?*

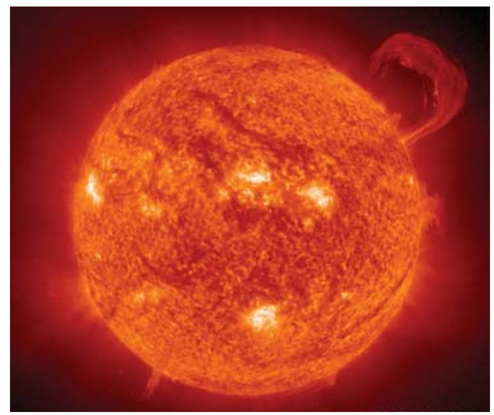
Why does the moon orbit Earth and Earth orbit the sun? In this Investigation, you will explore how objects stay in orbit. You will also discover how the orbital period of an object varies with its distance from the object it orbits, and the relationship between mass and orbital speed.

31.2	**The Solar System**	*How big is the solar system?*

Scale models are used to visualize large distances. For instance, the globe is a scale model of Earth, and maps are scale models of regions. To visualize distances in the solar system you will create a scale model. This model will help you visualize the true distances and sizes of objects in the solar system.

31.3	**The Sun**	*How can we use energy from the sun to generate electricity?*

We can harness the sun's energy in many ways. For example, a photovoltaic cell is used to convert sunlight directly into electricity. In this Investigation, you will explore how a photovoltaic cell works. You will also measure the power output of a photovoltaic cell and determine its efficiency.



Learning Goals

In this chapter, you will:

- ✔ Describe how Earth's dimensions were determined.
- ✔ Use the equation of universal gravitation to determine mass and gravitational force.
- ✔ Explain why the moon stays in orbit around Earth.
- ✔ Describe the moon's formation.
- ✔ Define the solar system in terms of gravity.
- ✔ Characterize the planets in terms of size, distance from the sun, atmosphere, and period of orbit.
- ✔ Name and describe other objects found in the solar system.
- ✔ Describe the size and composition of the sun.
- ✔ Explain the process through which the sun produces energy.
- ✔ Identify and define the parts of the sun.
- ✔ Explain how the sun's energy can be harnessed.
- ✔ Describe how a photovoltaic cell works.

Vocabulary

asteroid	gravitational force	orbital speed	solar system
astronomical unit	law of universal gravitation	satellite	sunspots
comet	meteor	solar constant	terrestrial planets
gas planets	orbit	solar energy	tides

31.1 Earth and Moon

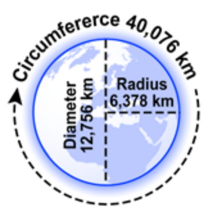
Earth is one of nine planets that along with numerous other smaller objects revolve around the sun in our solar system. It is approximately 150 million kilometers from Earth to the sun. Revolving around Earth at a distance of 384,400 kilometers is our only moon. Since the invention of spacecraft, our knowledge of Earth and the moon has grown tremendously. In this section, you will learn important information about Earth and the moon that will help you understand the rest of the solar system.

How fast are we moving?

To make a full rotation in 24 hours, Earth must spin at a speed of 1000 miles per hour. Earth also revolves around the sun. Since it is 93 million miles away, the total distance Earth must travel through one complete trip around the sun is close to 600 million miles. Since Earth travels this distance in only 365.25 days, its average speed is 66,000 miles per hour!

Earth dimensions

How big is Earth?



Earth's shape is almost spherical except for a slight bulge at the equator. If you were to travel exactly once around along the equator, you would travel 40,076 kilometers. This distance is the *circumference* of Earth. The *diameter*, or the distance through the center, is 12,756 kilometers and its *radius* at the equator is equal to half of this value, or 6,378 kilometers. Because of its slight bulge at the equator, if you were to measure the radius from one of the poles it would be slightly less (6,357 kilometers). Our current knowledge of Earth's dimensions comes mostly from satellite data, but how were its dimensions determined before this technology existed?

Eratosthenes and the circumference of Earth

More than 2,000 years ago, Greek astronomers knew that Earth was spherical. Eratosthenes was the first astronomer to discover a way to measure the circumference of the planet's sphere. He made a precise measurement of Earth's circumference by using *indirect measurement*. On the first day of summer in Seyene, Egypt, he could see the reflection of the sun at the bottom of a deep, narrow well. This meant the sun was *directly* overhead. Exactly one year later, he measured the angle of the sun's rays in Alexandria, which was 787 kilometers due south of Seyene. The angle he measured was 7.2 ° from the vertical. From this, he was able to compute the circumference of Earth using the following relationship:

$$\frac{7.2^\circ\,(^\circ\text{from Syene to Alexandria})}{360^\circ\,(^\circ\text{in a circle})} = \frac{787\,\text{km (distance from Syene to Alexandria)}}{x\ \text{(circumference of Earth)}}$$

$$x = \frac{360^\circ \times 787\,\text{km}}{7.2^\circ} = 39{,}350\,\text{km}$$

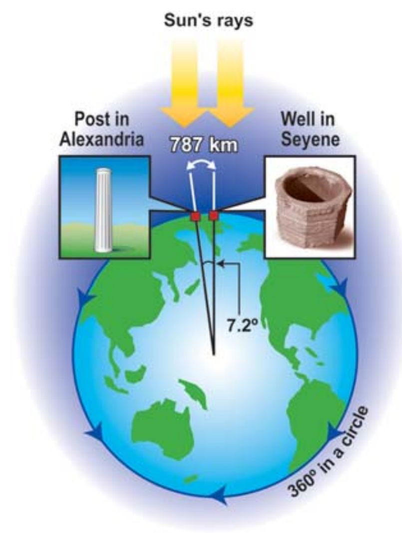


Figure 31.1: *How Eratosthenes figured out Earth's circumference.*

Mass and density of Earth

Law of universal gravitation

One of Isaac Newton's greatest discoveries helped astronomers solve other mysteries about Earth. He discovered that the force of gravity acting between two objects depends only on their masses and distance apart. This discovery, known as the law of universal gravitation, can be expressed as the following equation:

Equation of Universal Gravitation:

$$F = G\frac{m_1 m_2}{R^2}$$

Force (N)
Mass 1 (kg)
Mass 2 (kg)
Gravitational constant (6.67×10^{-11} N•m²/kg²)
Distance between mass 1 and mass 2 (m)

Determining Earth's mass

Newton's discovery helped scientists determine Earth's *mass*. That is because the law of universal gravitation provides all of the information needed to find this quantity (Figure 31.2). For example, Earth exerts a force (F) of 9.8 newtons on a 1-kilogram object (m_1) placed on its surface. The distance between the object and Earth (R) is equal to Earth's radius (6.4×10^6 meters). Since G (Newtonian constant of gravitation) is a constant, we can find Earth's mass (m_2):

$$9.8\,\text{N} = \left(6.67\times10^{-11}\,\frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}\right)\times\frac{1\,\text{kg}\times m_2}{\left(6.4\times10^6\,\text{m}\right)^2}$$

$$m_2 = \left(\frac{9.8\,\text{N}\times\left(6.4\times10^6\,\text{m}\right)^2}{6.67\times10^{-11}\,\frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}}\right) = 6.0\times10^{24}\,\text{kg}$$

Determining Earth's density

We can calculate the average *density* of Earth from its mass and volume. You have learned that density is equal to *mass* divided by *volume*. Since Earth is a sphere, we can calculate its volume using the formula $4/3\pi r^3$ where r is Earth's radius. The entire calculation (Figure 31.3) shows that Earth's average density is 5.52 g/cm³. This is about 5.5 times the density of water (1.0 g/cm³).

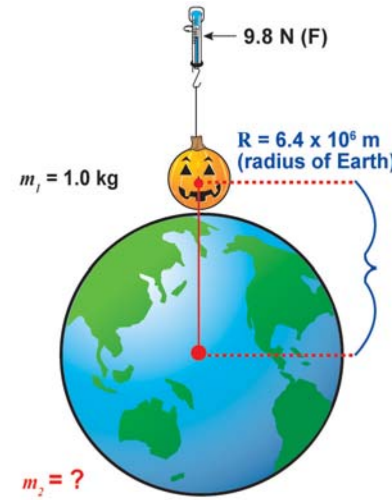


Figure 31.2: *Finding Earth's mass.*

$$\text{Volume} = \frac{4}{3}\pi r^3$$

$$V_{Earth} = \frac{4}{3}(3.14)\left(6.40\times10^8\,\text{cm}\right)^3 = 1.08\times10^{27}\,\text{cm}^3$$

$$\text{Density} = \frac{\text{mass (g)}}{\text{volume (cm}^3)}$$

$$D_{Earth} = \frac{\text{mass: } 6.00\times10^{27}\,\text{g}}{\text{volume: } 1.08\times10^{27}\,\text{cm}^3} = 5.52\ \text{g/cm}^3$$

Figure 31.3: *Calculating Earth's volume and density.*

Properties of the moon

What is the moon? Earth's only moon revolves around us at a distance of 384,400 kilometers (240,250 miles). While this may seem like a great distance, it is only a fraction of the distance of Earth from the sun—about 150 million kilometers, or 93 million miles. It is the only object beyond Earth that humans have visited.

Diameter, mass, and density If you have traveled from Boston to San Francisco, you have covered a distance that is about equal to the moon's diameter of 3,476 kilometers. the moon is about one quarter the size of Earth and its mass is 7.3×10^{22} kilograms, which is about one one-hundredth of Earth's mass. Because of the moon's small mass, its gravity does not attract an atmosphere. Its density is 3.34 g/cm^3, which is much lower than Earth's. Figure 31.4 compares Earth and the moon.

Property	Earth	Moon
Diameter	12,756 km	3,476 km
Gravitational force	9.8 N	1.6 N
Mass	6.0×10^{24} kg	7.3×10^{22} kg
Density	5.52 g/cm^3	3.34 g/cm^3
Rotation period	1 day	27.3 days

Figure 31.4: *Comparing Earth with the moon.*

Gravitational force on the moon **Gravitational force** is a measure of the attractive force exerted by an object (planet or moon) on a 1-kilogram object held at its surface. This quantity is measured in newtons or pounds. You just read that Earth exerts a gravitational force of 9.8 newtons on a 1-kilogram object. The moon exerts a gravitational force of only 1.6 newtons on the same object. This means that a 1-kilogram object weighs 9.8 newtons on Earth and the same object weighs only 1.6 newtons on the moon. It is easy to figure out how much something weighs in pounds on the moon if you know how much it weighs in pounds on Earth. Here is an example problem:

Example problem: An elephant weighs 2,500 pounds on Earth. How much would it weigh, in pounds, on the moon?

Solution You are asked for the elephant's weight in pounds on the moon. You know its weight in pounds on Earth. You also know how much a 1.0-kg object weighs, in newtons, in both places. To solve, you can set up a proportion:

$$\frac{\text{weight of elephant on Earth}}{\text{weight of 1.0 kg object on Earth}} = \frac{\text{weight of elephant on the moon}}{\text{weight of 1.0 kg object on the moon}}$$

Plug in the numbers you know, and solve for the unknown:

$$\frac{2{,}500 \text{ lbs}}{9.8 \text{ N}} = \frac{x}{1.6 \text{ N}} \qquad x = \frac{(2{,}500 \text{ lbs})(1.6 \text{ N})}{9.8 \text{ N}} = 408 \text{ lbs}$$

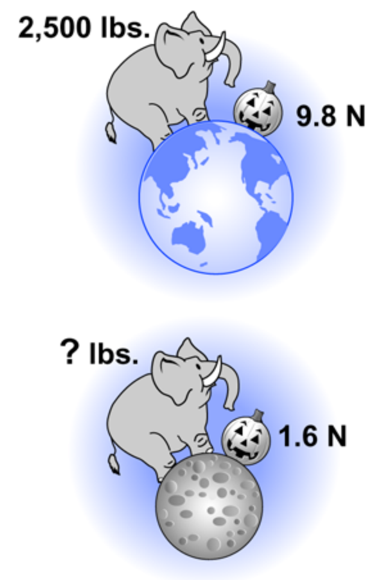


Figure 31.5: *How much does an elephant weigh on Earth and how much would it weigh on the moon?*

Why does the moon stay in orbit?

What is an orbit? An **orbit** is a regular, repeating path that an object in space follows around another object. An object in orbit is called a **satellite**. A satellite can be natural—like the moon, or artificial—like the International Space Station. Almost every object in space orbits around another object.

What keeps the moon in orbit? An orbit results from the balance between *inertia* (the forward motion of an object in space), and gravitational force. Because of the moon's inertia, it is moving in a direction *perpendicular* to the pulling force of gravity. According to Newton's first law, an object in motion will remain in motion unless something pushes or pulls on it. This means that without the pull of gravity, the moon would travel off into space in a straight line. The balance between the moon's inertia and the gravitational force between Earth and the moon results in its orbit (Figure 31.6).

Orbital speed **Orbital speed** is the speed required to achieve a balance between the pull of gravity on a satellite and its forward motion. The orbital speed of the moon is about 3,700 kilometers per hour. If the moon were any slower, it would fall toward Earth and eventually crash into it. If it were moving faster, it would break free of Earth's gravity and travel in a straight line into space. Because of its orbital speed, the moon falls *around* Earth instead of into it or away from it, and stays in orbit.

Orbital speed and distance The equation of universal gravitation that you used earlier shows how the gravitational force (F) between two objects is dependent on their masses and distance apart. Because the value for distance (R) squared is on the bottom of the equation, gravitational force decreases as the distance between the same two objects increases, and vice versa. A graph of this relationship is shown in Figure 31.7. If we could move the moon closer to Earth, the gravitational force would *increase*. Because orbital speed is directly related to gravitational force, the moon's orbital speed would need to increase for it to stay in orbit.

Gravity equation:

$$F = G\frac{m_1 m_2}{R^2}$$

Orbital speeds of Earth satellites Artificial satellites require high orbital speeds because they orbit close to Earth's surface. The space shuttle travels at a distance of only 250 kilometers above Earth's surface. To stay in orbit, the shuttle must travel at a speed of 28,000 kilometers per hour! To avoid air friction, all satellites travel above Earth's atmosphere (at least 200 kilometers above the surface) in the vacuum of space.

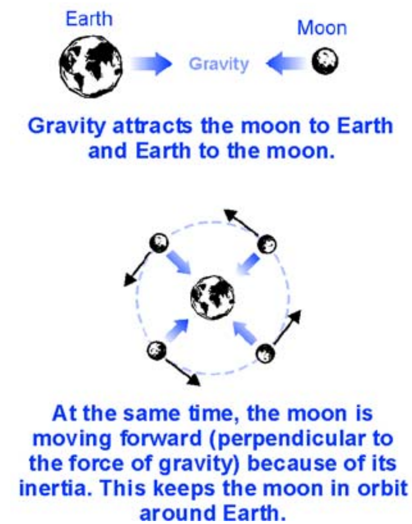


Figure 31.6: *Why does the moon stay in orbit? This also explains why the planets remain in orbit around the sun.*

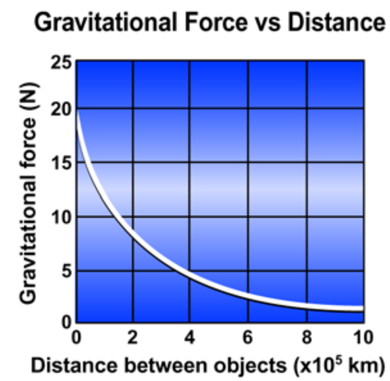


Figure 31.7: *This graph shows the mathematical relationship between gravitational force and distance (mass is constant). Why would the curve on a graph of orbital speed vs. distance look the same?*

Tides

What are tides? Earth's oceans are constantly moving. Winds push on the water causing waves and currents. Ocean levels rise and fall in daily rhythms called **tides**. Tides are the result of gravitational forces exerted between Earth and the moon. In most places, ocean levels rise and fall twice each day as the moon revolves around Earth, and Earth rotates.

Gravity causes tides Earth and the moon share a common gravitational force. Because Earth is more massive than the moon, it is less affected by this force than is the moon. Tides occur because the force of gravity varies with distance. As the moon orbits, the part of Earth that is on the same side as the moon experiences greater gravitational forces than does the opposite part. Because the oceans are fluid, they are easily distorted by these gravitational forces.

High and low tides To understand tides, imagine Earth covered completely by water as shown in Figure 31.8. As the planet rotates on its axis, the water is balanced evenly on all sides by centrifugal force. The moon has a gravitational pull on this layer of water as it orbits Earth. At point A, the water is closer to the moon and is pulled toward it by gravity, causing a *high tide*. At point B, the water is farther away from the moon than is Earth. However, gravity pulls Earth toward the moon, leaving the water behind. This causes high tide on the side opposite the moon as well. *Low tides* occur between high tides. As Earth rotates under these "bulges," a given point will experience two high and two low tides for each rotation of the planet.

The sun's affect on tides The sun's gravitational force also pulls on Earth's water, only to a much lesser extent. Even though the sun has much greater mass than the moon, its gravitational pull on Earth's water is weaker because it is so much farther away. When Earth, the moon, and the sun are aligned (during a new or full moon), the sun's gravitational force adds to the moon's, causing very high and very low tides. These are called *spring tides* (Figure 31.9 top picture). When the gravitational pull of the moon and the sun are at right angles to each other, differences between high and low tides are at their least. These are called *neap tides* (Figure 31.9 bottom picture).

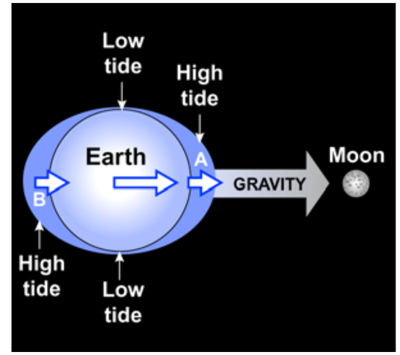


Figure 31.8: *How the moon causes tides on Earth.*

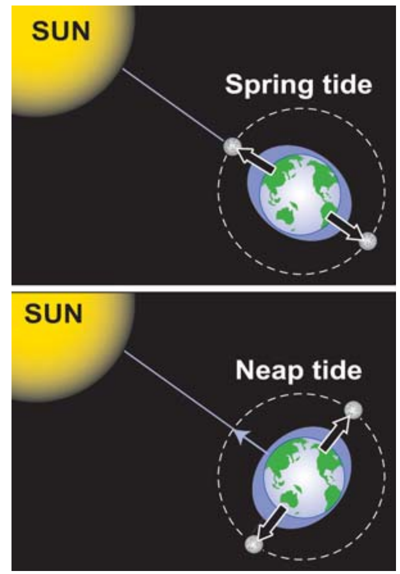


Figure 31.9: *Spring and neap tides.*

Why do we only see one side of the moon from Earth?

