UNIT 4

Space Exploration

The summer Milky Way invites us to marvel at its beauty and to ask questions. How did our solar system form? What are the stars made of? How old is the universe?

Key Ideas

10 **What we know about the universe has taken us thousands of years to learn.**

10.1 Observing the Stars
10.2 Early Models of the Universe
10.3 Standing on the Shoulders of Giants

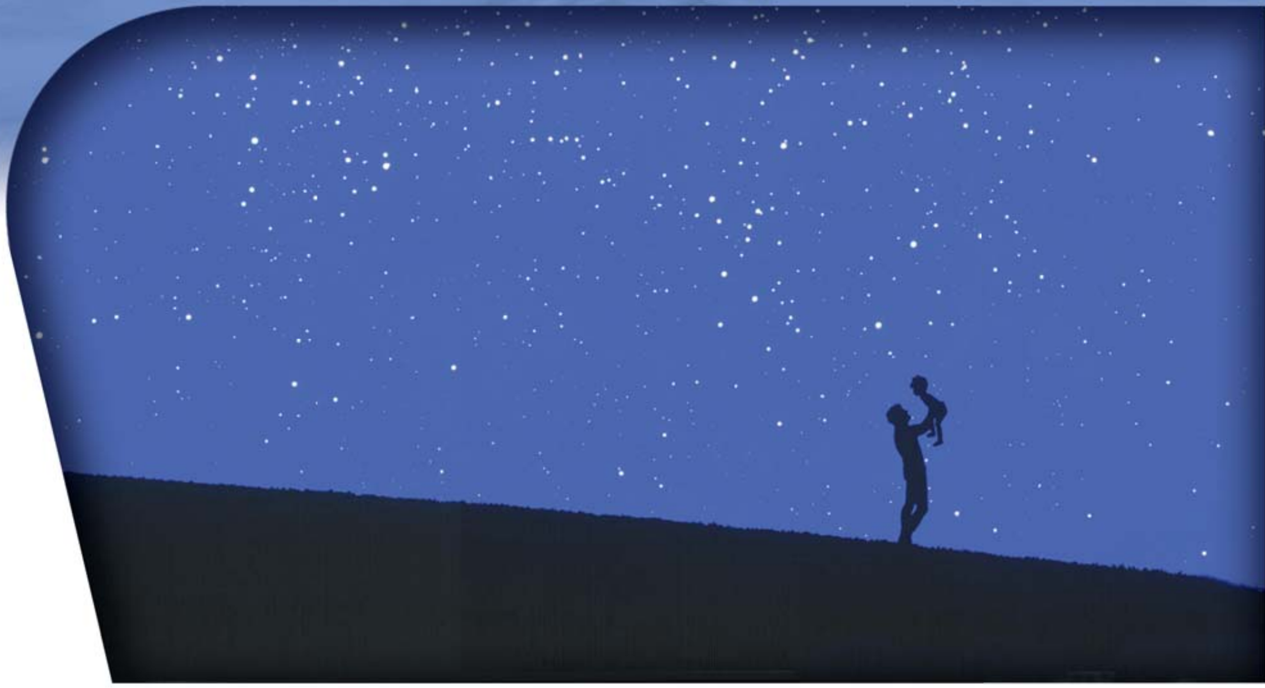
11 **We continue to learn a lot about our solar system by using space exploration.**

11.1 The Sun and Its Effect on Earth
11.2 Characteristics of the Celestial Bodies of the Solar System
11.3 The Exploration of Space

12 **We can use space exploration to learn about stars, nebulae, and galaxies outside our solar system.**

12.1 Explaining the Early Universe
12.2 Galaxies and Stars
12.3 Our Future in Space

Getting Started



Humans have always gazed into space with wonder and a longing to understand what is out there.

Imagine being born and raised on a tiny, remote island in the middle of a large ocean. If you and your neighbours had little ability to travel far from the island, your knowledge of the ocean and what lay beyond the horizon would be limited. You might come to understand the behaviour of the sea life on your island's shores and to notice patterns in the objects in the night sky. However, it would be impossible for you to develop any sense of the world beyond what you could see with your naked eye. Your knowledge would grow only when you had better ways of leaving your island and exploring new areas.

Earth is like an island in the universe, and humans are constantly looking for ways to explore and learn more about the universe and Earth's place in it. Step by step, as our technology has improved, we have increased our ability to get information from places that are very difficult to reach. Most of the time we collect information from Earth with the aid of tools such as telescopes, which help us see objects that lie far away.

Over the past century, however, we have also developed the ability to send instruments such as satellites and space probes out into space to collect information for us. Even sending humans off the "Earth island" and into space has become common.

The Dominion Radio Astrophysical Observatory, located near Penticton, British Columbia, is an example of a facility that enables scientists to study space from Earth. Among the projects carried out at the observatory is that of collecting information about the Milky Way galaxy we live in. A **galaxy** is an enormous collection of gases, dust, and billions of stars all held together by gravity. A **star** is an object in space, with a spherical shape. Its core is like a furnace, which means that it makes its own thermal energy.

Our Sun is one of the billions of stars that make up the Milky Way. When you look into the sky on a clear night, every single star you see is part of the Milky Way galaxy.

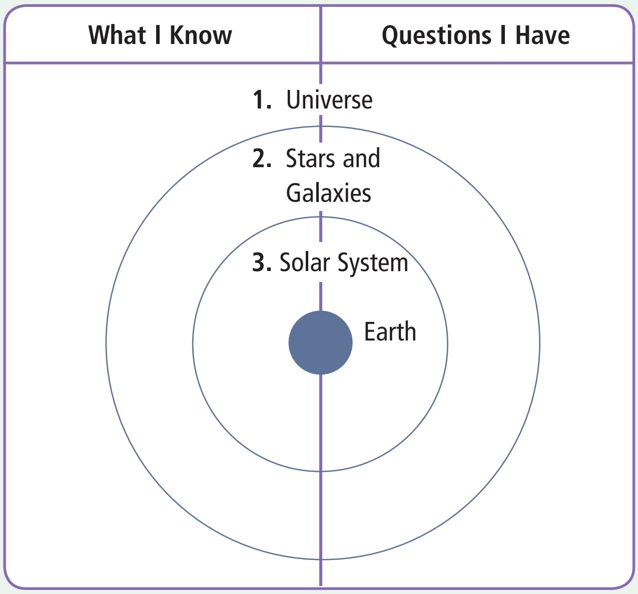
The Dominion Radio Astrophysical Observatory near Penticton, B.C.

What Do You Know about the Universe? Find Out ACTIVITY

The universe contains different types of objects. How many do you know about? In this activity, you will brainstorm what you already know about the universe and what you would like to learn. The chart you create will help you organize your thoughts as you read through the unit.

Materials

- chart paper
- felt pens



What to Do

1. Working with a partner or small group, use the chart paper and felt pens to make a graphic organizer like the one shown on this page.
2. Brainstorm objects you think are found in space. On the graphic organizer under "What I Know," write each object under one of the following categories: universe, stars and galaxies, or solar system. Try to place the object in the category that best describes its location relative to Earth.
3. Write at least one question per category on the "Questions I Have" section of the graphic organizer.

What Did You Find Out?

1. When you have finished brainstorming, look at another group's graphic organizer and read the objects listed. Discuss with your group any changes or additions you would like to make to your group's organizer.
2. As a class, discuss the different objects identified by the groups.
3. Post your organizer on a wall in the classroom. As you advance through this unit, add new terms about the universe to the organizer.

Chapter 10

What we know about the universe has taken us thousands of years to learn.

Astronomy is one of the oldest sciences. When early men and women lived in caves, they looked at the night sky. They noted the phases of the Moon and used them to keep track of time—an early calendar. It was felt that the star patterns and motions of these lights in the sky had an effect on their daily lives. Within the past 2000 years, men and women began making careful observation of the motion of these objects, and then they created and tested models to explain this motion. It took a long time and the scientists who came up with new, bold ideas sometimes faced hardships when their theories, although correct, were rejected.

In this chapter, you will have an opportunity to make your own observations of the night sky, and then you will look at how several astronomers took this evidence and determined where Earth fits in the universe.