Gravitational locking

If you have ever observed the moon, you may have noticed that only one side of it faces Earth at all times. You may believe that because only one side faces Earth, the moon does not spin on its axis. This is not the case. In fact, one complete rotation of the moon takes 27.3 Earth days. This exactly matches the amount of time it takes the moon to complete one revolution around Earth. That is why the same side of the moon faces Earth as it spins on its axis (Figure 31.10). This same phenomenon, called *gravitational locking*, occurs between other planets and some of their moons.

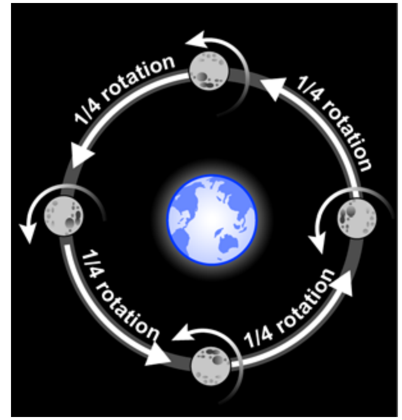


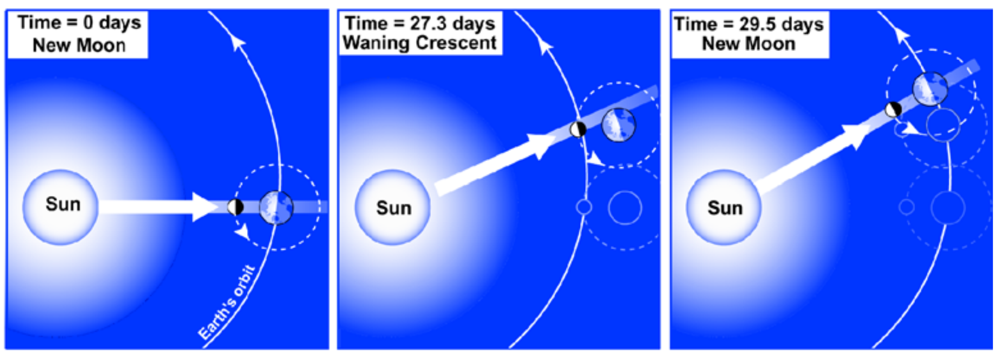
Figure 31.10: *The amount of time it takes the moon to complete a rotation is the same amount of time it takes it to revolve around Earth. Can you see why only one side of the moon faces Earth at all times?*

The moon's orbit and the lunar cycle

You have learned that it takes the moon 29.5 days to complete the lunar cycle—from new moon to new moon. Yet, you have just read that it takes the moon only 27.3 days to complete one orbit, or revolution, around Earth. There is a difference of 2.2 days between the lunar cycle and the period of the moon's revolution around Earth. Why is there a difference?

The Earth-moon system

Remember that as the moon revolves around Earth, the *Earth-moon system* revolves around the sun. This makes things more complicated. In the 27.3 days it takes the moon to revolve around Earth, the Earth-moon system has revolved about 27 degrees (out of 360 degrees in a circle) of its total orbit around the sun. The diagram below shows how the angle of the sun's rays have changed after the 27.3 days. It takes a few more days for the moon to move along its orbit to compensate for the change in angle of the sun's rays. In the meantime, Earth has moved even *farther* in its own orbit around the sun.



Geology of the moon

Where did the moon come from?

Throughout history, there have been many different theories about the origin of the moon. Before the Apollo landings that began in 1969, there were three main theories. Some scientists believed that the moon split off Earth during a period of very fast rotation. Others believed that the moon formed somewhere else and was "captured" by Earth's gravity. Still others proposed that the moon and Earth were formed together from a group of smaller chunks of matter when the solar system formed.

The giant impact theory

When scientists analyzed lunar rocks, they found that they were composed of much less iron and nickel than Earth. Recall that Earth's *core* is composed mostly of iron and nickel. The composition of lunar rocks closely resembled that of Earth's *mantle*. They also found that the moon's density was the same as Earth's mantle and crust combined. These discoveries gave rise to the *giant impact theory* that is widely accepted today. This theory proposes that about 4.5 billion years ago, an object about the size of Mars collided with Earth, causing material from Earth's mantle and crust to break off. This material, combined with material from the colliding object, was thrown into orbit around Earth and became the moon. Figure 31.11 shows how the moon was formed based on this theory.

Craters

If you look at the moon through a telescope, you can see the three main features of its surface: craters, highlands, and maria. *Craters* are large, round pits that cover much of the moon's surface. For many years astronomers believed they were caused by volcanoes. It was only about 50 years ago that scientists concluded that the craters were caused by the impacts of meteoroids—large rocks from space. One of the moon's largest craters, named Copernicus, is hundreds of kilometers across.

Highlands and marias

When you look at the moon, some areas appear bright, while others appear dark. The brighter areas are called *highlands* because they are higher in elevation. The darker areas are called *marias* (Latin for "seas") because early observers believed they were oceans. Marias are low, dry areas that were flooded with molten lava billions of years ago when the moon was formed. Among the marias you can see through a telescope is a large one named the Sea of Rains.

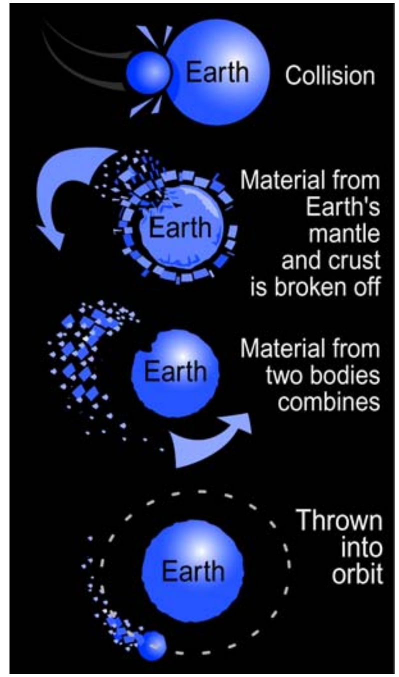


Figure 31.11: *The giant impact theory of the moon's formation.*

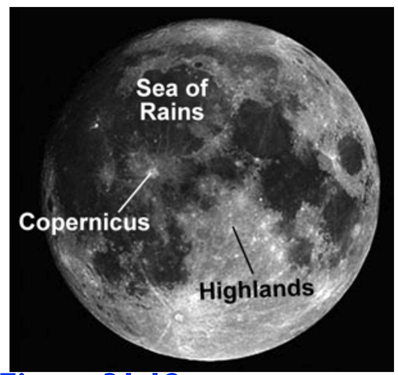


Figure 31.12: *Features of the moon are visible through a telescope or a pair of binoculars.*

31.2 The Solar System

Can you imagine what the night sky looked like thousands of years ago? With no "light pollution" from cities and street lights, ancient civilizations could make very good observations of what they saw in the sky each night. In fact, these civilizations could tell the difference between planets and stars because of the differences in the way they moved (or seemed to move) in the sky. Through these observations, early knowledge of our *solar system* began to accumulate. In this section, you will learn how that knowledge has changed over time.

How was the solar system discovered?

Early thoughts about the solar system

Through their observations of the night sky, those ancient observers noticed that five bright objects seemed to wander among the stars each night. They called these five objects *planets*, from the Greek word meaning "wandering star," and named them Mercury, Venus, Mars, Jupiter, and Saturn. In A.D. 140, the Greek astronomer Ptolemy explained that these planets, along with the moon, orbited *Earth*. For the next 1,400 years, people believed Ptolemy's ideas were correct.

Changing ideas about the solar system

In the early 1500s, the Polish astronomer Nicolaus Copernicus (1473-1543) concluded that the planets orbited the sun. More than 100 years later, his ideas were supported by the Italian astronomer Galileo Galilei (1564-1642). Using a telescope, Galileo made two discoveries that supported Copernicus. First, he saw that there were four moons orbiting Jupiter. This showed that not everything in the sky revolves around Earth. Second, he observed that Venus goes through phases like Earth's moon. He argued that the phases of Venus could not be explained if Earth were at the center of the planets (Figure 31.13).

What is an orbit?

While Galileo supported Copernicus's theory that all of the bodies in the solar system orbit the sun, other scientists were studying the nature of those orbits. In 1600, German mathematician Johannes Kepler (1571-1630) discovered that the orbits of some of the planets were not perfectly round but slightly oval or *elliptical* in shape. This explained the slight irregularities in the path of the planets across the sky. He used the detailed observations of his teacher, Danish astronomer Tycho Brahe, to arrive at his conclusions.

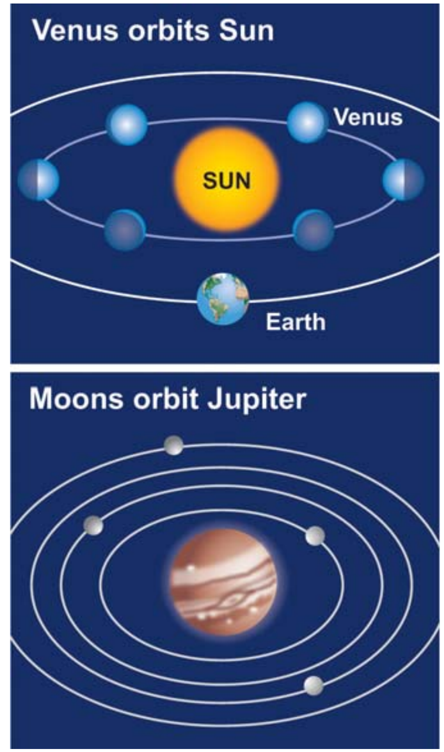


Figure 31.13: *Two of Galileo's discoveries that helped prove that Earth and the other planets orbit the sun. The top diagram shows how the phases of Venus are due to its orbit around the sun. The bottom diagram depicts moons orbiting Jupiter. This observation proved that not all objects revolve around Earth.*

What keeps the planets in orbit?

While Kepler discovered the slightly elliptical shape of their orbits, he could not explain why the planets *stay* in orbit. As you read in the last section, the work of Isaac Newton provided the answer. Newton (1642-1727) concluded that *gravity* and *inertia* keep the planets in orbit. Because of their inertia, the planets are moving in a direction *perpendicular* to the sun's attractive gravity. The reason they don't fall into the sun is because as they fall *toward* it, they are moving forward because of their *inertia*. The combination of the forward motion due to inertia, and the downward pull of gravity, keeps the planets falling *around* the sun instead of into it, as shown in Figure 31.14.

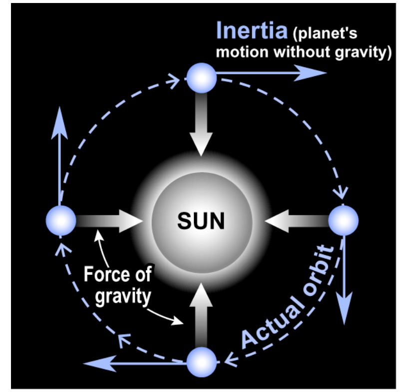
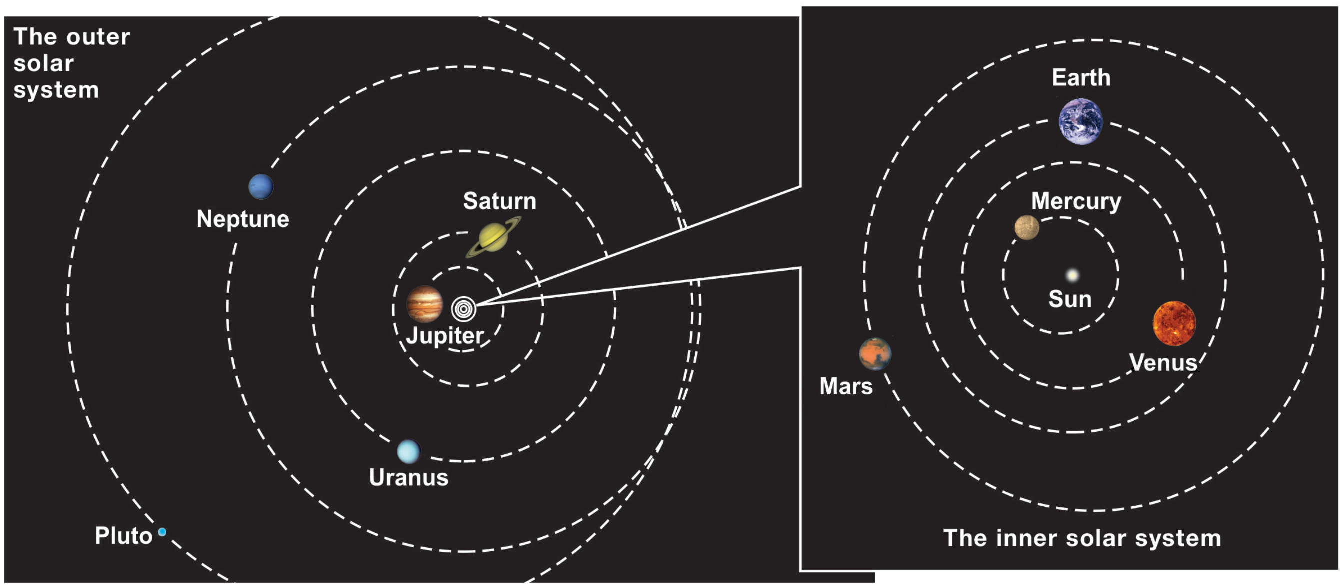


Figure 31.14: *Why do the planets stay in orbit around the sun?*

The solar system today

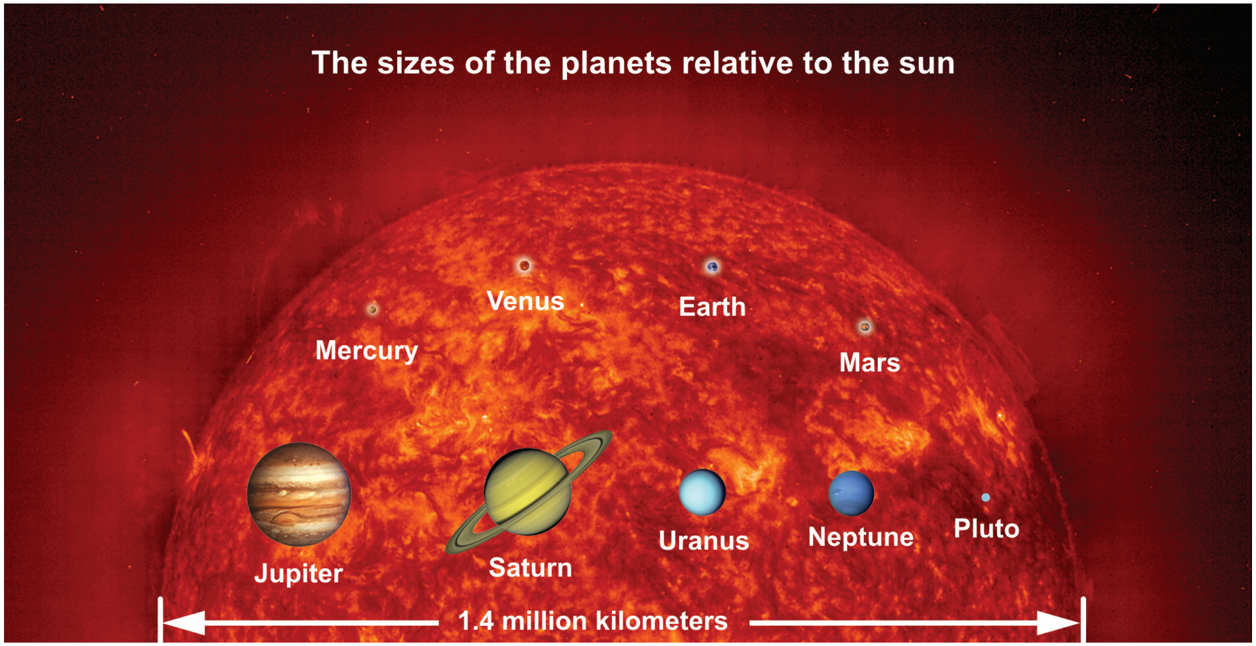
Today, we know that the sun consists of the sun, the planets and their moons, and a large number of smaller objects (asteroids, comets, meteors, and dwarf planets such as Pluto). All of these objects orbit the sun.

The solar system is the region in space where the sun's gravitational force is dominant.



Size and distance in the solar system

Relative sizes The sun is by far the largest object in the solar system. The next largest objects are the planets Jupiter, Saturn, Uranus, and Neptune. As you can see from the scale diagram below, the planets Mercury, Venus, Earth, Mars, and Pluto, a *dwarf planet*, appear as small specks when compared with the size of the sun.



Distance Astronomers often use the distance of Earth from the sun as a measurement of distance in the solar system. One astronomical unit (AU) is equal to 150 million kilometers, or the distance from Earth to the sun. Mercury is 58 million kilometers from the sun. To convert this distance to astronomical units, divide this distance by 150 million kilometers. Mercury is therefore, 0.37 AU from the sun (Figure 31.16). Figure 31.16 lists the planets and their distance from the sun in astronomical units.

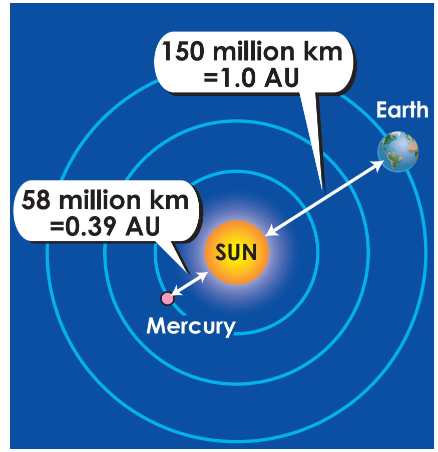


Figure 31.15: *One astronomical unit (AU) is equal to 150 million kilometers. If Earth is 1.0 AU from the sun, then Mercury, with a distance of 58 million kilometers, is 0.39 AU from the sun.*

Planet	Distance from the sun (AU)
Mercury	0.37
Venus	0.72
Earth	1.0
Mars	1.5
Jupiter	5.2
Saturn	9.5
Uranus	19.2
Neptune	30.0
Pluto (dwarf)	39.5

Figure 31.16: *Distances of the planets from the sun in astronomical units (AU).*

The planets

Classifying the planets

The nine planets are commonly classified in two groups. The terrestrial planets include Mercury, Venus, Earth, and Mars. The terrestrial planets are mostly made of rock and metal. They have relatively high densities, slow rotations, solid surfaces, and few moons. The gas planets include Jupiter, Saturn, Uranus, and Neptune. These planets are made mostly of hydrogen and helium. They have relatively low densities, rapid rotations, very thick atmospheres, and many moons. Pluto is neither terrestrial nor gas, but a frozen world in a class of its own.