What You Will Learn

In this chapter, you will

- **identify** the brighter stars and constellations visible from where you live
- **describe** early models of the universe
- **explain** the observed motions of the planets
- **state** the laws of planetary motion
- **examine** the vast distances between the planets

Why It Is Important

Human understanding of the universe has come from a need to learn and a desire to explore. By observing the sky and examining discoveries by historical astronomers, we can share in the excitement of this exploration and gain a better understanding of Earth's place in the universe.

Skills You Will Use

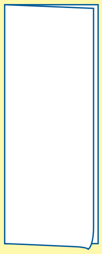
In this chapter, you will

- **observe** the night sky and draw the brighter constellations
- **construct** a three-dimensional constellation
- **model** the size of objects in the solar system and the distances between them

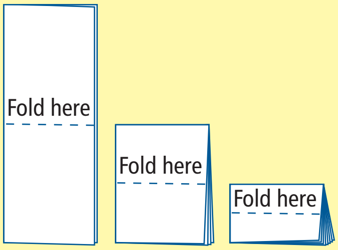
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you learn in Chapter 10.

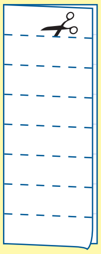
STEP 1 **Fold** a sheet of copy letter-sized paper in half lengthwise (hot dog fold).



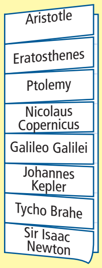
STEP 2 **Fold** in half to form two equal sections, fold in half again to form four equal sections, and in half again to form eight equal sections.



STEP 3 **Open** the folded paper and **cut** along the fold lines of one side only to form eight tabs.



STEP 4 **Label** the tabs as follows, from top to bottom: Aristotle, Eratosthenes, Ptolemy, Nicolaus Copernicus, Galileo Galilei, Johannes Kepler, Tycho Brahe, and Sir Isaac Newton.



Summarize Summarize information about the contributions of each astronomer. On the back, make notes and draw diagrams to summarize what you learn about the stars and constellations in the sky.

10.1 Observing the Stars

Ever since people first looked up at the night sky, they have been curious about what is out there. Scientists have studied the motions of the stars and planets and have proposed theories to explain what they saw. We have gone from imagining ourselves at the centre of the entire universe to seeing ourselves on a small planet orbiting an average star. Even with all that we have learned, people still want to learn more.

Key Terms

- asterism
- celestial body
- circumpolar constellation
- constellation
- ecliptic
- magnitude
- planet
- star
- zodiacal constellations

What do you think about when you look at the night sky? Do you ever wonder what is out there? You may see the Moon and some bright stars. Depending on how close you live to city lights, you may see a sky filled with thousands of stars and even the faint Milky Way.

The Moon is a place that people have visited and lived on for a few days at a time. We have learned through experiments and observations that the **stars** are like our Sun, giving off light and heat, but are very far away. Thousands of years ago, what must people have thought when they looked up at the sky?

Many people in early civilizations were farmers. They needed to ensure that the crops were harvested on time so that they could eat. They found that they could use the stars and other celestial bodies as a calendar. A **celestial body** is a natural object out in space such as a planet, a moon, an asteroid, a comet, or a star. People made note of the movement of the celestial bodies. When certain stars were visible at a certain time of the night, they knew it was time to plant their crops. When other stars were visible, they knew it was time to harvest their crops.

The sky was sometimes a source of fear. Ancient people did not understand what they were seeing. The daily rising and setting of the Sun and stars was predictable and comforting to people. If something unexpected appeared in the sky, like a new comet or a solar eclipse, it was often interpreted to be a sign of bad luck or of an impending major disaster (Figure 10.1).

Figure 10.1 In the past, the night sky has been a source of information, but also a source of fear of the unknown.

Did You Know?

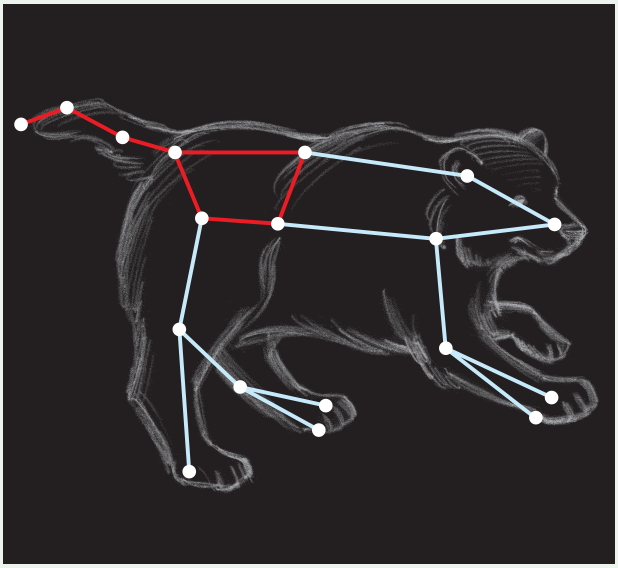
Chinese astronomers are credited with making the first formal records about star and planet motion. More than 4000 years ago, they recorded highly accurate observations.

Today, we understand more of what we see in the night sky. We can observe and enjoy a bright comet or an eclipse in the same way that we observe and enjoy any beautiful natural phenomenon.

10-1A Constructing Constellations

Think About It

Constellations are groups of stars that can be grouped to form shapes in the night sky. In the northern hemisphere, the group of stars we call the Big Dipper is part of the constellation Ursa Major. (Ursa means bear in Latin.)



You may see different patterns in the stars. The interpretations of star patterns are as different as the cultures that name them. In this activity, you and your classmates will be given the same image of a group of stars and asked to work individually to create your own unique constellation pattern.

Materials

- pencil
- pencil crayons
- star chart

What to Do

1. Study the star chart to create an idea for a constellation. To help you get some ideas, rotate the sheet to view the stars from different perspectives.
2. Once you have an idea, use your pencil to connect the most visible stars so that they form a very simple outline of the figure you see in the star pattern. This diagram will be the basic structure of your constellation.
3. Use pencil crayons to draw and colour the rest of the details of the figure.
4. Give your constellation a name.

What Did You Find Out?

1. Compare your constellation with some constellations your classmates drew. How did your classmates' constellations compare with your constellation? Did anyone interpret the star patterns in the same way?
2. How does your answer to question 1 explain why different cultures see different shapes and figures in the same set of stars?
3. Would using a telescope that can help you see many more stars make creating a constellation easier? Explain.

Constellations

When people thousands of years ago looked up at the night sky, they tried to explain what they saw. To them, the sky looked like an upside-down bowl and the stars were like points of light fixed on this bowl. They noticed that the stars made certain patterns. Those patterns are called **constellations**, from the Latin phrase meaning "with stars." The people told stories of kings and queens, heroes and villains, animals and mythical creatures, and put them in the sky. Characters from Greek and Roman mythology make up most of the constellations we use today. Amateur astronomers learn to identify the constellations and often use them to locate other objects in the night sky.

These patterns of stars remained the same night after night. People observing the sky also noticed five bright "stars" that wandered among these fixed patterns. They called these moving stars **planets** (the Greek word for wanderer). The planets were given the names Mercury, Venus, Mars, Jupiter, and Saturn—the names of Roman Gods.

Although it appears that the stars in the constellations we see all lie close to each other and at exactly the same distance from Earth, in fact they may be great distances apart. They look close together only because they are so bright and so far away.

The International Astronomical Union lists 88 constellations. Examples include Leo, Cassiopeia, and Orion (Figure 10.2). Smaller groups of stars forming patterns within the constellations are called **asterisms**, from the Greek word for star, *aster*. An example of an asterism is one of the most famous and visible patterns in the northern sky, the Big Dipper.

Did You Know?

The oldest map of the stars is believed to be that found in one of the prehistoric caves in Lascaux, France. Estimated to be about 16 500 years old, it is said to represent the bright stars Vega, Deneb, and Altair.

Figure 10.2 Three prominent constellations visible in the night sky: Cassiopeia the Queen, Orion the Hunter, and Leo the Lion

The Big Dipper's two end stars in the bowl are called "pointer stars" because they point toward the North Star, Polaris (Figure 10.3). Long before the invention of the compass, people used the North Star to tell direction. Many people think that Polaris is the brightest star in the sky, but it is not. In fact, Polaris is only as bright as the brightest stars in the Big Dipper.

Here in Canada, we cannot see all 88 constellations. There are approximately 20 that never rise above our horizon, and are seen only from south of the equator (Figure 10.4).

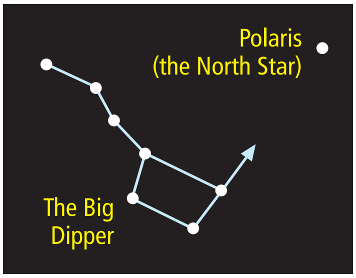


Figure 10.3 The two end stars in the bowl of the Big Dipper point directly to the North Star (Polaris).

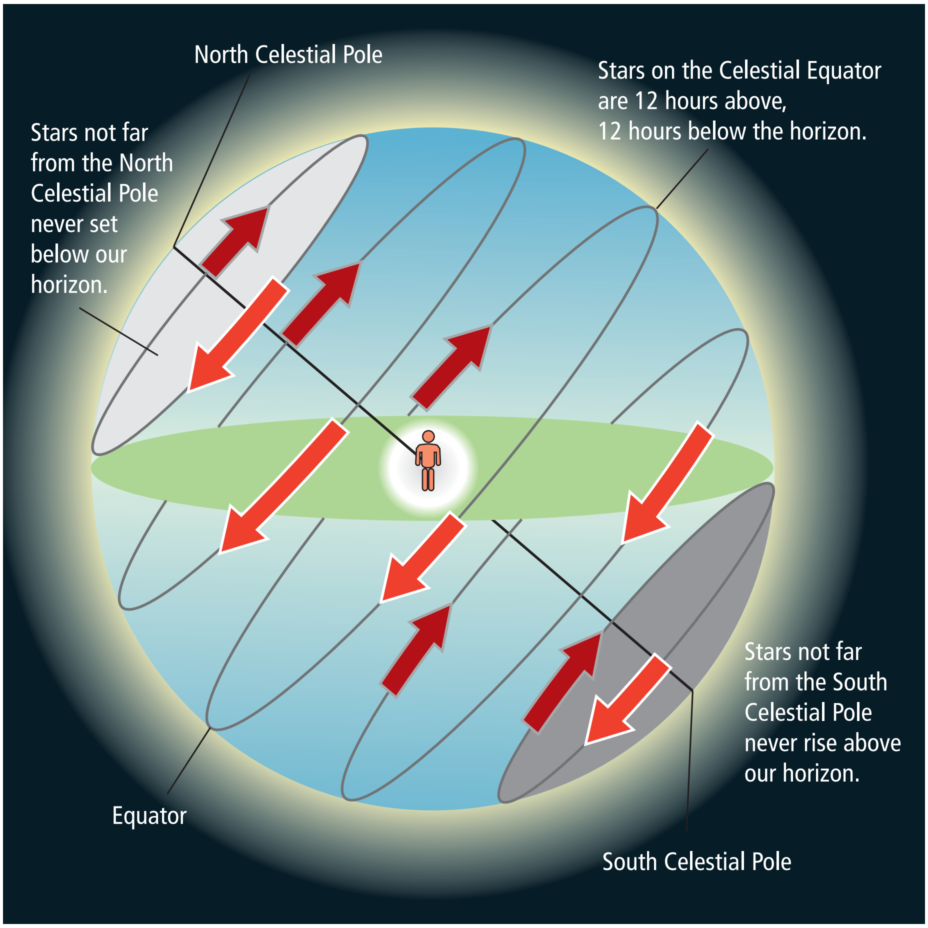


Figure 10.4 Imagine you are standing on flat land at night. As Earth turns, the stars in the sky appear to be on a sphere that moves slowly around Polaris—the North Star. (This movement is shown by arrows in the diagram.) You see stars in the sky above you, but there are stars below you too. You cannot see them because Earth blocks your view of them. The stars in the grey area never rise for the observer in the northern hemisphere.

When European explorers of the 15th century first sailed around the world and travelled to places like Australia and South America, they saw these stars for the first time. These explorers imagined new constellations out of these new stars—but they did not create animals or kings. They chose objects that were important to their lives, for example, a ship, a clock, a microscope, and a compass.

Explore More

The Big Dipper has been seen as a chariot, plough, and bear. Find out more about stories associated with many of the constellations. Begin your research at **www.discoveringscience9.ca**.

Magnitude

When we try to describe a star in the sky, we can talk about its brightness. A star's **magnitude** describes how bright it appears to us. The magnitude of a star depends on two things—how bright the star is and how close it is to Earth. If a person holds a flashlight 10 m away from you and another person holds an identical flashlight 100 m away from you, the closer flashlight will look brighter, even though the two are identical. Or if you hold a brighter flashlight 100 m away, it may look just as bright as the flashlight 10 m away. Stars are not all the same brightness, and the stars that look the brightest to us are not necessarily the closest. Some stars are much brighter than our Sun, but since they are far away, they appear very dim (Figure 10.5).

The first person to develop a scale to describe the brightness of a star was Hipparchus of Rhodes in 134 B.C.E. He created a system in which he assigned the brightest stars he could see an importance, or magnitude, of 1. He assigned the next brightest stars a magnitude of 2, and so on. The faintest stars he could see, he assigned a magnitude of 6. Today we use a scale of magnitude similar to the one developed by Hipparchus. The brighter stars have magnitudes close to 0 and the fainter stars have magnitudes 2, 3, 4, and greater. The lower the magnitude, the brighter a star appears (Figure 10.7). Modern astronomers have also expanded the scale to include objects brighter than the stars Hipparchus ranked, by using negative numbers. The planets can be as bright as –4 (Figure 10.6).

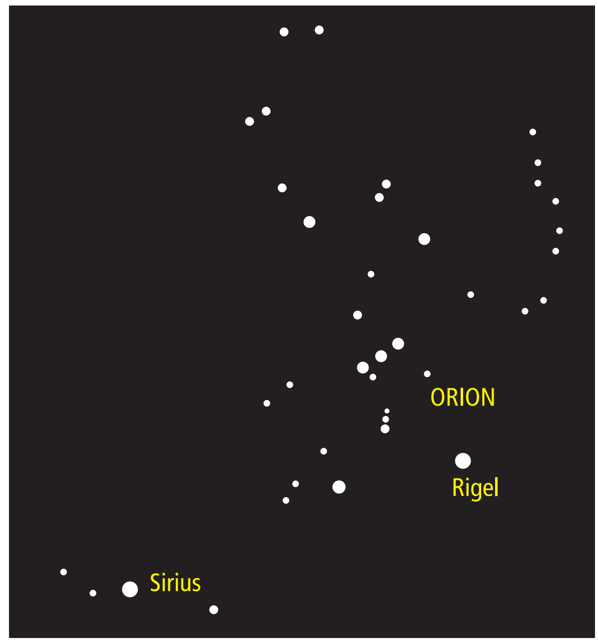


Figure 10.5 Rigel, one of the stars in the constellation Orion, appears dimmer than nearby Sirius in Canis Major, the brightest star in the sky. In fact, Rigel is a brighter star than Sirius, but it is 100 times farther away. It gives off 40 000 times more light than our Sun and if it was as close as Sirius, it would be as bright as the Moon!

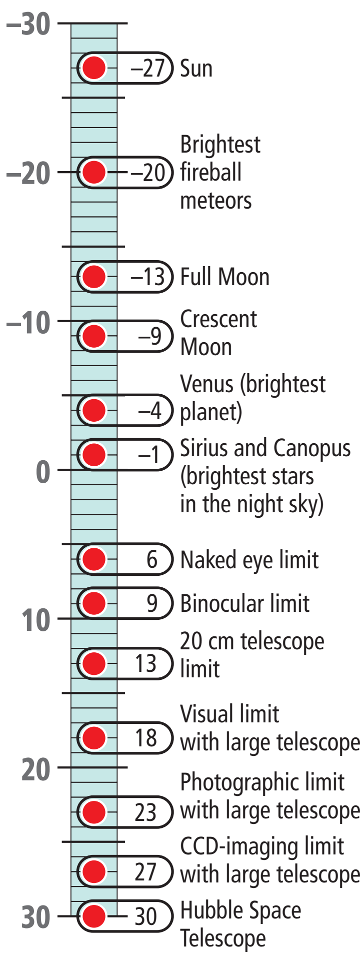


Figure 10.6 Magnitudes vary from –27 for the Sun, to +6 for stars barely visible to the eye, and to +30 for stars we cannot see but that a space-based telescope such as the Hubble Space Telescope can detect.