Mercury was named for the messenger of the Roman gods because of its quick motion in the sky.

Mercury

The closest planet to the sun, Mercury appears to move quickly across the night sky because its period of revolution is the shortest of all of the planets. It is the second smallest planet (after Pluto) in both size and mass. It has almost no atmosphere (except for traces of sodium), and its surface resembles that of the moon. Mercury rotates on its axis very slowly—only one and a half times for every revolution around the sun. This makes one day on Mercury about 59 Earth days, although its year is not much longer—about 88 Earth days! The side of Mercury that faces the sun is very hot, about 400°C, while the other side is very cold, about -170°C. It has no moons.

Venus was named after the Roman goddess of love because of its beautiful, shiny appearance.

Venus

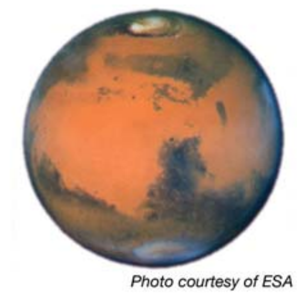
Venus appears as the brightest planet and the third brightest object in the sky (after the sun and moon). It has a very thick atmosphere and an atmospheric pressure at its surface that is 90 times that at Earth's surface. Because the atmosphere on Venus is 96 percent carbon dioxide, the greenhouse effect makes it the hottest planet in the solar system with a surface temperature of more than 500°C. It is one of three planets that rotate "backward," that is, east to west. Its rotation is the slowest of all of the planets; Venus makes a little less than one rotation for each revolution around the sun. This means that a day on Venus is 243 Earth days, while a year is shorter: 225 Earth days. Like Mercury, Venus has no moons.

Earth is the only planet not named after a Roman god. Its name comes from Old English "oerthe," meaning land or country.

Earth

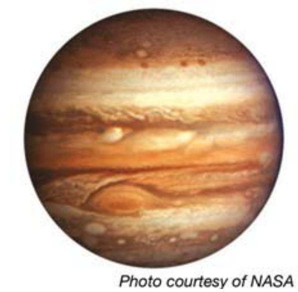
Earth is a small, rocky planet with a thin atmosphere that is made of mostly nitrogen and oxygen. This atmosphere, along with the oceans and a moderate temperature range, are what made the formation of life possible. As far as we know, Earth is the only planet in the solar system to support life. Because of its axial tilt, this planet experiences seasons. Earth has one moon. (Earth is described in great detail in earlier chapters.)

Mars Mars appears as a reddish point of light in the night sky. It has a widely varied surface that includes deserts, huge valleys and craters, and volcanic mountains that dwarf those on Earth. The atmosphere of Mars is very thin (about 0.7 percent as thick as that of Earth) and composed mostly of carbon dioxide, with the rest nitrogen and argon. The temperatures are below freezing most of the time. Like Earth, Mars has polar ice caps, but they are composed of a combination of water and frozen carbon dioxide. Because it has an axial tilt, Mars experiences seasons like Earth. A day on Mars (24.6 hours) is similar in length to Earth, while a year (687 days) is not. Mars has two small moons named Phobos and Deimos.



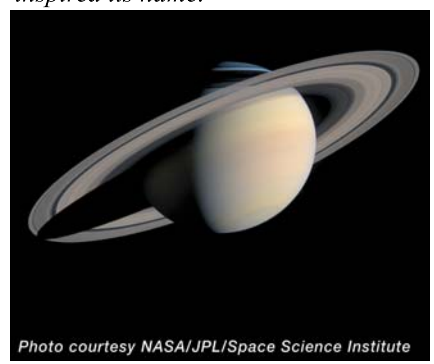
Mars' red color reminded the ancients of blood so they named it after the Roman god of war.

Jupiter Jupiter is by far the largest of the planets, and the fastest rotator, spinning on its axis about once every 10 hours. A year on Jupiter is about 12 Earth years. Jupiter does not have a solid surface on which to stand. In fact, Jupiter is more liquid than gaseous or solid—more than half of its volume is an ocean of liquid hydrogen. Its atmosphere is about 88 percent hydrogen, 11 percent helium, and 1 percent methane, ammonia, and other molecules. The atmospheric pressure below Jupiter's thick clouds is more than a million times that of Earth! It has a very stormy atmosphere and one storm known as the Great Red Spot has been observed for more than 300 years. Jupiter's mass is greater than the combined masses of all of the planets, but its density is very low—about one-quarter that of Earth. With 39 moons, Jupiter is like a mini solar system. Several of its moons are as large as small planets and have interesting features.



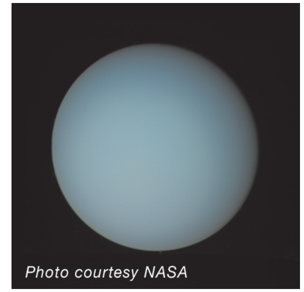
Jupiter was king of the Roman gods. The planet's eminent brightness inspired its name.

Saturn Saturn, at almost 10 times the size of Earth, is the second largest planet. Like Jupiter, Saturn's atmosphere is made mostly of hydrogen and helium. Saturn is a fast rotator, though slightly slower than Jupiter, with a day on Saturn lasting just longer than 10 Earth hours. A year on Saturn is about 29 Earth years. The most striking feature of Saturn is its system of rings, which are visible from Earth with a telescope. While Jupiter, Uranus, and Neptune also have rings, they are faint and not visible from Earth, but detectable by other means. Saturn's rings are made up of billions of particles of rock and ice ranging from microscopic to the size of a house. Although they are hundreds of thousands of kilometers wide, the rings are less than 100 meters thick. With 30 moons, Saturn is also like a mini solar system.



Because of its slow orbit around the sun, Saturn was named after the Roman god of agriculture and time.

Uranus Because Uranus can barely be seen without a good telescope, it was not discovered until 1781. This gas planet is four times as large as Earth and has an atmosphere of mostly hydrogen and helium with small traces of other gases. Uranus has a series of faint rings that were discovered in 1977 using a very powerful telescope. This planet rotates "backward" and has an axis that is tilted 98 degrees to the plane of its orbit. A day on Uranus is only 18 Earth hours but a year takes 84 Earth years. Uranus has at least 21 moons.



Uranus is the first planet discovered in modern times and is named after the first Roman god.

Neptune Neptune is the outermost of the gas planets and, like the others, its atmosphere is mostly hydrogen and helium with small traces of other gases. It was discovered in 1846 and its discovery almost doubled the diameter of the solar system because of its great distance from the sun. Neptune's orbit is nearly a perfect circle; only Venus has a more circular orbit. Neptune has a series of faint rings but these are not visible from Earth and have only been seen in photographs taken by space probes such as *Voyager*. This planet has eight known moons, six of which were found in photographs taken by *Voyager 2* in 1989.

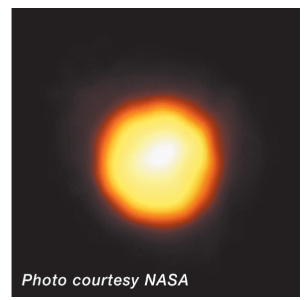
Photo courtesy of NASA

Because it is so far in the depths of space, Neptune was named after the Roman god of the deep sea.

Pluto Discovered in 1930, Pluto was named for the Roman god of the underworld. The first dwarf planet discovered, Pluto rotates slowly — one turn every six days — and backward. Its orbit is strongly elliptical and Pluto crosses the path of Neptune for about 20 years out of the 249 years it takes to revolve around the sun. Because their orbits are not in the same plane, Neptune and Pluto will never collide. Because it is so far away, little is known about Pluto.

Are there 8, 9, or 11+ planets? Outside the orbit of Pluto is a region called the Kuiper Belt. The Kuiper Belt stretches to 1,000 AU and is believed to contain many asteroid-size and a few Pluto-size objects. As of this writing, two Pluto-size bodies have been found, nicknamed Sedna and Xena. To avoid confusion, astronomers no longer count Pluto as a planet. Instead, Pluto is grouped along with Sedna, Xena, and similar distant bodies in the Kuiper Belt.

Table 31.1 on the next page compares the planets and some of their properties.



Discovered in 1930, Pluto was named for the Roman god of the underworld.

Table 31.1: *Comparing properties of the planets*

Property	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Diameter *(km)*	4,878	12,102	12,756	6,794	142,796	120,660	51,200	49,500	2,200
Mass *(kg)*	3.3×10^{23}	4.9×10^{24}	6.0×10^{24}	6.4×10^{23}	1.9×10^{27}	5.7×10^{26}	8.7×10^{25}	1.0×10^{26}	1.3×10^{22}
Density *(g/cm^3)*	5.44	5.25	5.52	3.91	1.31	0.69	1.21	1.67	1.75
Average distance from the sun *(km)*	58 million	108 million	150 million	228 million	778 million	1.43 billion	2.87 billion	4.50 billion	5.91 billion
Moons *(number of)*	0	0	1	2	39	30	21	8	1
Gravitational force *(N)*	3.7	8.9	9.8	3.7	23.1	9.0	8.7	11.0	0.6
Surface temperature *(°C)*	-170 to +390	+450 to +480	-88 to +48	-89 to -31	-108	-139	-197	-201	-223
Rotation period *(Earth days)*	59	243	1	1.03	0.41	0.43	0.72	0.67	6.4
Revolution period *(Earth years)*	0.24	0.62	1	1.9	12	29	84	165	249
Orbital speed *(km/sec)*	47.89	35.04	29.80	24.14	13.06	9.64	6.80	5.43	4.74
Principal gases in atmosphere	Na	CO_2	N_2, O_2	CO_2	H_2, He, CH_4, NH_3	H_2, He, CH_4, NH_3	H_2, He, CH_4, NH_3	H_2, He, CH_4, NH_3	N_2, CO, CH_4

Other objects in the solar system

Asteroids

Between Mars and Jupiter, at a distance of 320 million to 495 million kilometers, there is a huge gap that cuts the solar system in two. This gap is called the *asteroid belt* because it is filled with thousands of small, rocky bodies called *asteroids*. An **asteroid** is an object that orbits the sun but is too small to be considered a planet. At present, more than 10,000 asteroids have been discovered and more are found each year. The location of the asteroid belt is shown in the diagram on page 619.

The size of asteroids

Most asteroids are small—less than one kilometer in diameter—but many have been found that are over 250 kilometers in diameter. The largest asteroid, named Ceres, is 933 kilometers (580 miles) across. While the majority of asteroids are found in the asteroid belt, many have highly elliptical orbits that allow them to come close to Mercury, Venus, and even Earth. Some come so close to Earth that they are known as "Earth-grazers." About 65 million years ago, a large asteroid hit Earth near Mexico, leaving a huge crater. Some scientists believe this event led to the extinction of the dinosaurs.

Comets

A **comet** is an object in space that is made mostly of ice and dust. Comets are about the size of an Earth mountain. These objects revolve around the sun in highly elliptical orbits and many pass close to Earth. In 1997, the comet Hale-Bopp could be clearly seen in the night sky without the aid of a telescope. As a comet approaches the sun, some of its ice turns into gas and dust and forms an outer layer called a *coma*. The inner core of the comet is called the *nucleus* (Figure 31.18).

Evolution of a comet

Because the sun releases a stream of particles called *solar wind*, as a comet gets closer to the sun, it forms a *tail*. A comet's tail can stretch for millions of kilometers into space and faces away from the sun as the comet continues its orbit (Figure 31.19). Each time a comet passes the sun, it loses more of its ice. After many revolutions, the comet may no longer have enough material to form a tail. Eventually, the comet will look more like an asteroid.

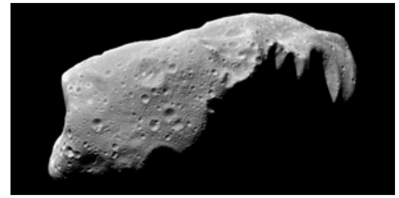


Figure 31.17: *The asteroid shown in this picture is named Ida and is about 54 kilometers wide.*

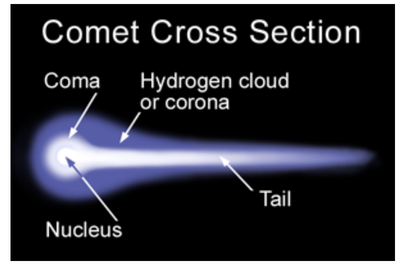


Figure 31.18: *The parts of a comet.*

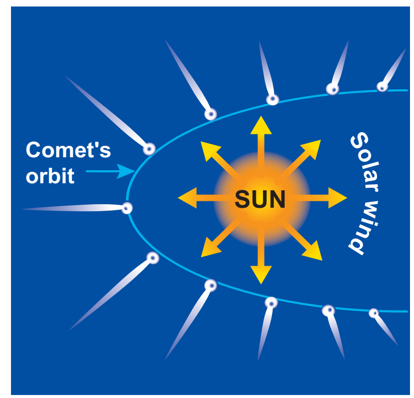


Figure 31.19: *A comet's tail faces away from the sun and can stretch for millions of kilometers in space.*

Meteors Occasionally, chunks of rock or dust break off from a comet or asteroid and form a **meteor**. Imagine a tennis ball traveling at about 30,000 miles per hour. That's about the size and speed of most meteors. These chunks of dust or rock travel through space and some of them end up hitting Earth's atmosphere. When this happens, meteors rub against air particles and create friction, heating them to more than 2,000°C. The intense heat vaporizes most meteors, creating a streak of light known as a "shooting star." Occasionally, larger meteors cause a brighter flash called a *fireball*. These sometimes cause an explosion that can be heard up to 30 miles away! If you go out into the country and look up at the sky on a clear night, chances are that you will see a meteor. In fact, a meteor can be seen in the night sky about every 10 minutes.

Name	Peak	Duration
Quadrantids	Jan. 4	2 days
Perseids	Aug. 11	4 days
Orionids	Oct. 21	4 days
Geminid	Dec. 13	varies

Figure 31.20: *Some annual meteor showers. Watch the skies for them!*

Meteor showers When a comet nears the sun, a trail of dust and other debris burns off and remains in orbit around the sun. As Earth orbits the sun, it passes through this debris, creating a *meteor shower* as the small bits of dust burn up in the atmosphere. During a meteor shower, you can see tens and even hundreds of meteors per hour. Because Earth passes the same dust clouds from comets each year, meteor showers can be predicted with accuracy (Figure 31.20).

Figure 31.21: *Meteors frequently streak across the night sky.*

Meteorites If a meteor is large enough to survive the passage through Earth's atmosphere and strike the ground, it becomes a *meteorite*. Meteorites are thought to be fragments from collisions involving asteroids. Most meteorites weigh only a few pounds or less and cause little damage when they hit. Most fall into the oceans that cover almost three-quarters of our planet's surface. In 1948, people in Nebraska saw a giant fireball that seemed brighter than the sun. The meteorite was later found in a field, buried deep in the ground. It weighed 2,360 pounds!

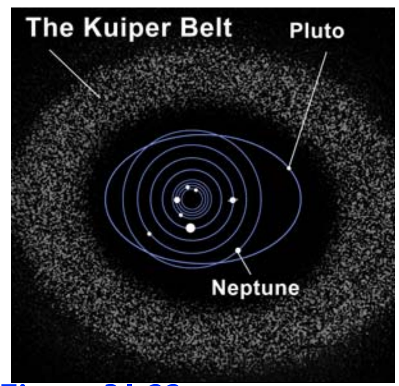


Figure 31.22: *The Kuiper Belt lies beyond Neptune.*

The Kuiper Belt The Kuiper Belt was discovered in 1992 and is named after the Dutch-American astronomer Gerard Kuiper (1905-73), who predicted its existence in 1951. It is a region beyond the planet Neptune where countless numbers of small, icy objects slowly orbit (Figure 31.22). Some astronomers believe that the Kuiper Belt is the reservoir for comets that orbit the sun in less than 200 years. So far, fewer than 400 objects have been identified, but astronomers suspect that there may be billions of them. Recently, an object half the size of Pluto was discovered in the Kuiper Belt.

Science controversy: Is Pluto a planet?

Is Pluto a planet? Recently, Pluto's status as a *planet* has been a subject of controversy. This is not the only time in history that an object's status as a planet has been questioned. According to the ancient Greeks, there were seven objects they called planets: Mercury, Venus, Mars, Jupiter, Saturn, the sun, and the moon. After the time of Copernicus and Galileo, astronomers said that there were only six planets, Mercury, Venus, Earth, Mars, Jupiter, and Saturn.

Asteroids are not planets In 1781, William Herschel (1738-1822) discovered Uranus outside the orbit of Jupiter. The "eighth" planet, Ceres, was discovered in 1801 between the orbits of Mars and Jupiter. Soon after, three more "planets" were discovered, Pallas, Juno, and Vesta. If you were to read a science textbook from the early 1800's, it would state there were 11 planets. Then astronomers began to find dozens of smaller "planets" between Mars and Jupiter. Astronomers soon realized that Ceres, Pallas, Juno, and Vesta were not planets at all but merely asteroids.

Planet X Later in the 1800's, astronomers realized that in addition to the sun, the orbit of Uranus was behaving as if it were influenced by another object. They theorized there must be another planet affecting its orbit. After many calculations, they discovered Neptune. However, they thought that even Neptune's orbit was being influenced by another object and began to search for what they called *Planet X*. In 1930, Clyde Tombaugh (1906-97) discovered Pluto, which was thought to be Planet X. Pluto's orbit is highly elliptical, and is not aligned in the same plane as the other planets in the solar system.