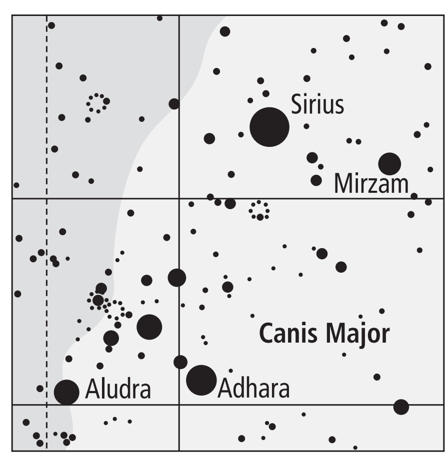


Figure 10.7 Star charts show the magnitude of a star by the size of the dot representing the star. The greater the magnitude of the star, the larger the dot.

Angular Dimensions

It is very difficult to describe how big something is without a unit of measure. For example, you can describe the height of a black spruce tree using metres. To describe length, we use units of measure such as centimetres, metres, or kilometres, depending on what we wish to measure.

If we look up into the night sky, though, we cannot use a centimetre ruler to measure the apparent distance between two stars, since the farther from our eyes we hold the ruler, the greater the distance between the stars will seem. We can, however, measure the angle between the stars using degrees (Figure 10.8). Doing so allows us to communicate the locations of stars in a way others can understand.

There are 360° (degrees) in a circle and 90° between the horizon and directly overhead. The diameter of the full Moon measures one half of a degree.

To measure angles on paper, you use a protractor. You can use your hand to estimate the angles between stars (Figure 10.9). Held at arm's length, your baby fingernail covers about 1°. Three fingers measures 5°, your fist measures 10°, your outspread little finger and index finger measures 15°, and your outspread thumb and little finger measures approximately 25°. (These results may vary depending on your hand size.)

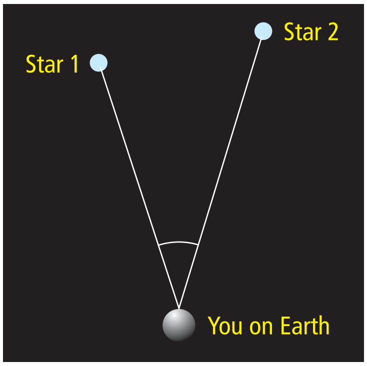


Figure 10.8 You can measure the angle between your line of sight to one star and your line of sight to another star to describe the apparent distance between the stars.

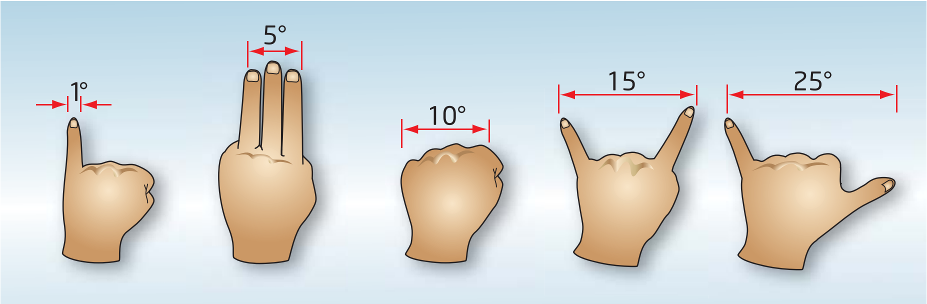


Figure 10.9 You can use your hand to estimate angles between stars.

You can check out your angular ruler on the Big Dipper. The bowl of the Big Dipper measures 10°, so you should be able to place your fist into the bowl.

Reading Check

1. What is a celestial body?
2. Define the term "constellation."
3. What two factors can affect a star's magnitude?
4. How can we estimate the apparent distance between two stars?

Did You Know?

Use your hand to estimate the diameter of the Moon in degrees. You will find that it is only about one half of a degree, no matter where the Moon appears in the sky.

Movement of the Stars

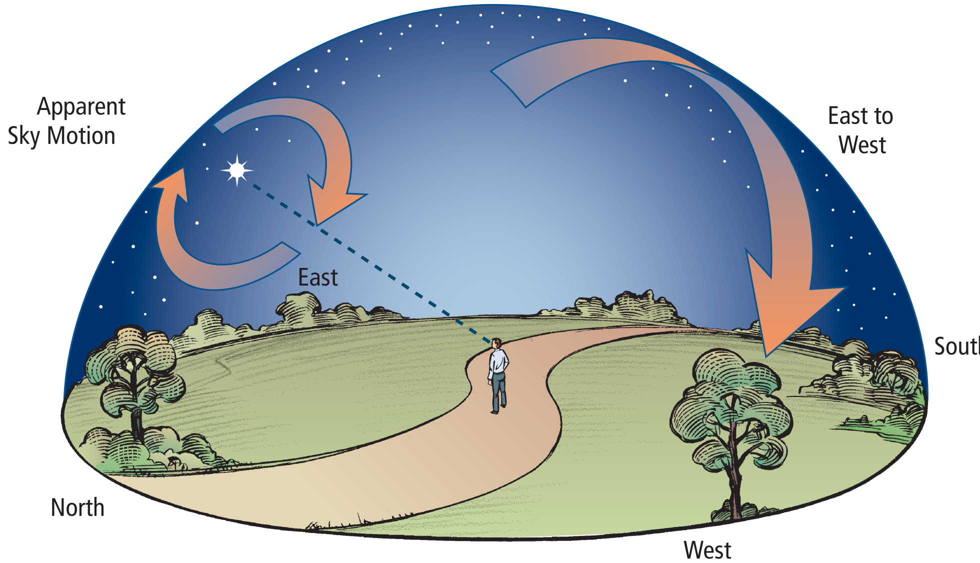


Figure 10.10 The stars in the sky seem to move from east to west. In the north, they seem to revolve around a common point.

If you were to watch the stars for an entire night, you would notice that they generally move from east to west, just like the Sun. Earth's rotation on its axis toward the east causes this gradual motion. Looking south, the stars appear to rise in the east and set in the west, some moving directly overhead. Looking north, we see something different. The stars seem to slowly rotate around a common point (Figure 10.10).

At the point around which the stars appear to rotate is the North Star—Polaris. If you were to extend Earth's axis out into space, it would point at Polaris. Polaris is at the end of the handle of Ursa Minor—the Little Bear (Figure 10.11). Ursa Minor is also called the Little Dipper, since the seven stars that make up this constellation appear to be in the shape of a small ladle.

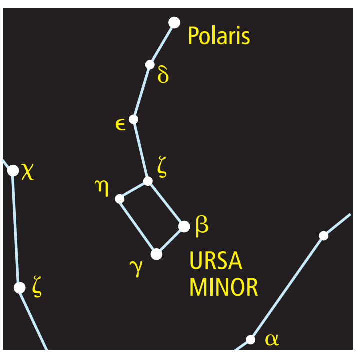


Figure 10.11 The last star in the handle of the Little Dipper, or Ursa Minor, is Polaris.

The constellations in our north sky, including the constellations of Ursa Major, Ursa Minor, and Cassiopeia, are called **circumpolar constellations**. They never go below the horizon.

If you took a picture of this region of the sky over several hours, the stars would make circular patterns like those shown in Figure 10.12.

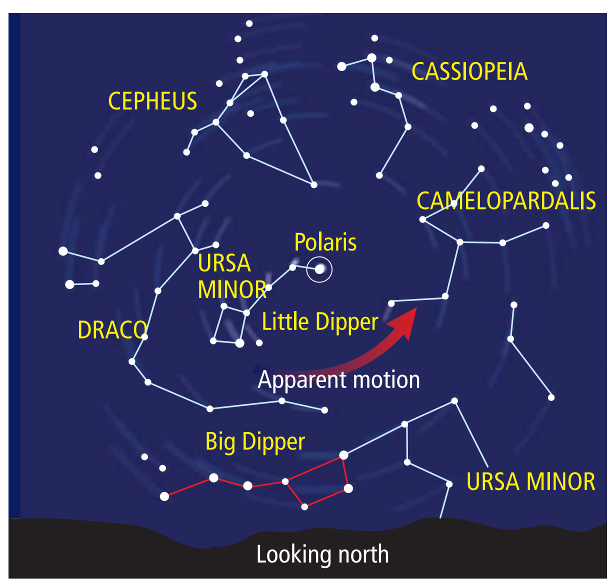


Figure 10.12 The constellations Cassiopeia, Cepheus, Draco, Ursa Minor, Ursa Major, and Camelopardalis rotate around Polaris and appear in the north sky all year.

Motion of the Sun, Moon, and Planets

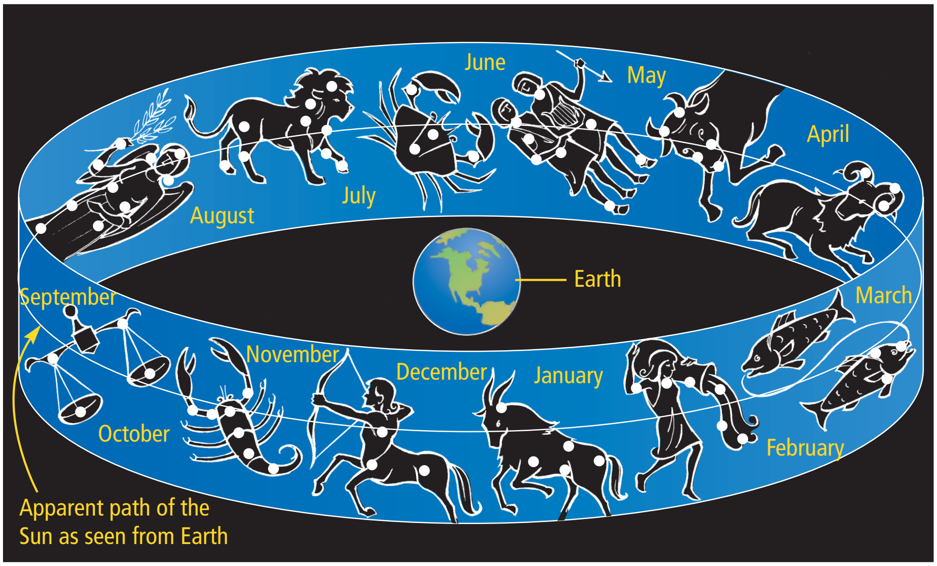


Figure 10.13 In a year, the Sun appears to move through all 12 constellations of the zodiac.

As Earth revolves around the Sun, it appears that the Sun is moving against the background stars. We cannot see the stars in the daytime because the bright Sun is in front of them. We know that the Sun follows the same path through the sky every day. We call this path the **ecliptic**. Along this path lie the 12 **zodiacal constellations**—Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn, Aquarius, and Pisces. These constellations are known as the signs of the zodiac. The Moon and planets also follow closely along the ecliptic so they always appear in one of the 12 zodiacal constellations (Figure 10.13).

As the planets revolve around the Sun, they move at different rates along the ecliptic. The planets inside Earth's orbit—Mercury and Venus—seem to race through the sky compared to the slower planets outside Earth's orbit. But Mercury and Venus never stray too far from the Sun, since their orbits are inside the orbit of Earth. These two planets can only be seen setting shortly after sunset or rising shortly before sunrise. The outer planets can be seen at all times throughout the night depending on their position compared to Earth (Figure 10.14).

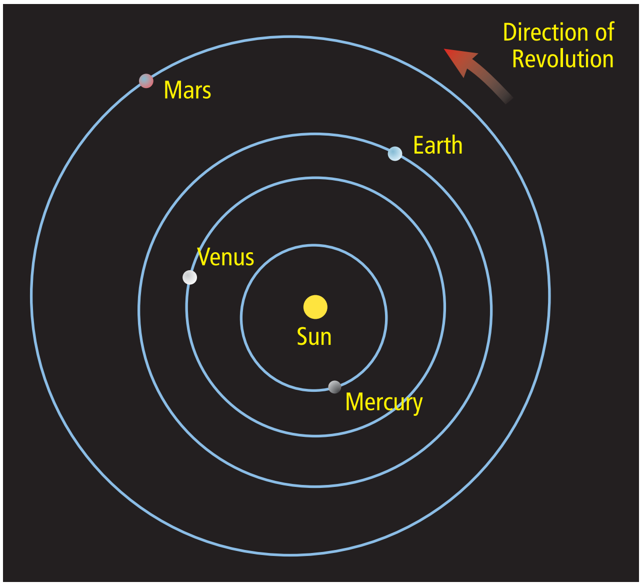


Figure 10.14 Because Mercury and Venus have a smaller orbit around the Sun than Earth does, they always appear to us to be close to the Sun in the sky. Other planets with larger orbits sometimes appear far from the Sun in the sky.

Asteroids between the orbits of Mars and Jupiter also seem to move against the background stars in the same way as these planets.

Comets are an exception. Their orbits can be above or below the orbit of Earth. For this reason, we do not always see comets on the ecliptic, as shown in Figure 10.15.

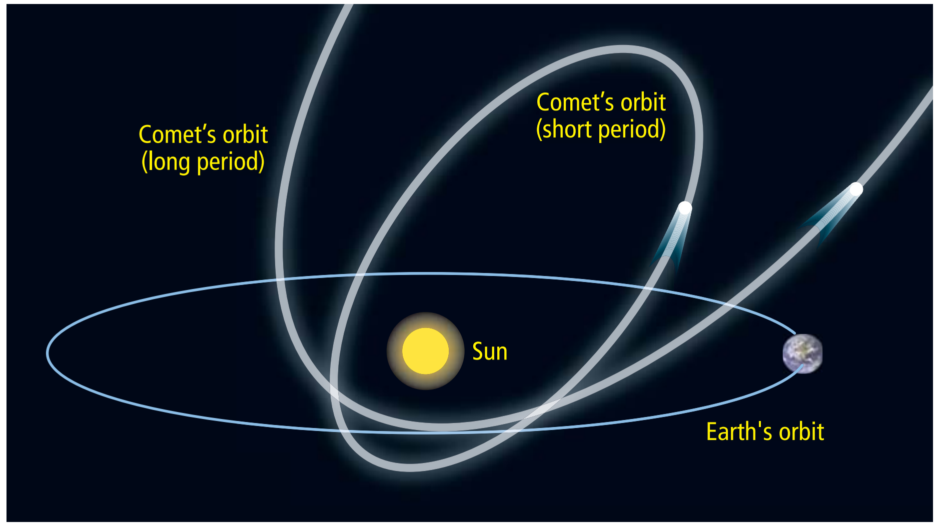


Figure 10.15 While Earth and all other plants revolve around the Sun in one plane, comets can orbit in different planes. We see planets along the ecliptic, the same path the Sun follows in the sky, but we can see comets in other areas of the sky as well. Some comets orbit relatively close to the Sun. Others have an orbit that takes them to the edge of the solar system.