Pluto is now classified as a dwarf planet On August 24, 2006, the International Astronomical Union (IAU) passed a new definition of a planet. The new definition excludes Pluto as a planet. According to the new definition, Pluto is classified as a "dwarf planet." Recently, astronomers have begun to find dozens of objects similar to Pluto—all small, icy, rocky, and with similar orbits.

The change in Pluto's status as a planet is a good example of the scientific method in progress. New discoveries sometimes cause scientists to revise their theories and ideas.

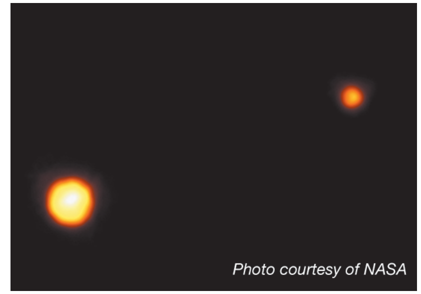


Figure 31.23: *Pluto is a very difficult planet to study. Even this NASA/HST image shows us very little about Pluto's surface.*

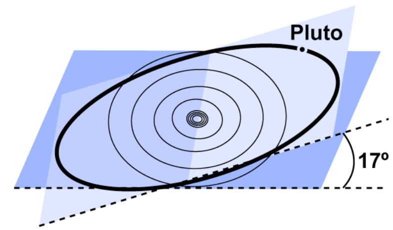


Figure 31.24: *Pluto's orbit is highly elliptical and tilts at a 17-degree angle with respect to the orbital plane of the other planets.*

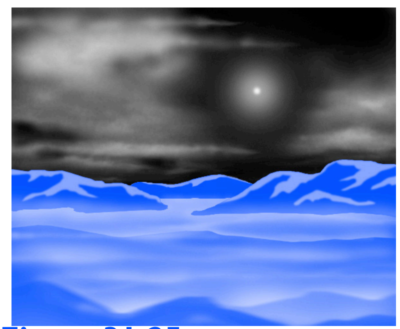


Figure 31.25: *The sun would look like a bright star from the surface of Pluto.*

31.3 The Sun

Can you imagine life without the sun? In fact, life could not exist without it. The sun is the source of energy that sustains all life on Earth. It is also Earth's timekeeper, governing the seasons, the harvests, and even the sleep patterns of animals. The sun has been worshiped by civilizations throughout history. What is the sun? Why does it produce so much energy? Read on to find the answers to these questions, and many more.

Figure 31.26: *The sun is a star.*

What is the sun?

The sun is a star

When you look up at the stars at night, it may be hard to believe that the sun is one of them. To the casual observer the sun looks very different from a star. The sun appears as a large golden disk in the daytime sky, while the stars twinkle as pinpoints of light in the night sky. Yet the sun is one of at least 200 billion stars in our galaxy. With the universe containing billions of galaxies, each filled with stars, you can see that our sun is only a tiny part of the universe. You will learn about the universe, galaxies, and stars in the next chapter.

A medium-sized star

The sun is medium-sized compared with other stars in the universe. Its diameter is about 1.4 million kilometers, or about 109 times the diameter of Earth. Approximately 1 million planet Earths could fit inside the sun! By contrast, one of the star "supergiants" called Betelgeuse sometimes reaches a diameter that is almost 600 times that of the sun. If the sun grew to the size of Betelgeuse, it would swallow up Mercury, Venus, Earth, and Mars!

What is the sun made of?

The sun is about 75 percent hydrogen, 25 percent helium, and very small traces of other elements. Unlike Earth, the sun does not have a solid surface—instead, it is made completely of gas. Because of its size, the sun contains 99.8 percent of the mass of the solar system. Because of its mass, the sun's gravitational force is strong enough to hold the entire solar system, including the nine planets, asteroids, and comets, in orbit.

Sun Facts

- The sun's diameter is 1.4 million kilometers.
- About one million Earths could fit inside of the sun.
- The core of the sun is about 15 million°C.
- The coolest parts of the sun are nearly 4,000°C.
- The outermost layer of the sun can stretch millions of kilometers into space.
- The sun is 150 million kilometers from Earth.
- The sun spins around once every 27.4 days.
- The sun is about 5 billion years old.

Where does the sun's energy come from?

Energy from the sun

Except for nuclear power, the source for almost all of our energy comes from the sun. Sunlight causes water to evaporate, which later falls as rain into rivers and streams. This flowing water can be used to generate electricity. Energy from the sun also drives the wind (created by uneven heating of Earth), which also can be used to generate electricity. Solar energy can be converted *directly* to electricity using *photovoltaic cells* like the ones found on solar-powered calculators. Even the energy we get from coal, natural gas, petroleum, and wood comes from the sun. That is because these fuels are created from *photosynthesis*. In this process, plants store energy from the sun in the form of carbon compounds. The energy in these compounds is released as heat when they are burned.

The sun's energy comes from nuclear fusion

Parts of the sun can reach 15 million°C! Where does all of this energy come from? Does the sun produce this energy from burning fuels such as oil, coal, or natural gas? Far from burning fuels, the energy output of the sun is instead produced by *nuclear fusion*. You have learned that nuclear fusion occurs when the nuclei of atoms are joined, or fused. Inside the sun, the nuclei of hydrogen atoms join together to form helium atoms. This results in the release of a tremendous amount of *energy* in the form of heat and light. Figure 31.27 shows a simple example of nuclear fusion.

How much energy does the sun produce?

Each second, about 700 million tons of hydrogen inside the sun are converted to about 695 million tons of helium through nuclear fusion. Notice that the total mass of helium produced is slightly smaller than the total mass of hydrogen used. The "missing" mass (about 5 million tons) is converted directly into energy. This mass creates an energy output of 3.9×10^{26} watts! In 1905 Albert Einstein proposed that matter can be converted into energy. His famous equation ($E = mc^2$) shows how huge amounts of energy can be created from a smaller mass (Figure 31.28). This helps explain why such a large amount of energy is produced by fusion.

The solar constant

The amount of this energy that actually reaches the edge of Earth's atmosphere is known as the **solar constant**. While the solar constant varies slightly, the accepted value is 1,368 watts per square meter (W/m^2). To visualize this amount of energy, imagine the energy of thirteen 100-watt light bulbs spread over a square meter surface.

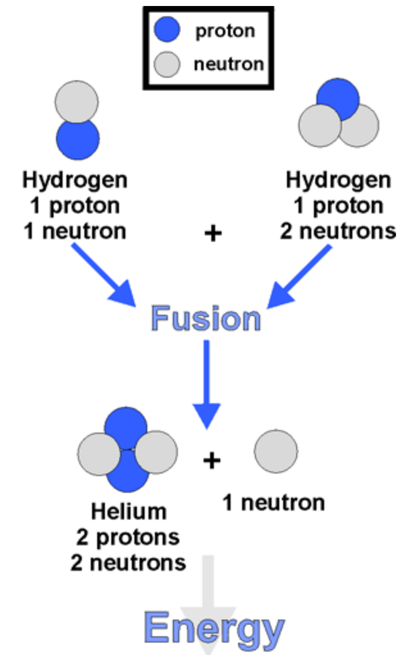


Figure 31.27: *A simple example of nuclear fusion. The fusion reactions in the sun are a lot more complicated!*

Energy

Mass

$$E = mc^2$$

Speed of light

Multiplying even a small mass by this number will result in a large amount of energy.

Figure 31.28: *Einstein's equation shows how large amounts of energy can come from a small mass.*

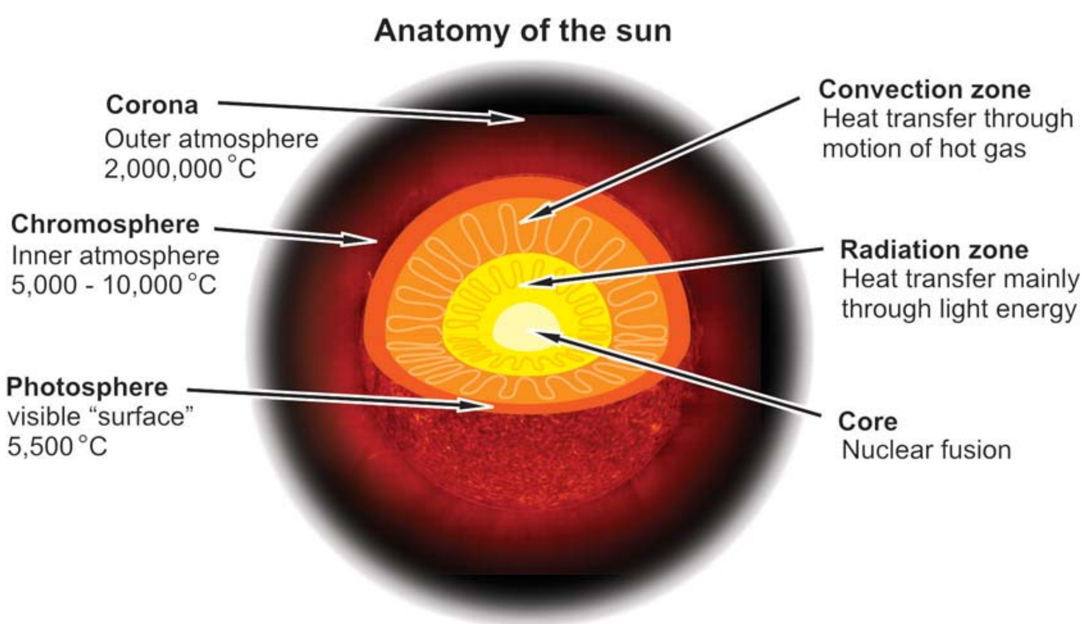
The sun's features and occurrences

The sun has three regions

Because the sun is made of gas, its surface is hard to define. The apparent surface that we can see from a distance is called the *photosphere,* which means "sphere of light." Just above it is the *chromosphere.* This is a very hot layer of plasma, a high-energy state of matter. The *corona* is the outermost layer of the sun's atmosphere, extending millions of kilometers beyond the sun. Both the corona and chromosphere can be seen during a total eclipse of the sun, as shown in Figure 31.29.

Sunspots

A safe method for viewing the sun is to use a telescope to project its image onto a white surface (You should NEVER look directly at the sun). When the sun is observed in this way, small, dark areas can be seen on its surface. These areas, called *sunspots*, may look small, but they can be as large as Earth. Sunspots are areas of gas that are cooler than the gases around them. Because they don't give off as much light as the hotter areas, they appear as dark spots on the photosphere (Figure 31.30).



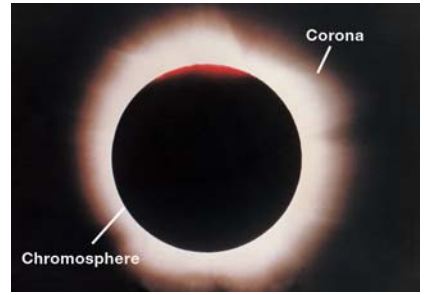


Figure 31.29: *The sun's corona and chromosphere can be seen during a total eclipse.*

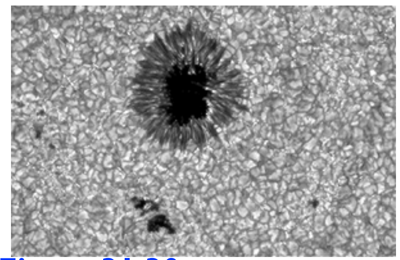


Figure 31.30: *Sunspots appear as dark spots on the photosphere.*

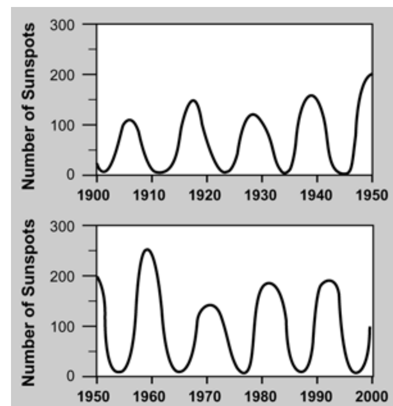


Figure 31.31: *Sunspot cycles for the years 1900 through 2000.*

Prominences and solar flares Sunspots are linked to other features of the sun. Occasionally, large “loops” of gas called *prominences* can be seen jumping up from groups of sunspots. These can be observed during eclipses and appear as loops that extend beyond the chromosphere. Sometimes prominences from different sunspot regions suddenly connect, releasing very large amounts of heat and light known as *solar flares*.

Theories about sunspots The number of sunspots seems to vary over an 11-year period known as the *sunspot cycle* (Figure 31.31 on page 630). Many scientists speculate that there is a relationship between the sunspot cycle and variations in our global climate. Two decades of satellite research have shown that at times of high sunspot number, the value of the solar constant increases slightly. While sunspots are cooler areas of the sun, as their numbers increase, so does the number of solar flares that release large amounts of heat. Does an increase in the solar constant contribute to warmer temperatures on Earth? Only through further research will scientists be able to answer this and other questions about global climate changes.

Solar wind The sun emits more than just heat and light. Another emission, called *solar wind*, is an electrically charged mixture of protons and electrons. Evidence of solar wind comes from the tails of comets. A comet’s tail acts like a “wind sock” and shows that there is a continuous flow of particles coming from the sun (Figure 31.32).

Magnetic storms Solar flares can greatly increase the amount of solar wind emitted by the sun. These solar wind particles can affect Earth’s upper atmosphere, causing *magnetic storms*. Magnetic storms can disrupt radio and television signals, interfere with telephone and cell phone signals, and even cause electrical power problems for homes and businesses.

Auroras Solar winds can also cause a mysterious phenomenon known as an *aurora* to occur. Auroras (known in the Northern hemisphere as the northern lights) occur when the protective layers of our atmosphere are energized by solar winds. This energy causes atoms and molecules in the upper atmosphere to emit light. The most common color produced is a yellow-green caused by oxygen atoms at an altitude of about 60 miles. These lights appear as curtains above the horizon (Figure 31.33).

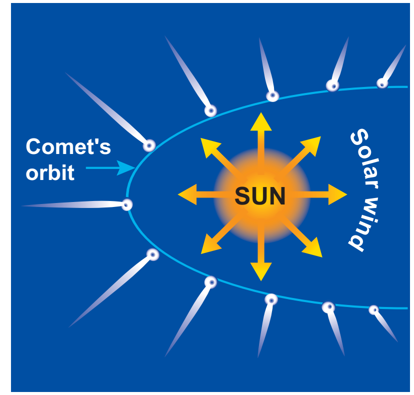


Figure 31.32: *The direction of a comet’s tail provides evidence that the sun emits solar wind.*

Figure 31.33: *Auroras are a mysterious phenomenon caused by solar winds. Energy from solar winds causes atoms in the upper atmosphere to emit light.*

Harnessing the sun's energy

What is solar energy?

The fusion of hydrogen into helium has been occurring on the sun for 5 billion years, and will continue for another 5 billion. As the fusion process continues, some of this energy reaches Earth in the form of *electromagnetic waves*. These waves can be classified according to their energy as shown in Figure 31.34. The only electromagnetic wave we can detect with our eyes is *visible light*. As you can see from Figure 31.34, this is only a tiny portion of the electromagnetic spectrum. When light from the sun passes through a prism, we can see that it is made up of all of the colors of the visible spectrum.

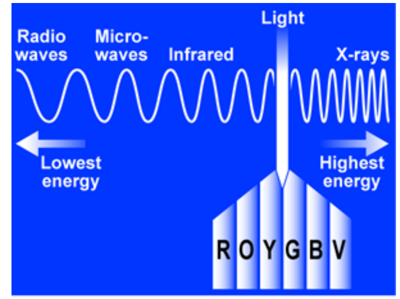


Figure 31.34: *The sun emits waves in all frequencies of the electromagnetic spectrum. The only waves we can detect with our eyes are visible light. The colors of light, from lowest to highest energy are: Red, orange, yellow, green, blue, and violet.*

How we use sunlight

There are many ways to collect sunlight and use it to produce energy for our everyday needs. When we use energy from the sun it is called **solar energy**. Different ways of collecting solar energy are discussed below.

Passive solar heating

Buildings that use passive solar heating are designed to trap the warmth of the sun. Houses can be built with large glass windows that face the direction of the sun. Sunlight passes through the windows and is trapped in the room, causing it to become warmer. Greenhouses use passive solar heating to grow plants during the winter in cold climates.

Circulated solar heating

Have you ever seen a building with large glass panels covering part of its roof? Buildings with these panels use them to harness the sun's energy. Underneath the glass panels, water is circulated through tubes. The water is heated by the sun and flows into the building where it can be used for hot water or heating. The heated water can also be stored in an insulated tank for use at night.

Photovoltaic cells (PV cells)

Photovoltaic (or PV) cells, also called *solar cells*, are devices that convert sunlight directly into electricity. You may have seen PV cells on calculators, watches, or some outdoor light fixtures. They are made out of at least two layers of a semiconductor material such as silicon. One layer has a positive charge, and the other has a negative charge. When light falls on the cell, some of it is absorbed by the semiconductor atoms, freeing electrons from the PV cells' negative layer. These electrons then flow through an external circuit and back into the positive layer. The flow of electrons produces electric current (Figure 31.35).

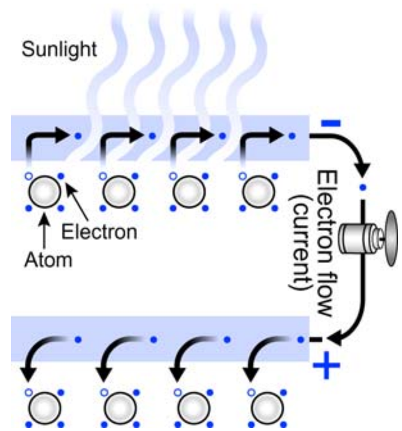


Figure 31.35: *Sunlight enters the PV cells, causing electrons to flow through a circuit to produce electric current.*

Increasing the efficiency of PV cells

The uses for PV cells

In space, virtually all communications satellites are powered by PV cells. On Earth, their use is more limited. PV cells are common in remote places that do not have electrical power lines. For example, they are often used to provide power to radar stations and radio towers. However, they are not as common in places that have power lines. Since PV cells can generate electricity without producing harmful emissions, scientists are working on ways of improving them so they can be used more often.

PV cells are inefficient

Low efficiency of energy conversion is the biggest obstacle to getting more electricity from PV cells. Less than 10 percent of the light energy falling on a PV cell is converted to electricity. Many research projects are underway to increase the efficiency of PV cells. One technique being tested is to make cells of multiple layers. Each layer is designed to be more efficient for a certain range of colors. For example, the top layer could be designed to be efficient with blue light. The second layer with red light, and so on.