Seasonal Constellations

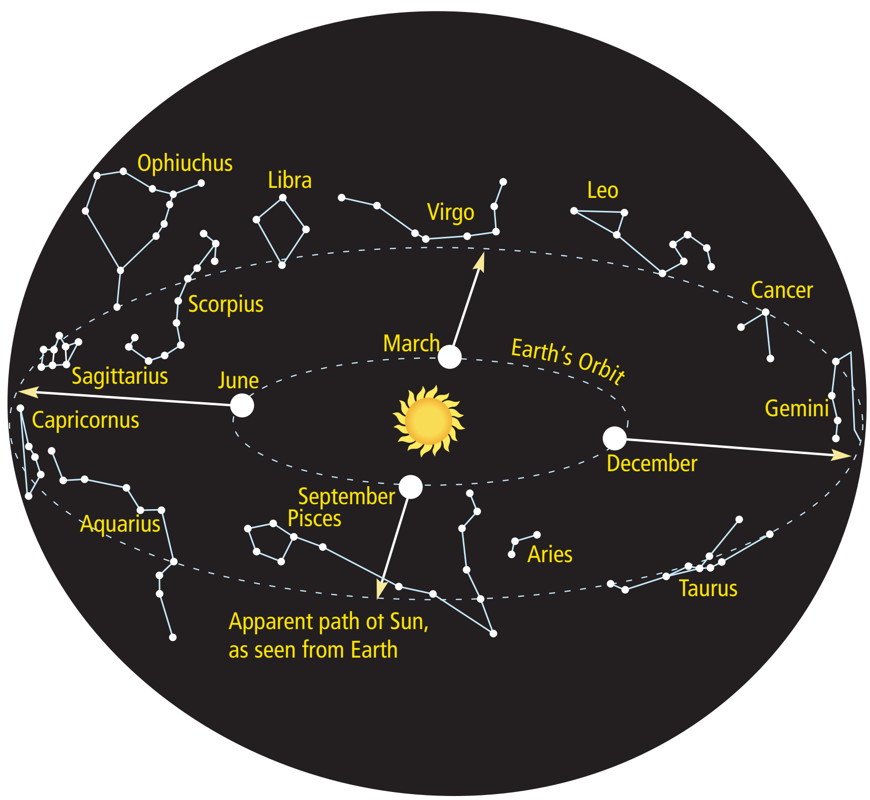


Figure 10.16 We see different constellations in every season. The Sun's brightness prevents us from seeing others. Since we can see stars only at night, we see only the stars that are in the opposite direction to the Sun at that time of year.

Suggested Activity

Conduct an Investigation 10-1B on page 362
Think About It 10-1C on page 363

Because Earth moves around the Sun every year, we see a different part of the sky every season (Figure 10.16). Some constellations are visible all year long but change positions, and some constellations are visible in certain seasons only, as shown in Figures 10.17 to 10.20 on the next page.

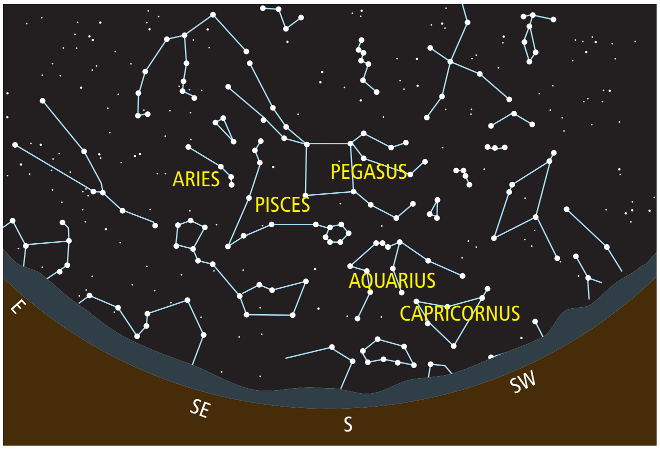


Figure 10.17 In the fall, the constellation Pegasus dominates the sky. It looks like a great square. The constellations along the ecliptic are relatively dim—Aries, Pisces, Aquarius, and Capricornus.

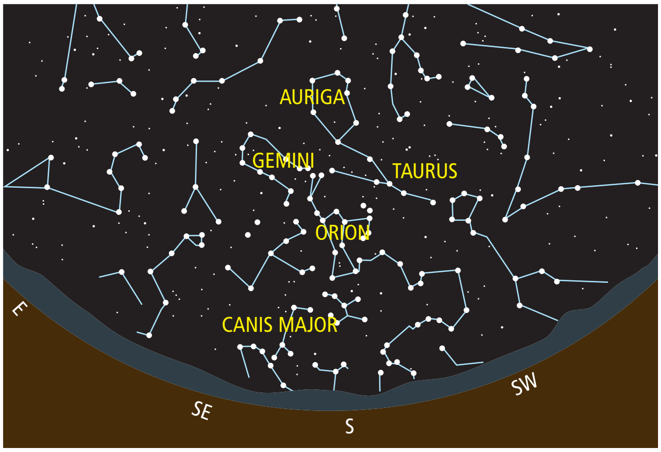


Figure 10.18 In the winter, we see constellations made up of many bright stars. In the centre is the constellation of mighty Orion the Hunter. Surrounding Orion are the constellations Gemini, Canis Major, Taurus, and Auriga. Sirius, the brightest star in the sky, is in the constellation of Canis Major. You can use the three stars in Orion as a guide to find Sirius.

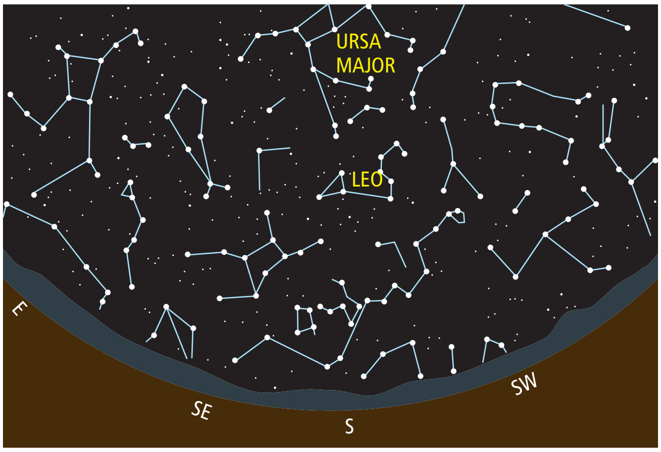


Figure 10.19 In the spring, the majestic constellation of Leo the Lion dominates the sky. Ursa Major is at its highest in the spring, nearly overhead.

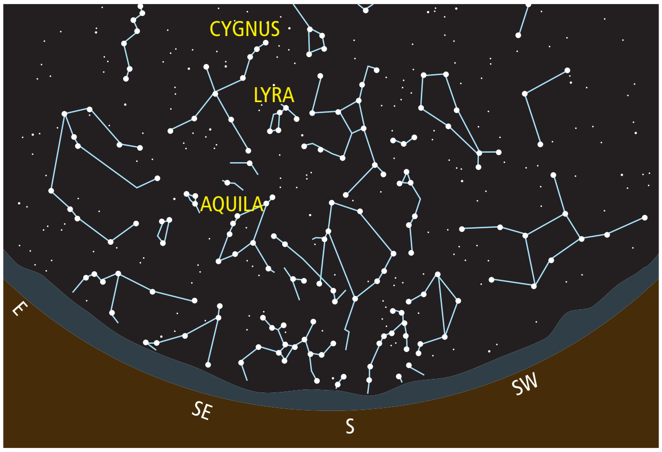


Figure 10.20 In the summer, the constellation of Cygnus, Lyra, and Aquila dominate along the summer Milky Way. The three bright stars in these constellations (Deneb, Vega, and Altair) form what is called the Summer Triangle.

Reading Check

1. What three constellations in the north sky are called circumpolar constellations?
2. Name the type of path the Sun follows through the sky every day.
3. What are the differences in the motion of asteroids and comets?
4. Why do we see a different part of the sky every season?

10-1B Observing the Sky

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Evaluating information
- Drawing conclusions
- Explaining systems

Safety

- Always observe the night sky with a trusted and responsible adult present.
- Check the forecasted weather conditions for your area and dress appropriately.

Materials

- a seasonal star chart from your teacher
- coloured pencils
- a flashlight with red cellophane filter
- a list of the planets that may be visible, from your teacher

As Earth revolves around the Sun, the positions of the constellations we see in the sky change with the seasons. The Moon changes its position in the sky nightly as it orbits Earth. The Moon orbits around Earth once every 28 days. The planets appear as bright stars and slowly move from constellation to constellation as they revolve around the Sun.

In this activity, you will observe and identify some constellations, observe the motion of the Moon over a few days, and identify any planets visible in the sky at the time of your observation.