Atmospheric conditions

A second problem with generating electricity from solar energy is that clouds get in the way! Earth's atmosphere is a very active place. The top of the atmosphere receives 1,358 watts per square meter from the sun. On a sunny day, about 1,000 watts per square meter reach the ground as light. On a cloudy day less than 50 watts per square meter reach the ground.

PV cells do not work at night

Because photovoltaic cells cannot make any electricity at night, they must rely on batteries to store the energy for later use. Unfortunately, the efficiency of batteries is not much greater than that of PV cells. Many scientists and engineers are doing research to improve the efficiency of batteries.

Solar power from space?

Scientists are working on the possibility of collecting solar power above Earth's atmosphere. Concentrators on satellites would focus the sun's energy onto arrays of PV cells. The energy produced would then be transmitted back to Earth in the form of microwaves or laser beams and "received" by consumers much like radio and television signals. While this idea may be possible, there are many unanswered questions, including: How much will it cost? What are the health or environmental hazards of transmitting power using laser beams or microwaves?

Figure 31.36: *PV cells are commonly used to power satellites. Why aren't they more common on Earth?*

Research idea: Space solar power

Conduct research on the concept of *space solar power.* Is this type of energy feasible? What are the major advantages? What are the potential hazards? Based on your research, do you think it's a good idea? Why or why not? Prepare a presentation or paper summarizing your findings. Here are some good websites:

www.space.com

spacesolarpower.nasa.gov

www.eree.energy.gov

Chapter 31 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. gravitational force	a. a regular, repeating path that one object in space follows around another
2. satellite	b. the measure of the attractive force exerted by one object on a 1.0 kg object held at its surface
3. orbit	c. the speed required to keep an object in orbit around another object
4. orbital speed	d. the forward motion of an object in space
5. tides	e. the rising and falling of ocean levels in daily rhythms
	f. an object in orbit

Set Two

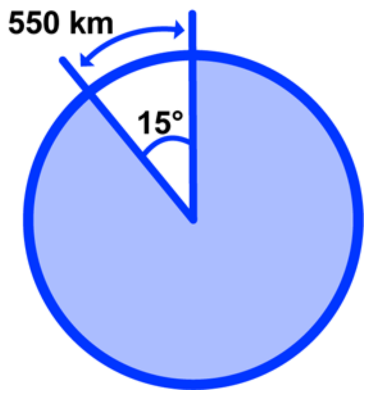
1. solar constant	a. made mostly of rock and metal and have high densities, slow rotations, and few moons
2. astronomical unit	b. an object that orbits the sun but is too small to be considered a planet
3. terrestrial planet	c. made mostly of hydrogen and helium and has low density, fast rotations, and many moons
4. gas planet	d. objects made mostly of ice and dust and which form a tail as they approach the sun
5. asteroid	e. equal to the distance of Earth from the sun
	f. the amount of the sun's energy that reaches one square meter at the edge of Earth's atmosphere

Concept review

1. According to Newton's law of universal gravitation, the force of gravity acting between two objects involves two variables. Name these two variables.
2. Describe how you would measure Earth's gravitational force.
3. Explain why the moon would need a faster orbital speed to stay in orbit around Earth if it were moved closer to Earth's surface.
4. Why does the sun's gravitational force have a lesser affect on tides than the moon's, even though the sun has a much greater mass than the moon?
5. Describe the *giant impact theory* of the moon's formation.
6. What is gravitational locking? How does it explain the fact that we can only see one side of the moon from Earth?
7. Describe the factors that keep a satellite in orbit.
8. What are the differences between terrestrial planets and gas planets? Which type is Pluto?
9. Why does a comet form a visible tail as it approaches the sun?
10. What is the difference between a meteor and a meteorite?
11. What are auroras and what causes them?
12. Name three ways to harness the sun's energy.

Problems

1. Use the information in the diagram below to calculate the circumference, in kilometers, of the planet.



2. Jupiter exerts a gravitational force of 23.1 N on a 1.0 kg object held at its surface. Use this information and the equation of universal gravitation to calculate Jupiter's mass.

3. CHALLENGE! In the previous problem, you calculated Jupiter's mass. This value is equal to over 300 times Earth's mass, yet Jupiter's gravitational force is only about 2.5 times that of Earth's. Can you explain why Jupiter's gravitational force is not higher?

4. A large truck weighs 6,990 pounds on Earth. How much would the same truck weigh, in pounds, on Jupiter?

5. A moon rock weighs 8.5 pounds on the moon. How much would this rock weigh on Earth?
(Gravitational force on the moon = 1.6 N)

6. Venus has a mass of 4.9×10^{24} kg. Use the equation of universal gravitation to calculate Venus's gravitational force. Show all of your work.

7. Saturn has a mass of 5.7×10^{26} kg. Its radius is 60,330 km. Calculate Saturn's density in g/cm^3. Show your work. You can check your answer using Table 31.1, "Comparing properties of the planets," on page 624.

8. The sun's diameter is 1.4 million km. Its mass is 332,830 times that of Earth's. Use this information to calculate the density of the sun. Show all of your work.

9. The star Alpha Centauri is 4.13×10^{13} km from the sun. Calculate this distance in astronomical units (AU).

10. Betelgeuse appears as a twinkling red star in the night sky. It is 700 light years from Earth. Answer the following questions:

    a. How far from Earth is Betelgeuse in kilometers?

    b. How far from Earth is Betelgeuse in AU?

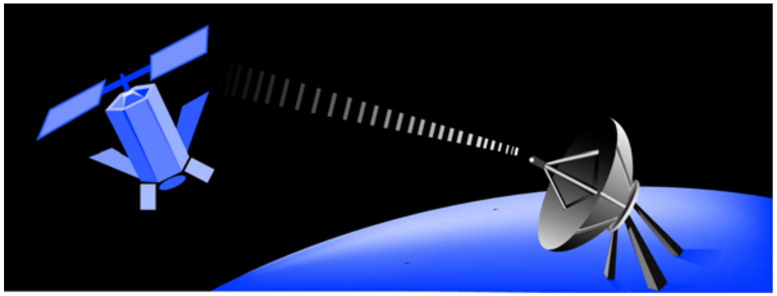
11. If you traveled a distance of one light year, how far did you travel in AU?

12. You have read that each second on the sun, 700 million tons of hydrogen is converted through fusion into 695 million tons of helium. There is a missing mass of 5 million tons. What happens to it? How does Einstein's equation $E = mc^2$ help explain what happens to this "missing" mass in terms of energy output from the sun?

13. You have learned that hydrogen fusion occurs inside the core of the sun. If one hydrogen atom fuses with another hydrogen atom, helium is produced. In some stars, the core becomes hot enough for the fusion of helium atoms to occur. If two helium atoms fused, what possible atoms could be formed? Support your answer with sketches of the nuclei of the atoms involved.

Applying your knowledge

1. A satellite in *geosynchronous orbit* travels at the correct orbital speed so that it takes it exactly 24 hours to orbit Earth. From Earth, a satellite in geosynchronous orbit appears to "hover" over one spot on the equator. That means a receiving dish on the Earth can point at the satellite at one spot in the sky and not have to "track" its motion.



Conduct research on satellites in geosynchronous orbit. Find the following information: At what distance above Earth do these types of satellites orbit? What orbital speed is necessary for a satellite to be in geosynchronous orbit? What are these types of satellites used for? What are the advantages and disadvantages of these types of satellites?

2. Even though Mercury is closer to the sun, surface temperatures on Venus are hotter. In fact, Venus is the hottest planet in the solar system. Explain why this is so.

3. Pluto is called the ninth planet though sometimes it is actually the eight planet. Explain why.

4. Explain why the exact dates for meteor showers can be predicted with accuracy.

5. Using the density data from Table 31.1, "Comparing properties of the planets," on page 624, make a bar graph comparing the densities of the nine planets. Explain the density differences among the planets.

6. Use the data in Table 31.1, "Comparing properties of the planets," on page 624, graph distance from the sun on the *x*-axis and orbital speed on the *y*-axis. You may plot the distance in kilometers or astronomical units. What is the shape of the graph? How does this graph support the universal law of gravitation? Explain your answer in detail.

7. You have read that the Kuiper Belt was discovered in 1992, yet its existence was predicted in 1952. Conduct research on the Kuiper Belt to answer the following questions:

   What technology led to the discovery of the Kuiper Belt?
   What evidence was used to predict its existence?
   What is the largest Kuiper Belt Object found to date?
   How do astronomers look for objects in the Kuiper Belt?

8. Use the data in Table 31.1, "Comparing properties of the planets," on page 624 to answer the following questions:

   a. Which planet would float in a giant bathtub of water?
   b. Which planet has the most moons? What data from the table explains why?
   c. Which planets have similar atmospheres? Why do you think their atmospheres are similar?
   d. Make a graph of mass versus gravitational force. Does the graph show a strong, medium, or weak relationship? Explain the reason behind your answer.

UNIT 11 Astronomy

Chapter 32 The Universe

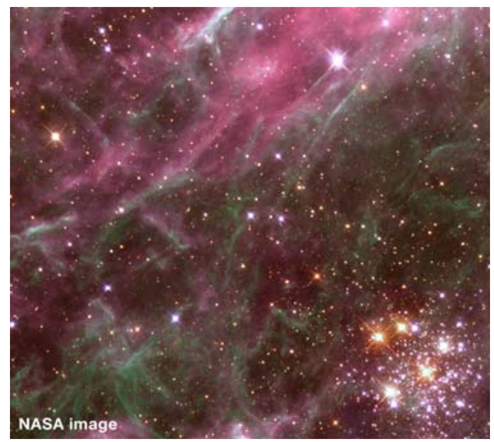
So far in this unit, you have learned mostly about objects that are relatively close to Earth such as other planets, their moons, and the sun. The solar system occupies a very tiny portion of the Milky Way Galaxy. This galaxy contains hundreds of billions of stars like the sun, and is one of many billions of galaxies in the universe. The universe is a term astronomers use to describe everything that exists including all matter and energy. In this chapter, you will learn about objects that are very far away including stars and galaxies. You will also read about how many scientists believe the universe began.

32.1 Stars — *What are stars made of?*

Astronomers use a spectrometer to analyze the light emitted by stars and determine the elements from which stars are composed. In this Investigation, you will use a spectrometer to analyze light and examine spectral diagrams to determine the composition and temperature of stars.

32.2 Galaxies and the Universe — *How do we use light to measure the distances to stars and galaxies?*

Distances to stars and galaxies in the universe are so vast that they are very difficult to measure. One of the tools astronomers use to measure distances in the universe is light. In this Investigation, you will discover the mathematical relationship between how bright an object appears from a distance, and how much light it actually gives off. This important relationship is used by astronomers to calculate distances in the universe.



Learning Goals

In this chapter, you will:

- ✔ Identify the conditions necessary for fusion to occur inside a star.
- ✔ Describe the information that spectroscopy provides about stars.
- ✔ Relate the color of a star to its temperature.
- ✔ Explain the factors that determine the brightness of a star in the sky.
- ✔ Discuss the importance of the H-R diagram to astronomers.
- ✔ Explain the relationship between mass and the life cycle of a star.
- ✔ Describe the phases in the life cycle of a sun-like star.
- ✔ Discuss how the death of a massive star is responsible for the creation of elements heavier than helium on the periodic table.
- ✔ Describe how the composition and size of planets is related to their formation and proximity to the sun.
- ✔ Identify the structure of the Milky Way Galaxy and the location of our solar system within the galaxy.
- ✔ Explain how astronomers measure the distance to stars and galaxies.
- ✔ Identify the scientific evidence that supports the Big Bang theory.

Vocabulary

absolute brightness	constellation	main sequence stars	protostar
apparent brightness	Doppler shift	nebula	spectroscopy
Big Bang	H-R diagram	parallax	standard candle
Cepheid	inverse square law	planetary system	supernova

32.1 Stars

During the day, we see only one star, the sun, which is 150 million kilometers away. On a clear night, about 6,000 stars can be seen without a telescope. The closest star in the nighttime sky is Alpha Centauri—4.3 light years (41 trillion kilometers) away. Where do stars come from? How long do they last? In this section you will find the answers to these questions and more.

Figure 32.1: *The star at the tip of the Little Dipper's handle is called Polaris. If you look toward Polaris, you are facing the North Pole.*

Constellations

A constellation is a group of stars that, when seen from Earth, form a pattern. The stars in the sky are divided into 88 constellations. The largest, Centaurus, contains 101 stars. The most familiar star formation, the Big Dipper, is actually part of a larger constellation called Ursa Major (the Great Bear). The Little Dipper, part of Ursa Minor, contains Polaris, the North Star, which is located at the tip of the handle (Figure 32.1). Anybody in the Northern Hemisphere who is looking toward Polaris is facing the North Pole.

Stars and fusion

What is a star? A *star* is essentially a giant, hot ball of gas. Stars generate light and heat through nuclear reactions. Specifically, they are powered by the fusion of hydrogen into helium under conditions of enormous temperature, mass, and density. When hydrogen atoms fuse, helium is created. During this process, some mass is lost and converted to energy as described in Albert Einstein's famous equation:

$$\overset{\text{Energy}}{E} = \overset{\text{Mass}}{m}\underset{\text{Speed of light}}{c}^2$$

What makes fusion occur? The conditions required for the continuous fusion of hydrogen include extremely high values for temperature, density, and mass. Furthermore, hydrogen fusion does not take place throughout the star, but only deep in its core, where the temperature is hot enough. The minimum temperature required for fusion to occur is 7 million°C. The sun's core reaches a temperature of 15 million°C.

Density and mass Even though stars are made of gas, they have extremely high values for density and mass. For example, the density of the sun's core is about 158.0 g/cm^3. This is about 18 times the density of copper. The sun has a total mass that is equal to 330,000 Earths. Stars can range in mass from about 100 times that of the sun to less than one-tenth its mass. At masses lower than this, the internal temperature does not get hot enough to sustain the fusion of hydrogen.

Examining light from stars

What is spectroscopy? Stars shine because they are hot. Astronomers analyze the light emitted by stars, and other "hot" objects in space in order to determine their chemical composition and temperature. Sometimes they can even determine how fast the object is moving, its mass, and its density by analyzing the light it emits. **Spectroscopy** is a tool of astronomy in which the electromagnetic radiation (including visible light) produced by a star or other object (called its spectrum) is analyzed.

Chemical composition of stars During the mid-1800s, scientists used a device called a *spectrometer* to observe flames produced by burning substances. A spectrometer splits light into a spectrum of colors and displays lines of different colors along a scale. The scale measures the wavelength of each of the lines of color in nanometers (nm). The scientists discovered that each element has its own unique pattern of lines—like a fingerprint. For example, when the element sodium is burned, two prominent yellow lines at precisely 589.0 and 589.6 nanometers are observed when the light is passed through a spectrometer (Figure 32.2). *Spectroscopy* was born, and astronomers now had a tool they could use to determine the chemical composition of the stars.

The composition of the sun In 1861, Sir William Huggins, an amateur astronomer in England, used spectroscopy to determine that the sun and the stars are composed mostly of hydrogen. A few years later, his countryman Sir Joseph Norman Lockyer observed a line at the precise wavelength of 587.6 nanometers. Since no known element on Earth had a line at this wavelength, he concluded that this must be an undiscovered element and named it helium, after the Greek name for the sun, *Helios*. Today, we know that hydrogen is the most abundant element in the universe, with helium second (Figure 32.3).

Color and temperature When a bar of iron is heated, it first glows red. As its temperature increases, its color changes to orange, yellow, and finally white. The hottest objects have a bluish color. Scientists use this fact to determine the temperature of stars and other objects in space. For example, red stars have the coolest temperatures while blue stars have the hottest. Our sun is yellow, which means that its temperature is somewhere in between those of red stars and blue stars.

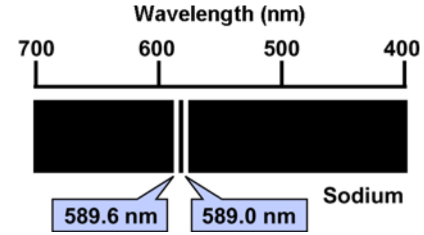


Figure 32.2: *When the element sodium is burned, two prominent yellow lines are observed at 589.0 and 589.6 nanometers on the scale of a spectrometer.*

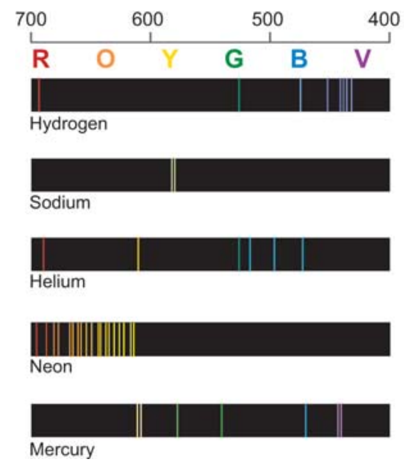


Figure 32.3: *Spectral lines for some of the other elements.*

Classifying stars

How are stars classified?

At least 6,000 stars are visible in the night sky without the aid of a telescope. There are countless billions of stars in the universe that you cannot see. Astronomers classify stars according to their physical characteristics. The main characteristics used to classify stars are *size*, *temperature*, and *brightness*.

Sizes of stars

The sun, with a diameter of 1.4 million kilometers, is a *medium-sized* star. The closest star to the sun, Alpha Centauri, is also a medium-sized star. The largest stars, called *supergiants*, have a diameter that can exceed 1,000 times that of the sun. The largest known supergiant is 2,700 times the diameter of the sun. The next largest group of stars, simply called *giants*, are about 250 times the diameter of the sun. Stars that are smaller than the sun come in two categories, *white dwarfs* and *neutron stars*. White dwarfs are about the size of the smaller planets. Sirius B, the largest known white dwarf, has a diameter of 10,400 kilometers, making it slightly smaller than Earth. Neutron stars are even smaller—their diameter is only 20 to 30 kilometers! Figure 32.4 shows the relative sizes of each type of star.