What to Do

1. Conduct your observing session on a clear night within a few days of First Quarter Moon. (Conducting your observations during this time places the Moon in a position easily observed in the early evening. Also, it avoids the bright light reflected from a full Moon, which can make observing some constellations more difficult.)
2. Look north. Find and sketch the positions of the following circumpolar constellations: Ursa Major, Ursa Minor, and Cassiopeia. Use the star chart to help you identify each constellation. Note the date and time on your sketch.
3. Look south. Identify some of the brighter seasonal constellations. Use the star chart to help you identify them. Sketch the position of the constellation in relation to a foreground object (a tree, chimney, streetlight).
4. Note the position of the Moon with respect to a bright star of a foreground object. Make a sketch.
5. If possible, a few hours later, stand in the same spot and note the positions of these constellations and the Moon. Make another sketch in a different colour on the same page.
6. The next clear night, perform these steps again. Try to observe at the same times.
7. A few weeks later, perform these steps again. Try to observe at the same times.

What Did You Find Out?

1. Look at the positions of the circumpolar stars that you marked at different times. Do they rotate clockwise or counterclockwise around Polaris?
2. Does the Moon appear to move to the west or to the east from one observation to the next in one night? Why do you think it appears to move in this way?
3. Does the Moon appear to move to the west or to the east from one night to the next? Why do you think it appears to move this way over several nights?
4. What did you notice about the positions of the constellations when you observed them a few weeks later? How do you explain this?
5. After a few weeks, could you still see the Moon at the same time? If not, why not? When will it be visible at the same time and place again?

10-1C Building a 3-D Constellation

Think About It

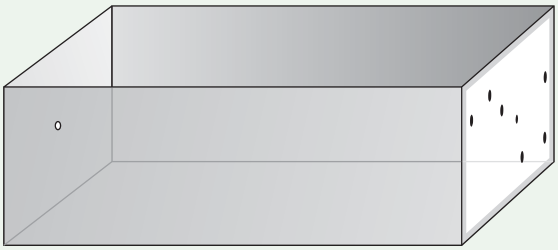
The stars in constellations appear to all be the same distance away. In this activity, you will build a three-dimensional model to show the positions of the stars in the Big Dipper.

Materials

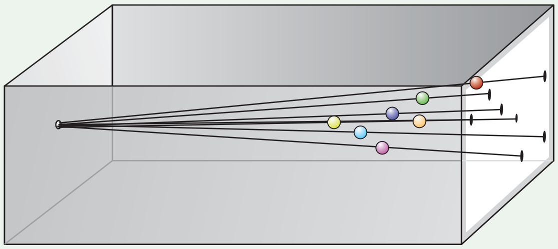
- a small box (for example, a shoebox)
- string, scissors, glue, and tape
- a Big Dipper diagram (see below)
- 7 small beads (stars)
- a table of the stars and the distances to make them from Earth on your model (see below)

What to Do

1. Glue the Big Dipper diagram to the inside of one end of the box.
2. On the opposite end of the box, poke one hole through the middle. This hole will be Earth.



3. Cut seven pieces of string a few centimetres longer than the length of the box. Thread each piece of string with a bead (the star).
4. Poke a hole through the box for each of the seven stars on the diagram.
5. Thread the end of one piece of string through the hole at Earth and tape the end to the outside of the box.
6. Ensure the bead is threaded on the string. Then thread the other end of the string through a hole on the Big Dipper diagram and tape the end of the string to the outside of the box.
7. On the table below, find the distance from Earth to place the star (bead) on that string. Then use glue to attach the bead to the string at the correct point.
8. Repeat steps 5 through 7 for each piece of string.



Star	Distance From Earth on Model (cm)	Magnitude
Dubhe	25	1.8
Merak	16	2.3
Phecda	17	2.4
Megrez	16	3.3
Alioth	16	1.7
Mizar	16	2.2
Alkaid	20	1.8

What Did You Find Out?

1. Which star in the Big Dipper appears the brightest? Which appears the faintest?
2. Megrez is one of the closer stars although its magnitude is the highest. How can you explain this?
3. If you placed all the stars at the same distance, which do you think would appear the brightest? the faintest?

Science Watch

Stories of Ursa Major

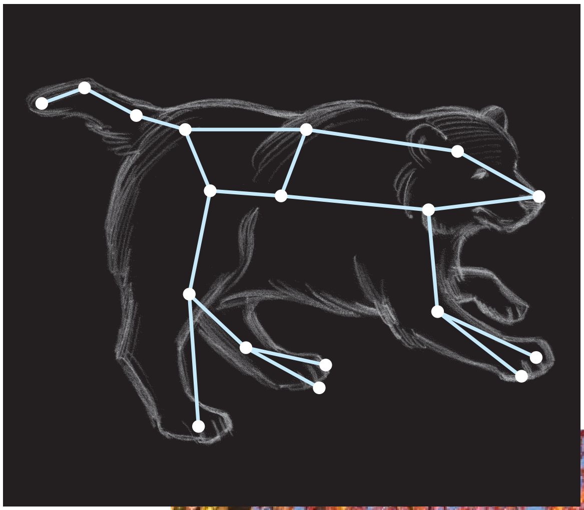
The night sky has been a source of wonder for people for thousands of years. People of different cultures have imagined stories to help explain how constellations came to exist in the sky. Ursa Major and the Big Dipper feature in many stories.

Many cultures believed the stars forming Ursa Major represented a bear. Within Ursa Major, seven stars create an outline that looks like a large dipper or ladle. We know this constellation as the Big Dipper. In one First Nations story, the stars forming the handle of the Big Dipper (Alioth, Mizar, Alkaid) are three hunters chasing the bear. Because the stars are low in the sky during autumn, it is said that the hunters had injured the bear. Blood from the bear is turning the leaves red. Nova Scotia Mi'kmaq and St. Lawrence River Iroquois tell stories in which Alioth is a hunter carrying a bow and arrow to kill the bear; Mizar is a hunter carrying a pot to cook the bear in; and Alkaid is a hunter carrying firewood to use to heat the pot.

A Greek myth said that Zeus' wife Hera was jealous of beautiful Callisto. Zeus changed Callisto into the Great Bear to save her from Hera. As a bear, Callisto was safe from Hera but was in danger of being killed by hunters. Callisto's son Actas tried to kill her, not knowing she was his mother. Zeus changed Actas into a bear too, to prevent him from killing Callisto. The pattern of stars representing Actas is known as Ursa Minor, or Little Bear.

In many African cultures, the stars that make up the Big Dipper represent a drinking gourd. Africans who were slaves in North America sang songs about the gourd. As you have read, the handle of the dipper, or the gourd, points to Polaris, the North Star. Some slaves may have followed the outline of the gourd to travel north and escape slavery.

An Arabic story interprets the stars in the Big Dipper's bowl as a coffin and the three stars in the handle as mourners following the coffin.



Questions

1. How did the First Nations' story of the injured bear help people predict and explain seasonal changes?
2. Imagine you lived thousands of years ago. Write a short story explaining how the Big Dipper formed in the sky.
3. Imagine you could travel back in time. With your knowledge of modern astronomy, how would you explain the Big Dipper to people in Ancient Greece?

Check Your Understanding

Checking Concepts

1. Constellations are often named after characters from Greek and Roman mythology. What characters can be used to describe the following constellations?
   (a) Ursa Major
   (b) Cassiopeia
   (c) Orion
   (d) Leo
2. What are the five planets named after Roman Gods?
3. Why does the star Rigel in constellation Orion appear dimmer than the star Sirius in Canis Major?
4. If you were to select a method of angular measurement to calculate the angle between stars, what method would be the most accurate—using your fist or using an astrolabe? Why?
5. Where is the star Polaris located in the sky?
6. As Earth revolves around the Sun, it appears that the Sun is moving against a background of stars. What are the constellations that lie along the ecliptic path that the Sun follows?
7. Why can we see comets in many parts of the sky?
8. In the northern sky, which constellations are easily seen during each season?
   (a) fall
   (b) winter
   (c) spring
   (d) summer

Understanding Key Ideas

9. Not every star visible from Earth has a name. Why not?
10. Everyone living in the northern hemisphere generally sees the same patterns of stars. Why, then, are the various constellations and asterisms interpreted in so many different ways?
11. When looking at the northern sky, how does one locate the North Star?
12. The International Astronomical Union lists 88 constellations. Why can you not see all of them in the Canadian sky?
13. On a star chart, identify each of these constellations:
    (a) Ursa Major
    (b) Ursa Minor
    (c) Orion the Hunter
    (d) Cassiopeia
    (e) Leo the Lion
14. Using the scale of brightness developed by Hipparchus, the Sun is assigned a magnitude of –27, while planets can be assigned a magnitude score of +30 for stars detected only by the Hubble Space Telescope. What is this scale measuring?