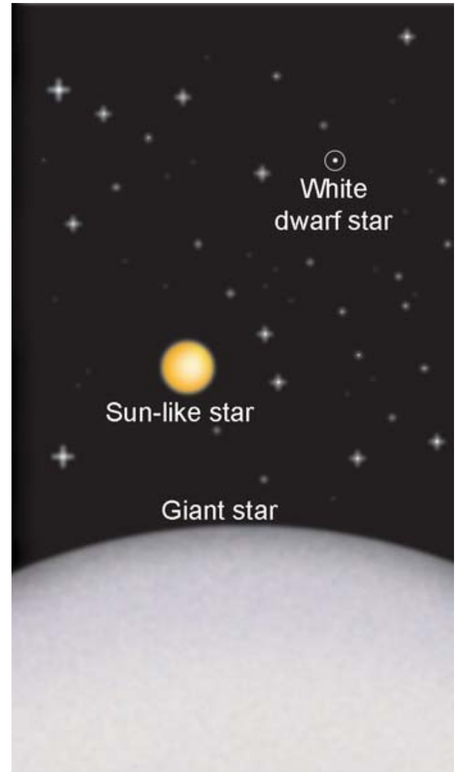


Figure 32.4: *Comparing different sizes of stars.*

Temperatures of stars

If you look closely at the stars on a clear night, you will see slight differences in their colors. This is related to the fact that their surface temperatures are different. You have already read that a red star is cooler than a white star, while blue stars are the hottest. The table below names some stars and gives their colors and their surface temperatures.

Table 32.1: ***Stars, their colors, and their surface temperatures***

Star	Color	Temperature range (°C)
Betelgeuse	red	2,000 to 3,500
Arcturus	orange	3,500 to 5,000
Sun	yellow	5,000 to 6,000
Polaris	yellow-white	6,000 to 7,500
Sirius	white	7,500 to 11,000
Rigel	blue-white	11,000 to 25,000
Zeta Orionis	blue	25,000 to 50,000

Magnitudes You will notice too that stars vary in their brightness. About 2,200 years ago, a Greek astronomer named Hipparchus classified the stars into six groups according to their brightness. He called these groups *magnitudes*. In his system, the brightest stars were called first-magnitude stars, and the faintest stars sixth-magnitude. Hipparchus' system is still in use. Because of improved tools, the magnitude scale has been extended to include fainter and brighter objects. Through a good telescope, we can see much fainter stars, almost to the 30th magnitude. This is 4 billion times fainter than the human eye can see unaided!

Apparent and absolute brightness How bright a star appears in the sky depends on two factors: the star's distance from Earth and the amount of light (energy) it actually gives off. Astronomers define a star's brightness as observed from Earth as its **apparent brightness**. This quantity can be measured fairly easily using a *photometer* (an instrument that measures brightness). A star's **absolute brightness** is defined as the brightness the star would have if it were a standard distance from Earth. Astronomers arbitrarily set the standard distance at 10 *parsecs*. One parsec is equal to 3.26 light years. This means that 10 parsecs equals 32.6 light years.

The difference between apparent and absolute brightness Imagine observing a candle that is two meters from you, and a campfire that is 100 meters away. From where you are, the candle appears brighter than the campfire, even though the campfire is giving off much more light. At these distances, the candle has a greater *apparent* brightness than the campfire. Suppose the candle and campfire are moved so that both are now 10 meters from you. When this happens, the campfire appears much brighter than the candle. This is because the campfire has a greater *absolute* brightness than the candle. Therefore, absolute brightness is a measure of how much light an object actually emits (Figure 32.5).

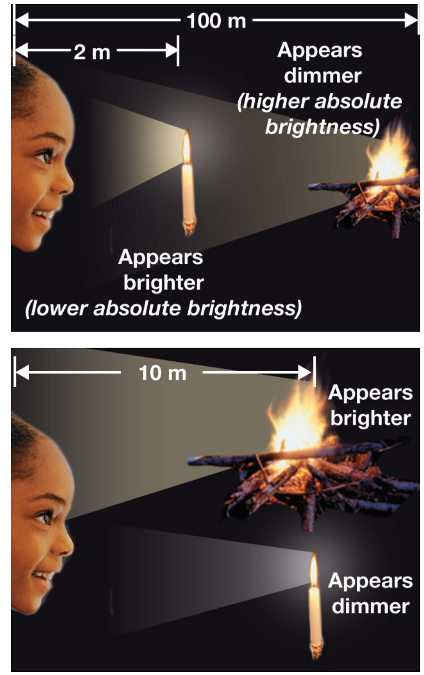


Figure 32.5: *An illustration of apparent and absolute brightness.*

Apparent brightness decreases as distance increases This example explains why the apparent brightness of an object depends on its absolute brightness and on how far away it is from an observer. As Figure 32.6 shows, just because one star appears brighter than another does not mean that it has a higher absolute brightness. The apparent brightness of an object decreases the farther away from it you move regardless of its absolute brightness. If you were to observe the sun from Pluto, the farthest planet, the sun would appear much dimmer. The relationship between apparent brightness, absolute brightness, and distance will be explored in Section 32.2.

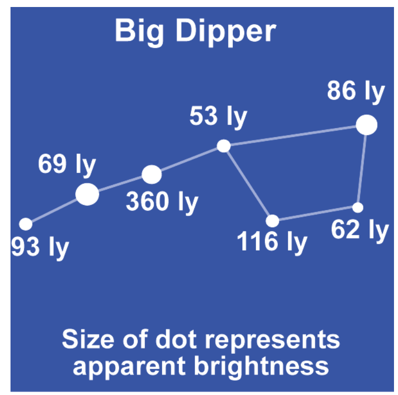
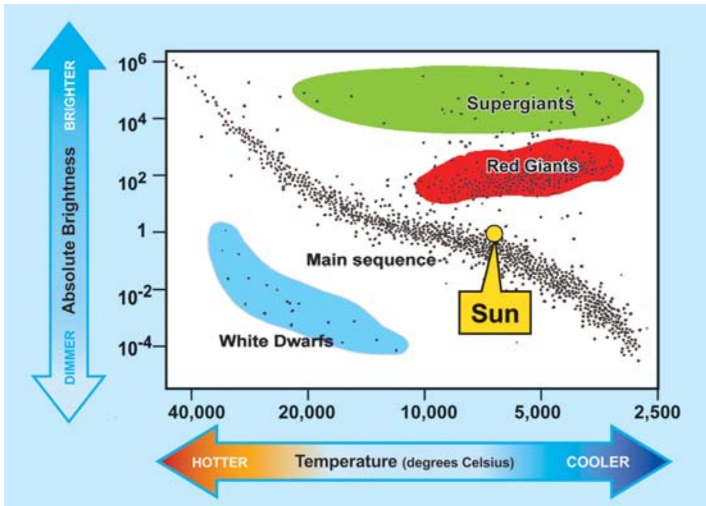


Figure 32.6: *Which star do you believe has the greatest absolute brightness? Explain your answer.*

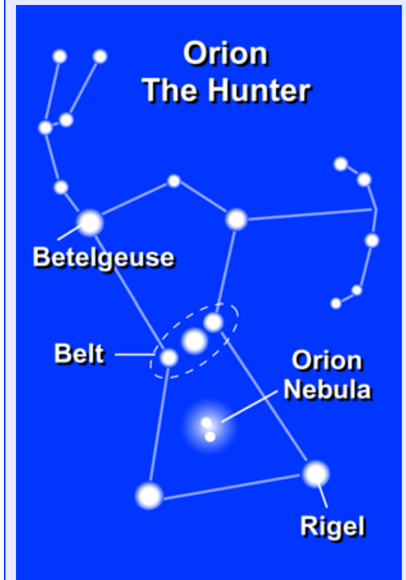
Comparing temperature and brightness of stars

H-R diagrams In the early 1900s, the Danish astronomer Ejnar Hertzsprung and American astronomer Henry Russell developed an important tool for studying stars. They made a graph in which they plotted the temperature of the stars on the x-axis and the absolute brightness on the y-axis. The result is known as the *Hertzsprung-Russell*, or H-R diagram. In the example below, each dot on the diagram represents a star whose absolute brightness and temperature are known.



Reading H-R diagrams H-R diagrams are useful because they help astronomers categorize stars into distinct groups. Stars that fall into the band that stretches diagonally from cool, dim stars to hot, bright stars are called main sequence stars. Main sequence stars, like the sun, are in a very stable part of their life cycle (described on the next page). *White dwarfs* are in the lower left corner of the diagram. These stars are hot and dim and cannot be seen without a telescope. *Red giants* appear in the upper right side of the diagram. These stars are cool and bright and can be seen without the aid of a telescope in the night sky. *Supergiants*, both red and blue, are found in the extreme upper portion of the diagram. H-R diagrams are also useful because astronomers can use them to predict the absolute brightnesses of stars for which that value has not been determined.

Observing stars



If you locate the constellation Orion in the night sky, you can see Betelgeuse, a red supergiant, and Rigel, a blue supergiant. It is easy to find this constellation because of the three stars that form its belt. Just below the belt is the Orion Nebula, which you can see with a pair of binoculars. You will learn about nebulas on the next few pages.

Life cycle of stars

Stars have a life cycle

Like living organisms, stars have a life cycle. Of course, stars are not truly "alive" but astronomers sometimes use the terms "born," "live," and "die" to represent parts of that cycle. Our sun, a medium-sized star, was born about 5 billion years ago. Because most medium-sized stars have a life span of around 10 billion years, it will live for another 5 billion years before it dies. Stars that are larger than the sun have shorter life spans.

How are stars born?

A star, regardless of its size, begins its life inside a huge cloud of gas (mostly hydrogen) and dust called a nebula (Latin for "mist"). Gravitational forces cause denser regions of the nebula to collapse, forming a *protostar*. A protostar is the earliest stage in the life cycle of a star. The gases at the center of the protostar continue to collapse, causing pressure and temperature to rise. A protostar becomes a *star* when the temperature and pressure at its center become great enough to start nuclear fusion. This is the nuclear reaction in which hydrogen atoms are converted into helium atoms and energy is released. Figure 32.7 shows a portion of the Orion Nebula, the birthplace of many stars.

A star is born when temperature and pressure become great enough to start nuclear fusion.

Main sequence stars

Once nuclear fusion begins, a star is in the *main sequence* stage of its life cycle. This is the longest and most stable part of a star's life. The length of the main sequence stage depends on a star's *mass*. You may suppose that stars with larger masses live longer than those with smaller masses because they contain more hydrogen fuel for nuclear fusion. The opposite is true. **Stars with large masses use up their hydrogen fuel more quickly than stars with small masses, so they have much shorter life spans.** Because of this, they burn brighter, and hotter than smaller stars. The main sequence stage of sun-like stars (stars with the same mass as the sun) lasts for about 10 billion years. The main sequence stage of stars over 100 times more massive than the sun lasts only a few million years. This stage for stars that are less massive than the sun can last for more than 50 billion years.

Photo courtesy of NASA-HQ-GRIN

Figure 32.7: *A NASA/HST photo of a portion of the Orion Nebula. A group of protostars is visible in the center of the nebula.*

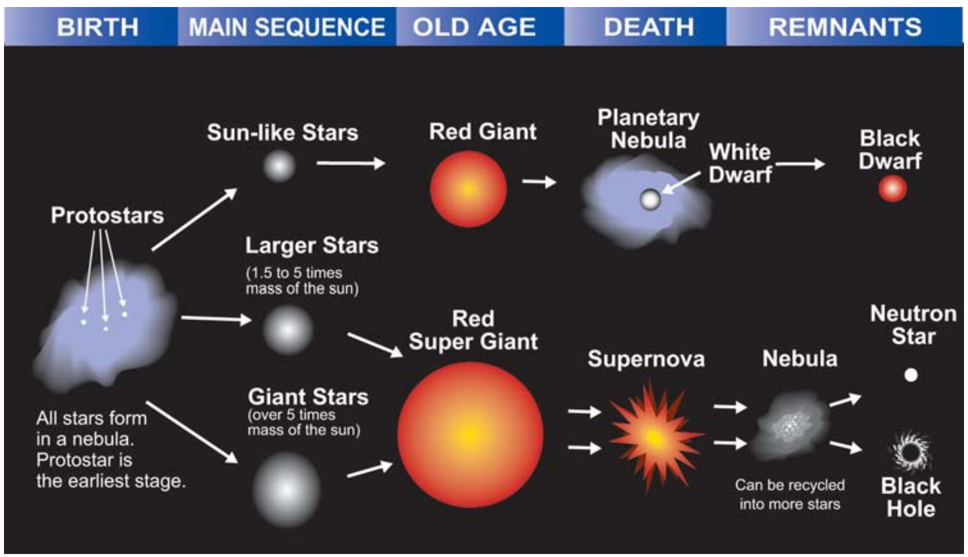
The Orion Nebula

You can see the Orion Nebula if you look closely below the three stars that form Orion's belt. It will appear as a fuzzy spot to the naked eye on a very clear night. This nebula is over 20 light years in width. With binoculars, you can see some bright, young stars lighting up its center. With a powerful telescope, many protostars can be seen. When you look at the Orion Nebula, you are witnessing how our sun was born almost 5 billion years ago.

Old age As a star grows old, its core begins to run out of hydrogen fuel. Gravity causes the core to contract, raising its temperature and igniting the helium inside the core, along with any hydrogen in the outer layers. The star expands, and the outer layers begin to cool. At this stage in its life cycle, a small or medium-sized star becomes a *red giant*. When the sun reaches this stage in its life cycle (about 5 billion years from now), it will become so large that it will swallow up Mercury, Venus, and Earth.

Death Once the nuclear reactions in the core of small to medium-sized stars cease, there is nothing to prevent gravity from crushing the matter together as close as possible. At this stage, the core glows brightly and is called a *white dwarf*. It is about the size of Earth, and has the same mass as the sun. Because of its high density, a thimbleful of matter from a white dwarf on Earth would weigh about the same as an elephant! During the white-dwarf stage, the outer layers of the star expand and drift away from the core, forming what is called a *planetary nebula*. This is different from a nebula where stars are born.

Remnants When a white dwarf stops glowing, it is called a *black dwarf*, the final stage in the life cycle of small and medium-sized stars. The life cycle of stars is summarized in the diagram below. The death of massive stars is discussed on the following page.



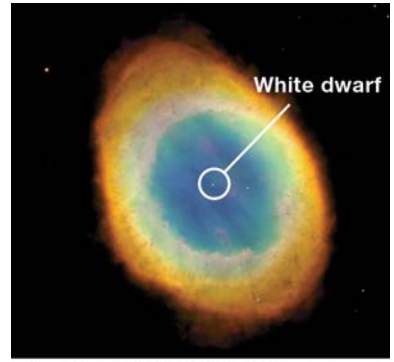


Photo courtesy of NASA-HQ-GRIN

Figure 32.8: *The famous Ring Nebula, showing the death of a sun-like star. The outer rings are called the planetary nebula. The glowing, white dwarf can be seen in the center. Photo courtesy NASA/HST.*

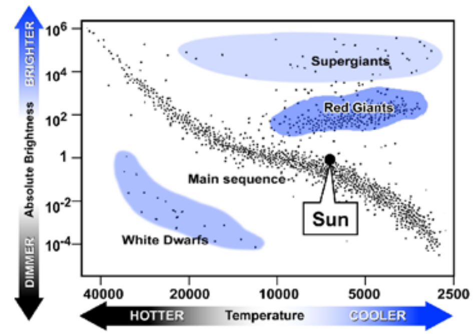


Figure 32.9: *Different stages in the star life cycle appear in clusters on the H-R diagram. Stars in the main sequence stage form the diagonal band that includes the sun. 90 percent of all stars are main sequence stars.*

The death of massive stars = the birth of elements

The creation of elements

Stars that are at least five times more massive than the sun have a different end to their life cycle. As the core begins to run out of hydrogen fuel, it yields to gravity and begins to shrink, growing hotter and denser. More heat is generated by this contraction than in a small or medium star, so the core does not become a white dwarf. Instead, the tremendous heat generated causes helium atoms to fuse into carbon and oxygen atoms. This is followed by the fusion of carbon and oxygen atoms into neon, sodium, magnesium, sulfur, and silicon. Meanwhile, the outer layers of the massive star expand and cool, making the star a *red supergiant*.

The end of fusion in the core

Once the carbon atoms in the core are depleted, it shrinks again, creating even greater pressure and temperatures. This causes the fusion of even heavier elements such as calcium, nickel, chromium, copper, iron, and others. When the core of the star contains mostly iron, the fusion stops. This is because iron's nuclear structure does not allow the fusion of heavier elements. In fact, the fusion of elements heavier than iron *requires* energy, rather than *producing* it.

Supernovas

Because a giant star has such a great mass, almost the moment fusion stops in its core, it begins to collapse from the tremendous gravity. This collapse of the entire mass of the star upon the core causes the temperature inside to rise to over 100 million °C as the iron atoms are crushed together. A huge repulsive force between the iron nuclei overcomes the force of gravity, causing a spectacular explosion to occur, called a **supernova**. The actual explosion takes only a few minutes (Figure 32.10). During this brief period, heavier elements such as gold and uranium are created, as atomic nuclei are smashed together. The explosion propels the matter out into space in all directions.

Neutron stars and black holes

The light and heat produced by a supernova fades over time, and the remnants become a nebula that can be recycled again to make more stars. All that remains of the original star is a core composed entirely of neutrons called a *neutron star*. This super-dense object is no more than a few kilometers in diameter! If a dying star has a core that is three or more times the mass of the sun, the force of its collapse is so strong that an explosion cannot occur. The gravitational forces are so strong that not even light can escape. All that is left is a phenomenon called a *black hole*.

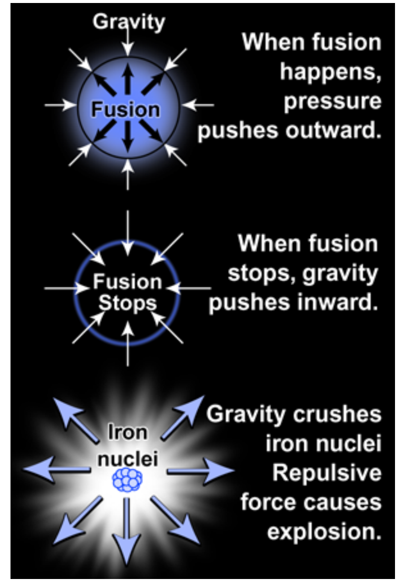


Figure 32.10: *How a supernova happens.*

Supernova sightings

In 1054 AD, a supernova was observed and recorded by Chinese astronomers. They observed a star so bright that it could be seen both night and day. The remnants make up the Crab Nebula. The only supernova to be observed in modern times occurred in 1987. Light from the explosion reached Earth on February 23, 1987, after a journey of 169,000 light years.

The formation of the solar system

Do other planetary systems exist?

In 1995, three Earth-sized planets were discovered orbiting a star much like our sun. This was among the first evidence of a star other than the sun with orbiting planets. A star with orbiting planets is called a planetary system. Since then several other planetary systems have been detected. Scientists now believe that planets are a natural by-product of the formation of stars. Therefore, planets of some type should exist around many stars in the universe.

How was our solar system formed?

The solar system was formed out of the same nebula that created the sun. As the sun was being formed 4.6 billion years ago, it was surrounded by a cloud of dust and gas. This cloud was made mostly of hydrogen and helium, but contained smaller amounts of other elements such as carbon, nickel, iron, aluminum, and silicon. As this cloud spun around, it flattened, with the help of gravity, into a disk-shape along the axis of its rotation. This explains why all of the planets formed in the same plane around the sun, and why they all orbit in the same direction.

Planet formation

At the center of the disk, temperatures became hot enough for fusion to begin, creating the sun. Farther away from the center, the heaviest molecules began to condense into solid and liquid droplets. These droplets began to collide, forming small clumps—the seeds of the planets. Through further collisions, these clumps of material grew larger and eventually formed into the planets.

The terrestrial planets

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

The gas planets

The outer regions of the disk were rich in icy materials made of lighter elements and the planets there grew comparatively large. Because of their large masses, they were able to capture hydrogen and helium through their gravitational force and so form thick atmospheres. These became *gas planets*, rich in hydrogen and helium with dense, frozen cores. The outermost planet, Pluto, is neither a gas nor a terrestrial planet, but a tiny, frozen object with a thin atmosphere.

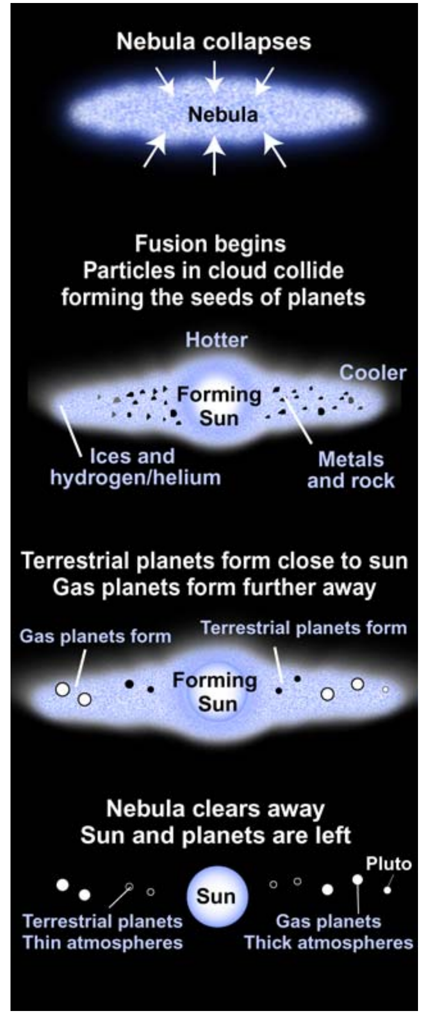


Figure 32.11: *The formation of our solar system. Scientists now believe that this is a common process in the universe.*

32.2 Galaxies and the Universe

Early civilizations believed that Earth was the center of the universe. In the 16th century, we became aware that Earth is a small planet orbiting a medium-sized star. It was only in the 20th century that we became aware that the sun is one of billions of stars in the Milky Way Galaxy, and that there are billions of other galaxies in the universe. In the past three decades, astronomers have found evidence that the universe is expanding and that it originated 10 to 20 billion years ago. In this section you will learn about galaxies and theories about how the universe began. You will also learn how astronomers measure the vast distances of galaxies and stars from Earth.

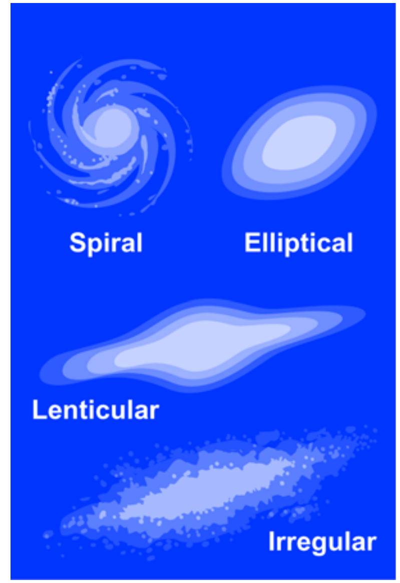


Figure 32.12: *Galaxy shapes.*

What is a galaxy?

The discovery of other galaxies

A *galaxy* is a huge group of stars, dust, gas, and other objects bound together by gravitational forces. In the 1920s, American astronomer Edwin Hubble (1889-1953) discovered that there were galaxies beyond the Milky Way. He used a new, 2.5-meter reflecting telescope to establish that some of the many fuzzy patches of light long known to astronomers were indeed separate galaxies. For example, when he focused the huge telescope on an object thought to be a nebula in the constellation Andromeda, Hubble could see that the "nebula" actually consisted of faint, distant stars. He named the object the Andromeda Galaxy. Just since Hubble's time, astronomers have discovered a large number of galaxies. In fact, many new galaxies are detected each year using the telescope named after Hubble—the Hubble Space Telescope or HST.

Galaxy shapes

Astronomers classify galaxies according to their shape. *Spiral galaxies* like the Milky Way consist of a central, dense area surrounded by spiraling arms. *Elliptical galaxies* look like the central portion of a spiral galaxy without the arms. *Lenticular galaxies* are lens-shaped with a smooth, even distribution of stars and no central, denser area. *Irregular galaxies* exhibit peculiar shapes and do not appear to rotate like those galaxies of other shapes. Figure 32.12 shows an example of each galaxy shape. The Cartwheel Galaxy (Figure 32.13) demonstrates what happens when two galaxies collide. This shape occurred when a large, spiral galaxy was struck by a smaller galaxy. The ring-like band of stars formed much like ripples occur when a rock is dropped into water.

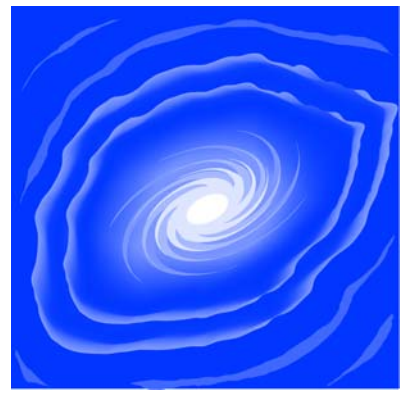


Figure 32.13: *When the Cartwheel Galaxy was struck by a smaller galaxy, a ring-like band of stars formed, much like ripples form in a pond.*

The Milky Way Galaxy

Structure of our galaxy

The sun, along with an estimated 200 billion other stars, belongs to the Milky Way Galaxy. The Milky Way is a typical spiral galaxy. From above, it would look like a giant pinwheel, with arms radiating out from a central region. The stars are arranged in a *disk* that is more than 100,000 light years across. If you could look at it from the side, you would see that our galaxy is much flatter than it is wide. In fact, it is only about 3,000 light years thick on average. At the center of the disk is a denser region of stars called the *nuclear bulge*. Surrounding the outer regions of the galaxy is an area containing clusters of older stars known as the *halo*. Figure 32.14 shows a diagram of the Milky Way Galaxy.

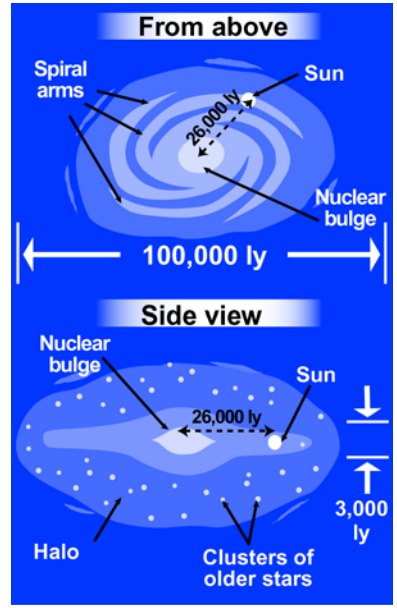


Figure 32.14: *The Milky Way is a typical spiral galaxy.*

The disk

The disk of the Milky Way is a flattened, rotating system that contains young to middle-aged stars, along with gas and dust. The sun sits about 26,000 light years from the center of the disk and revolves around the center of the galaxy about once every 250 million years. When you look up at the night sky, you are actually looking through the disk of the galaxy. On a very clear night, you can see a faint band of light stretching across the sky. This is the combined light of billions of stars in the disk of our galaxy, so numerous that their light merges together.

The center of the galaxy

Since we are located in the outer part of the galaxy, the *interstellar* (between the stars) dust blocks out much of the visible light coming from objects within the disk. Because of this, astronomers use infrared and radio telescopes to study our galaxy. Using these tools, they have learned that the center of the galaxy is crowded with older stars and hot dust. Recent studies have suggested that a black hole, with a mass of more than a million suns, exists at the very center of the galaxy. It is believed that this black hole has enough gravitational pull to keep in orbit all of the stars, gas, and dust in the Milky Way Galaxy.

Evidence for the black hole theory

The evidence for a huge black hole comes from measurements of the orbital speeds of stars and gas at the center of the galaxy. In one study, an infrared telescope was used to measure the orbital speeds of 20 stars over a three-year period. It was determined that these stars were orbiting at speeds of up to 1,000 kilometers per second (3 million miles per hour!). This extremely high orbital speed requires an object with a mass that is over 2 million times that of the sun.

The Local Group

The Milky Way is part of a cluster of galaxies known as the Local Group. In addition to our galaxy, the group contains other spiral galaxies such as the Andromeda Galaxy. Irregular galaxies in the Local Group include the Large and Small Magellanic Clouds. In all, there are about 40 galaxies in the Local Group. Other groups of galaxies also exist.

Determining distances to closer objects in the universe

Measuring the distance of closer stars

One of the greatest challenges facing astronomers is how to determine the vast distances of stars and galaxies from Earth. This information is key to mapping the universe. For objects that are under 1,000 light years from Earth, astronomers use a method called **parallax**. Parallax is the apparent change in position of an object when you look at it from different directions.

An illustration of parallax

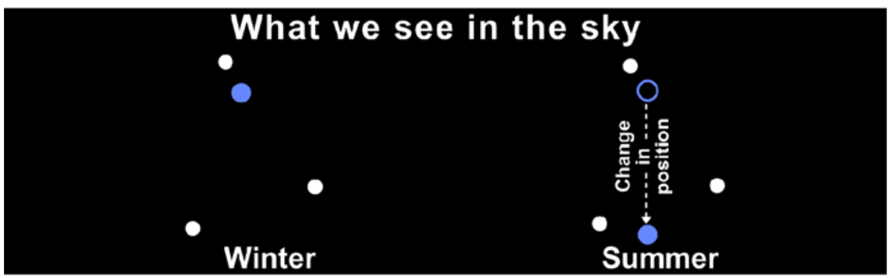
To illustrate parallax, hold one finger about six inches from your nose. Close your left eye and look at your finger with your right eye. Next, close your right eye and look at your finger with your left eye. Because your eyes are in different positions, your finger appears to move. The same is true of stars in the sky. As Earth revolves around the sun, the stars appear to change positions in the sky over the course of one year. It is actually Earth that is changing position as it revolves around the sun, while the stars remain fixed in the background (Figure 32.15).

Parallax only works for closer stars

Parallax only works for stars that are relatively close because as distance from Earth increases, the change in angle of a star becomes less measurable. You can demonstrate this by looking at a finger held before your nose as you did before. This time, try moving your finger farther and farther away from your nose while looking at it with each eye. You will notice that the farther away it is, the smaller the movement appears to become until you can detect no movement at all.

How to measure distance using parallax

To use parallax, astronomers determine the position of a star in the sky in relation to other stars that are too far away to show movement. Next, they look at the star six months later—when Earth is on the opposite side of the sun, and measure its change in position in relation to the faraway stars. Using geometry, they can determine the distance of the star from Earth (Figure 32.16 and below).



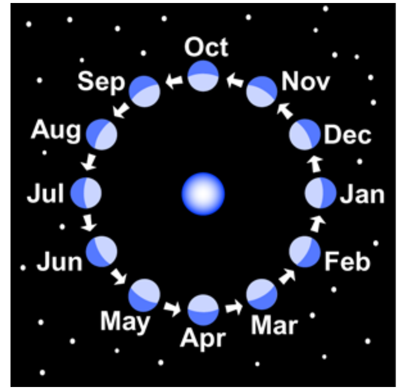


Figure 32.15: *The night side of Earth always faces away from the sun. As Earth revolves around the sun, the stars seen in the sky appear to move even though they remain fixed.*

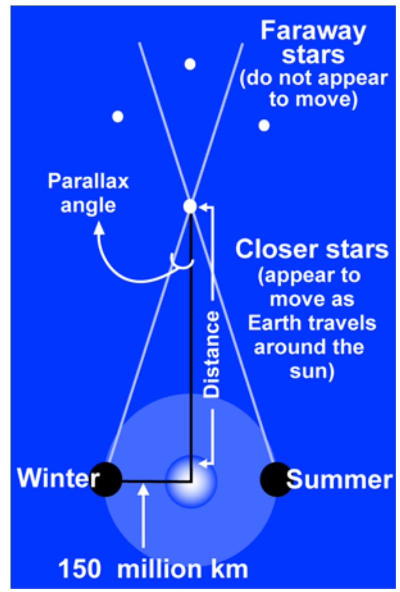


Figure 32.16: *Using parallax to measure the distance to a star.*

Measuring distances to faraway objects in the universe

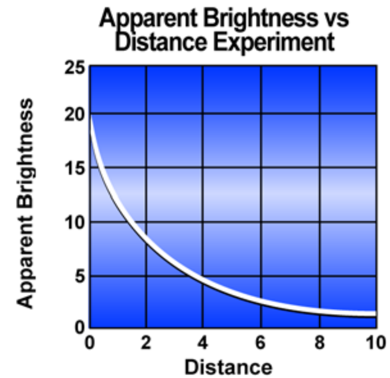


Figure 32.17: *A graph of the apparent brightness of a candle at various distances.*

The inverse square law

Light is very important to astronomers in measuring the distances to objects that are more than 1,000 light years away. Recall that the apparent brightness of an object depends on how far away it is, and how much light it actually gives off (its absolute brightness). The mathematical relationship between these variables is known as the inverse square law and is used to determine the distance to stars and galaxies.

Inverse square law

$$\underbrace{B}_{\text{Apparent brightness}} = \frac{\overbrace{L}^{\text{Absolute brightness}}}{\underbrace{4\pi}_{\text{Constant } (4 \times 3.14)} \underbrace{D^2}_{\text{Distance}}}$$

Apparent brightness vs. distance

$$B \,\alpha\, \frac{1}{D^2}$$

The inverse square law shows how the apparent brightness of an object decreases as you move away from it. The amount of decrease in apparent brightness can be quantified using the formula at left. The symbol α indicates a proportional relationship. For example, if you are looking at a candle from one meter away, and then you move two meters away, its apparent brightness will decrease by a factor of *four*. Or if you move three meters away, its apparent brightness will decrease by a factor of *nine*. By what factor will its apparent brightness decrease if you move 10 meters away? If you did an experiment where you measured the apparent brightness of a candle at various distances, starting at one meter, your graph would look similar to Figure 32.17.

Solving for distance

$$D = \sqrt{\frac{L}{4\pi B}}$$

The inverse square law is important to astronomers because if they know the apparent and absolute brightness of an object, they can determine its distance by rearranging the variables to solve for D as shown in the equation at left.

Recall that apparent brightness (B) can be easily measured using a photometer. The challenge facing astronomers is how to determine the absolute brightness (L) of faraway objects.

Measuring brightness

Brightness is measured in units of power. In the laboratory, you can measure the brightness of a light source in *watts*. Because the brightness of objects in space is so great, astronomers developed *solar luminosity units*. One solar luminosity unit is equal to the brightness of the sun, or about 3.9×10^{26} watts. This is comparable to the combined brightness of 400 trillion trillion 100-watt light bulbs! Our galaxy emits as much light as 1.0×10^{10} suns.

Standard candles

Astronomers have found a way to *infer* values for absolute brightness (L) using a source of light called a **standard candle**. A standard candle is an object, such as a star, whose absolute brightness is known.

Measuring the distance to stars in the Milky Way

You are already familiar with one type of standard candle called *main sequence stars*. Recall that main sequence stars are found in a diagonal band on the H-R diagram. It is estimated that 90 percent of all stars are main sequence. Through observation, astronomers can determine if a star is a main sequence star by comparing it to stars on the H-R diagram. By determining the unknown star's temperature (using a spectrometer), they can infer its absolute brightness by choosing a similar main sequence star on the H-R diagram as shown in Figure 32.18. Next, they measure the unknown star's apparent brightness, and use the inverse square law to calculate its distance. Astronomers use this method to measure distances to stars in the Milky Way and nearby galaxies—out to distances of about 200,000 light years. Beyond that, astronomers cannot see main sequence stars and must rely on other types of standard candles.

Measuring distances to galaxies

A second type of standard candle is called a **Cepheid** star. This type of star was discovered by Henrietta Leavitt (1868-1921), an American, in the early 1900s. Cepheid stars "pulsate" in regular periods ranging from a few days to a few weeks. Leavitt discovered that there is a relationship between the period of Cepheid star and its absolute brightness. This meant that by measuring the period of a Cepheid star, astronomers could determine its absolute brightness and then, use the inverse square law to calculate its distance. Astronomers locate Cepheids in faraway galaxies and use them to map distances between galaxies in the universe. The Hubble Space Telescope actively searches for Cepheids in faraway galaxies.

Going even farther

Beyond 100 million light years, Cepheid stars are too faint to observe—even with the Hubble. For these distances, astronomers must rely on a third type of standard candle—a certain type of supernova. By observing the rate at which light from the supernova fades after the initial explosion, astronomers can use a mathematical formula to determine its absolute brightness, and then use the inverse square law to infer the distance to the galaxy in which the supernova resides.

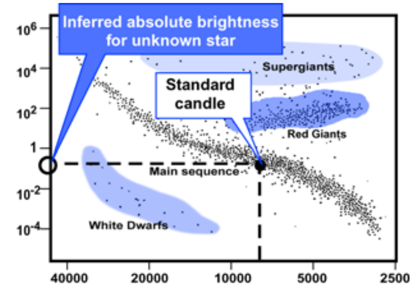


Figure 32.18: *Inferring the absolute brightness of an unknown star using the H-R diagram and main sequence stars as a standard candle.*

The North Star

The North Star is the brightest Cepheid star. Because it is only 390 light years from Earth, its distance can also be measured using parallax. This is one of the stars that helped astronomers refine the use of Cepheids to determine distances. The Cepheid star first discovered, Delta Cephei, is also relatively close to Earth at 300 light years.

The Big Bang theory

What is the Big Bang theory?

The *universe* is defined as everything that exists, including all matter and energy. While there are many theories about how it began, the one that has gained credibility among scientists is called the Big Bang. The Big Bang theory states that the universe began as a huge explosion that occurred somewhere between 10 and 20 billion years ago.

The explosion

According to the Big Bang theory, all of the matter and energy in the universe started out compressed into a space no bigger than the nucleus of an atom. Suddenly, a huge explosion occurred that sent everything that makes up the universe out in all directions. For an instant, the universe was an extremely hot ball of fire that began to expand rapidly. Extreme heat from the explosion (10 billion°C) caused the formation of subatomic particles.

Formation of hydrogen and helium

Immediately after the explosion, the universe began to expand and cool. Some scientists believe that it expanded from the size of an atomic nucleus, to 6×10^{30} kilometers in a fraction of a second! In less than a second, the expansion of the universe started to slow down. The universe became a cloud of matter and energy that was rapidly cooling and becoming less dense as it expanded. After a few minutes, at temperatures of around 1 billion°C, hydrogen nuclei began forming. Next, hydrogen nuclei began combining in pairs to form helium nuclei.

Radiation period

Ten thousand years after the explosion, most of the energy in the universe was in the form of electromagnetic radiation of different wavelengths including X rays, radio waves, and ultraviolet radiation. As the universe continued to cool and expand, these waves were changed into a form called *cosmic microwave background radiation* which can be measured today.

The first galaxies

After 300,000 years, the temperature had cooled to around 10,000°C. Lithium atoms began to form at this stage and electrons joined with the atomic nuclei to form the first stable (neutral) atoms. The universe continued as a giant cloud of gas until about 300 million years after the Big Bang. Parts of the gas cloud began to collapse and ignite to form clusters of stars—the first galaxies. The universe has continued to form galaxies since then. These galaxies continue to expand outward from the initial point of the Big Bang.

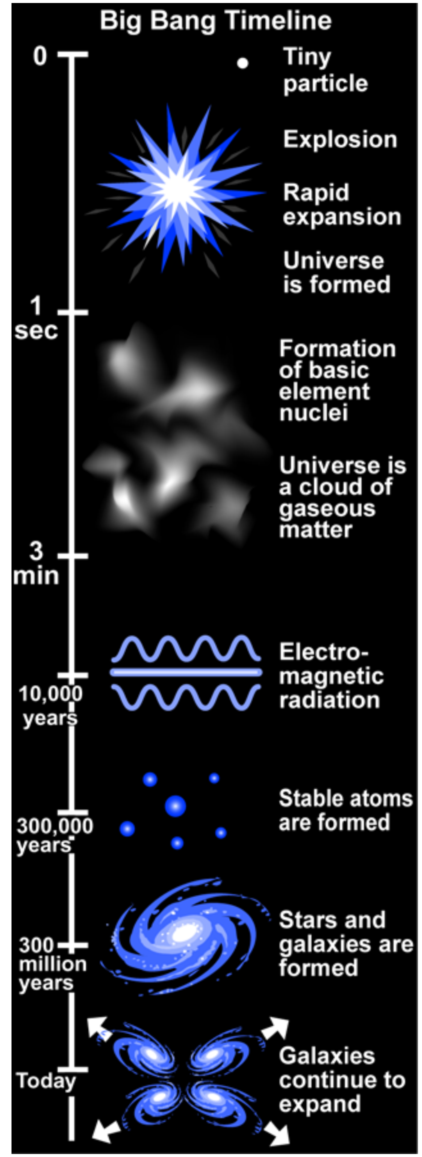


Figure 32.19: *A timeline for the Big Bang.*

Evidence for the Big Bang

Growing evidence

When it was first introduced, not everyone believed the Big Bang. In fact, the name "Big Bang" was made up by scientists to mock the theory. Unfortunately for them, the name stuck! As with any new theory, the Big Bang became more accepted as new scientific tools and discoveries established supporting evidence. In particular, scientific understanding of electromagnetic waves such as visible light, X rays, and microwaves, has provided important evidence to support the Big Bang theory.

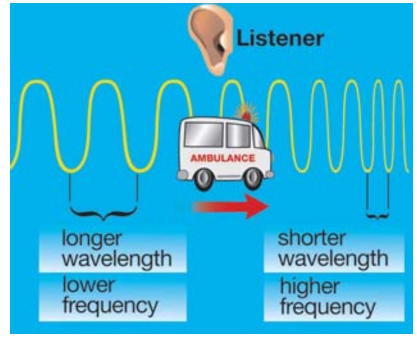


Figure 32.20: *The Doppler effect occurs when an object is moving toward or away from an observer.*

Doppler shift

In the 1800s, Christian Doppler (1803-53), an Austrian physicist, discovered that when the source of a sound wave is moving, its frequency changes. You may have noticed this effect if you have heard a car drive by with its horn blaring. As the car approaches, you hear the horn playing high "notes," and as the car passes, you hear the horn shift to lower notes as the car moves farther away. The change in sound you hear is caused by a **Doppler shift** (also called the Doppler effect).

How does it work?

As the car is moving toward you, the sound waves are compressed relative to where you are standing. This shortens the wavelength and causes the frequency to increase (recall that wavelength and frequency are inversely related). As the car moves away, the sound waves are stretched out, causing longer wavelengths and lower frequencies (Figure 32.20). The sound of the horn changes as the car passes by because the sound waves are being compressed and then stretched. If you could measure the rate of change in the frequency, you could measure the speed of the car.

Doppler shift and electromagnetic waves

Doppler shift also occurs with electromagnetic waves such as visible light, X rays, and microwaves. This phenomenon is an important tool used by astronomers to study the motion of objects in space. For example, if an object is moving toward Earth, the light waves it emits are compressed, shifting them toward the violet end (shorter wavelengths, higher frequencies) of the visible spectrum. If an object is moving away from Earth, the light waves it emits are stretched, shifting them toward the red end (longer wavelengths, lower frequencies) of the visible spectrum (Figure 32.21).

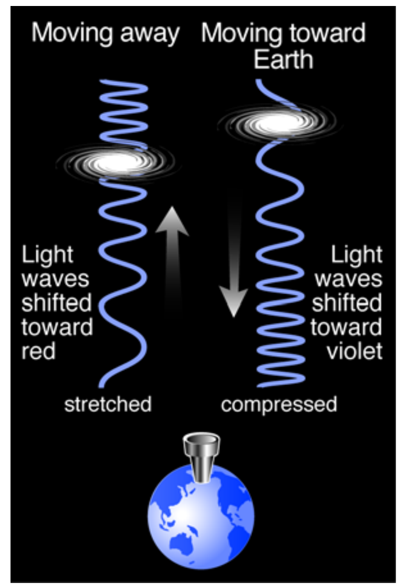
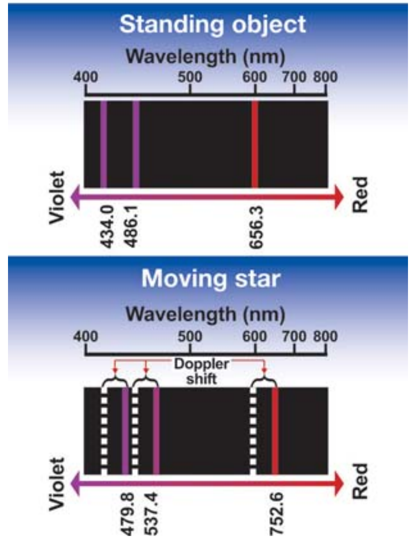


Figure 32.21: *Doppler shift is used to study the motion of objects in space.*

Sirius is moving away from Earth

In the 1890s, astronomers began to combine the use of spectroscopy and Doppler shift to study the motion of stars and other objects in space. One of the first stars they studied, Sirius, had spectral lines in the same pattern as the spectrum for hydrogen. However, these lines did not have the exact same measurements as those for hydrogen. Instead, they were shifted toward the red end of the visible spectrum. Scientists realized that this meant that Sirius was moving away from Earth. They could even determine how fast Sirius was moving away by measuring the amount that the lines had shifted toward red. The top diagram (right) shows the wavelength of hydrogen spectral lines for an object that is not moving. The bottom diagram shows the hydrogen spectral lines for a moving star. Can you see how the lines have shifted?



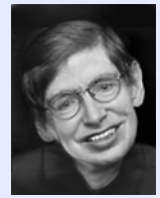
Evidence for the Big Bang

In the early 1900s, Hubble began to study the motion of galaxies. He used Cepheid stars to determine the distances of galaxies from Earth. Next, he studied the Doppler shift of each galaxy and found that the farther away a galaxy was, the faster it was moving. He was also able to determine the direction that each galaxy was moving. By the early 1930s, he had enough evidence to prove that galaxies were moving away from a single point in the universe. This supported two key parts of the Big Bang Theory: that the universe is expanding and that it originated from a single point.

Microwave background radiation

In the 1960s, Arno Penzias and Robert Wilson, two American astrophysicists, were trying to measure electromagnetic radiation emitted by the Milky Way. No matter how they refined their technique, they kept detecting a background noise that interfered with their observations. This noise seemed to be coming from all directions and had little variation in frequency. After publishing a paper describing their failed experiment, it was determined that they had discovered the cosmic microwave background radiation predicted by the Big Bang theory. Penzias and Wilson won the Nobel Prize for their discovery.

Stephen Hawking



Stephen Hawking was born on January 8, 1942, in Oxford, England. As a teenager, he invented elaborate games. As a young man, Hawking studied physics at Oxford University. In 1962, he went to Cambridge to study cosmology, the branch of astrophysics that studies the evolution and structure of the universe. At Cambridge, Stephen was diagnosed with Lou Gehrig's disease, which destroys the nerves that control muscles. Hawking was told he would become weaker, then paralyzed, and that he had only two years to live. Although devastated by this diagnosis, Hawking realized there were things he wanted to do with his time. He found he was enjoying his studies and he became engaged to Jane Wilde. Hawking said his engagement gave him something to live for, and also meant that he needed to finish his doctorate and get a job. In time, Hawking did both and became a highly-acclaimed scientist. He is known for his work on black holes, "space-time singularities," and linking Einstein's theory of relativity and quantum mechanics. He is also the author of popular books such as *A Brief History of Time* (1988) and *The Universe in a Nutshell* (2001).

Chapter 32 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1.	apparent brightness	a.	A cloud of gas and dust that gives rise to stars
2.	absolute brightness	b.	The most numerous category of stars in the universe
3.	main sequence star	c.	A diagram used to categorize stars
4.	protostar	d.	How bright an object appears from a distance
5.	nebula	e.	How bright an object actually is; for a star, how bright it appears from a standard distance
		f.	The earliest stage in the life cycle of a star

Set Two

1.	parallax	a.	A star with orbiting planets
2.	inverse square law	b.	An object, such as a star, whose absolute brightness is known
3.	standard candle	c.	The universe began when a huge explosion occurred
4.	Big Bang theory	d.	The apparent change in position of an object when viewed from different positions
5.	Doppler shift	e.	The relationship between apparent brightness, absolute brightness, and distance
		f.	A change in frequency of waves emitted by an object related to its movement

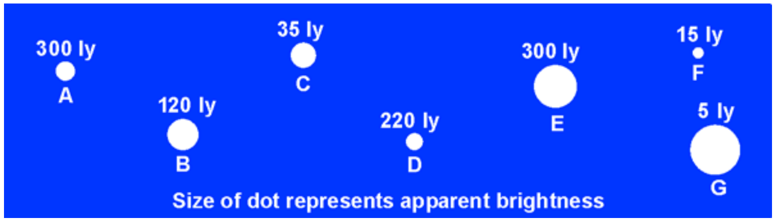
Concept review

1. Describe the conditions necessary to create a star.
2. Explain why spectroscopy is an important tool of astronomy.
3. What information does the color of a star provide?
4. What are the three main characteristics used to classify stars?
5. What is the difference between apparent brightness and absolute brightness?
6. What is the difference between a refracting telescope and a reflecting telescope?
7. What information about a star is required in order to plot it on the H-R diagram?
8. Why is the H-R diagram useful to astronomers?
9. Describe the life cycle of a sun-like star. Include in your description the following terms: nebula, protostar, red giant, planetary nebula, white dwarf, and black dwarf.
10. How long a star lives is related to which of the following quantities: (a) size; (b) temperature; (c) mass; or (d) color
11. How do astronomers classify galaxies?
12. What is a standard candle? How are they used to measure distances to faraway galaxies?
13. What is Doppler shift? How does Doppler shift provide evidence for the Big Bang theory?

Problems

1. A star is 15 parsecs from Earth. How far is this distance in light years? How far is it in kilometers?

2. The diagram below shows a group of stars as seen in the night sky. In the diagram, the relative size of each star indicates how bright it appears in the sky. Next to each star, its distance from Earth, in light years (ly) is shown. Use the diagram to answer the three questions below.

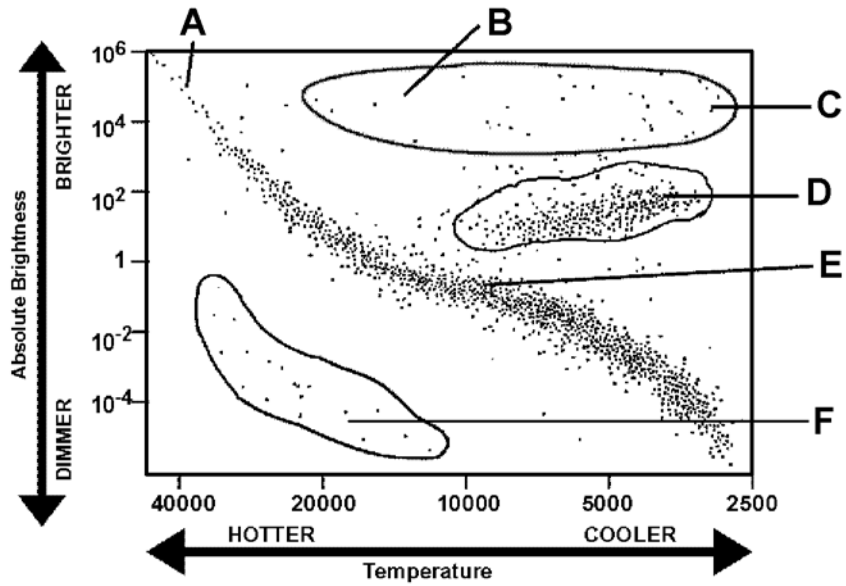


   a. Which star has the greatest apparent brightness? Explain your answer.
   b. If all of the stars in the diagram were moved to a distance of ten parsecs from Earth, which star would appear the brightest?
   c. Which star do you think has the lowest absolute brightness? Explain your answer.

3. Arrange the stars in the table below in order, from highest temperature, to lowest temperature.

Star	Color
A	white
B	orange
C	blue
D	red
E	blue-white
F	yellow

4. Use the H-R diagram below to answer the following questions.



   a. Which letter corresponds to a sun-like star?
   b. Which letter corresponds to a blue supergiant?
   c. Which letter corresponds to a white dwarf?
   d. Which letter corresponds to a red supergiant?
   e. Which letter corresponds to an old star that was once a sun-like, main sequence star?

5. You are looking at a candle from 3 meters away. By what factor will its apparent brightness decrease if you move 18 meters away?

6. You are looking at a candle from 20 meters away. By what factor will its apparent brightness increase if you move 10 meters closer to the candle?

Applying your knowledge

1. The table below lists some data for six stars. Use the table, and your knowledge of stars, to answer questions **a** through **g**.

Star	Color	Solar mass (× mass of the sun)	Solar diameter (× diameter of the sun)	Prominent spectral lines (elements present)
A	white	1.0	.02	carbon, helium
B	red	6.0	400	magnesium, sodium
C	yellow-white	1.5	1.5	hydrogen
D	blue	12.0	900	hydrogen, helium
E	blue	1.5	1.5	hydrogen, helium
F	red	1.5	250	carbon, helium

   a. Which star is the final stage of a sun-like star's life cycle? Explain your answer. What is the name astronomers give to this type of star?

   b. Which star is the most like our sun? Justify your answer.

   c. Which star is a blue supergiant?

   d. Which stars could become black holes? Explain your answer.

   e. Which star will have the shortest life span? Explain why.

   f. Which stars are most likely main sequence stars? Explain your answer.

   g. Which star resembles what our sun will become in about 5 billion years? Explain your answer.

2. Everything you are made of originally came from the stars. Explain the meaning of this statement and why it is reasonable.

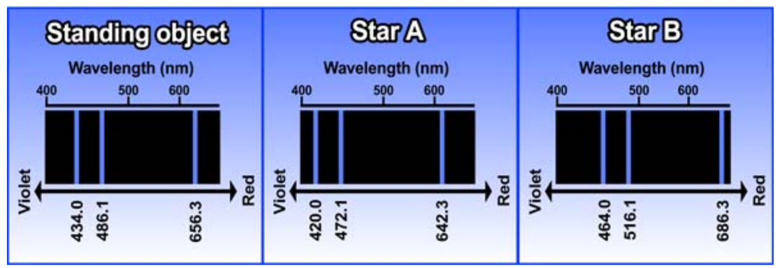
3. Create a printed catalog or computer presentation about the astronomical objects you learned about in this unit (planets, stars, galaxies, etc. Follow these steps:

   a. Make a list of all of the astronomical objects you learned about in this unit (planets, stars, etc.).

   b. Write a definition and description of each type of object.

   c. Using the Internet, find images of each type of object to use for your catalog or presentation.

4. The light from two stars (A and B) is analyzed using a spectrometer. The spectral lines for these stars are shown below. Also shown are the spectral lines for hydrogen from a light source that is not moving.



Which star is moving toward Earth? Which star is moving away from Earth? Explain your answer in both cases.