Pause and Reflect

Orion is a prominent constellation often referred to as "The Hunter." It is one of the largest, most conspicuous, and most recognizable constellations in the night sky.

The pattern of stars in this constellation was interpreted by the ancient Sumerians as a shepherd with his sheep, or a shepherd's crook. The Seri people of northwestern Mexico call the three stars in the middle of this constellation *Hapj* (meaning a hunter). In Australia, the constellation of Orion is seen as a canoe. The story told is that three brothers went fishing, and caught and ate fish that were forbidden under their law. Seeing this act, the Sun sent a waterspout that carried the three brothers and their canoe up into the sky where they became the Orion constellation.

Write a short paragraph describing a myth related to a constellation of your choice. The myth could be real or one created by you.

10.2 Early Models of the Universe

Human understanding of Earth and its place in the universe has evolved as technology has enabled us to see farther into space. Early astronomers built observatories to track the motions of the heavens and developed theories and models to explain the motions they saw. The earliest models showed all celestial bodies rotating around Earth. Later, new observations and calculations enabled astronomers to prove that Earth and other plants rotate around the Sun. Modern tools allow us to expand on these early discoveries to learn more about distant planets and about the universe outside our solar system.

Key Terms

astrolabe
geocentric
heliocentric
retrograde motion
telescope

Human beings have always been curious about the world around them (Figure 10.21). Our observations in any area of science have long depended on the tools available to us. The development of microscopes enabled scientists to observe new life forms. The development of Sound Navigation and Ranging (SONAR) helped us to learn about the ocean floor. Observation of the sky improved greatly after the invention of the first optical telescope in the 17th century. Suddenly, people were able to see details they could never have imagined were there before. This new technology was how they came to realize that the Moon has craters, that stars exist in the millions rather than thousands, and that Earth is not the centre of the universe. Constant improvement of tools and technologies has helped astronomers continue to make new discoveries, both from Earth and by going into space.

Figure 10.21 The mysteries of the universe have long captured the curiosity and imagination of humans.

Ancient Observatories

Compared with most people today, early people were much more aware of daily and seasonal changes in their everyday lives. Fishermen and other mariners, for example, knew the fixed pattern of stars in the sky and used the stars to navigate by. Hunters, gatherers, and farmers watched the changing phases of the Moon through a month and the changing path of the Sun through the year. They used that information to prepare for changing seasons, animal migrations, flooding rivers, and other natural phenomena. Several highly sophisticated structures were designed and built around the world with the express purpose of observing and tracking celestial movements. Several of these structures are shown in Figure 10.22.

Figure 10.22 Many astronomical observatories built in ancient times remain today. Shown here are Cheomseongdae in Korea (A); Chichén Itzá in Mexico's Yucatán (B); Stonehenge in England (C); the pyramids of Giza in Egypt (D); and the Bighorn Medicine Wheel in Wyoming, U.S.A. (E).

Aristotle

Figure 10.23 Aristotle

While some of the observatories used by ancient peoples still exist, we know very little about the individuals who designed and used them. There are several early astronomers, however, who left written records of their work and who made significant contributions to our current understanding of Earth and space.

Aristotle (383–322 B.C.E.), shown in Figure 10.23, was a Greek philosopher. Like others at his time, Aristotle visualized the universe as being geocentric. A **geocentric** universe has Earth at the centre and the Sun, Moon, planets, and stars revolving around it (Figure 10.25).

Like other scientists, Aristotle based his theories of the universe on observations he was able to make. Because the patterns of stars in the sky did not change, he concluded that Earth was fixed in place. If it moved, he reasoned, we would see the patterns of stars change.

He observed the shadows created on the Moon during a lunar eclipse. Since those shadows had curved edges, Aristotle concluded that Earth must be a sphere (Figure 10.24). As further evidence of Earth's spherical shape, Aristotle noted that as you travel north or south, you see different constellations in the sky.

Figure 10.24 The curved edges of the shadow that Earth cast on the Moon during a lunar eclipse convinced Aristotle that Earth must be a sphere. No other shape always casts a curved shadow.

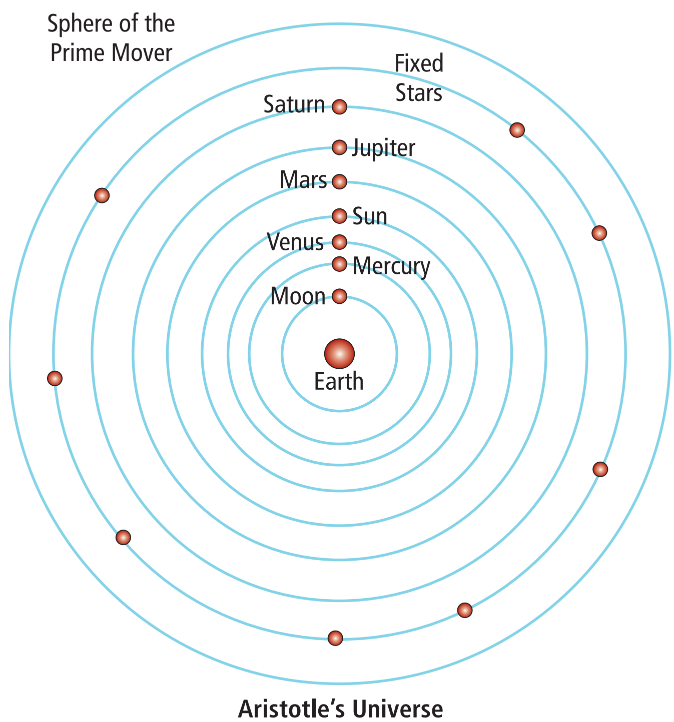


Figure 10.25 To explain the motion of celestial bodies that we see from Earth, Aristotle developed a model that placed the celestial bodies on 22 concentric spheres. These spheres, he explained, moved at different speeds, causing the different observed motions of the planets.

Not long after Aristotle lived, another Greek astronomer, Aristarchus of Samos (310–230 B.C.E.) proposed that the universe was not geocentric but **heliocentric**, meaning the Sun was at the centre and the planets revolved around the Sun. He observed the Sun and Moon and was the first person to attempt to measure the distance to the Sun. He proposed that Earth and the other planets rotate on an axis and revolve around the Sun. Aristarchus was the first to propose a heliocentric universe but Aristotle's model had such strong support that the idea of a Sun-centred universe was not accepted.

Eratosthenes of Cyene

Eratosthenes of Cyene (276–194 B.C.E.) was a mathematician and astronomer in ancient Egypt. He was the first person to measure the diameter of Earth with remarkable accuracy. He did this using only two sticks and his mind.

Eratosthenes had heard that at noon on June 21, the longest day of the year (and the first day of summer), a stick cast no shadow in the Egyptian city of Cyene. This observation meant that the Sun was directly overhead. Eratosthenes lived in Alexandria some distance to the north. He noticed that a stick on the same day at the same time in Alexandria did in fact cast a shadow. If Earth were flat, you would expect both sticks to cast no shadow, since the Sun's rays that arrive at Earth are parallel. Since one stick did cast a shadow, Eratosthenes concluded that Earth must be round.

Eratosthenes went one step further. He measured the angle at which the Sun's rays struck the stick in Alexandria to create the shadow. Then he calculated that if you extend the two sticks to the centre of Earth, they made an angle of 7°. Since 7° is approximately one fiftieth of a circle (360°), Eratosthenes concluded that the distance from Alexandria to Cyene was one fiftieth the circumference of Earth. He paid someone to pace off the distance between the two cities—approximately 800 km. Eratosthenes concluded that the circumference of Earth was 800 km × 50 km, or 40 000 km—very close to the correct answer (Figure 10.26). Not bad science based on only two sticks!

Eratosthenes' method of measuring the diameter of Earth

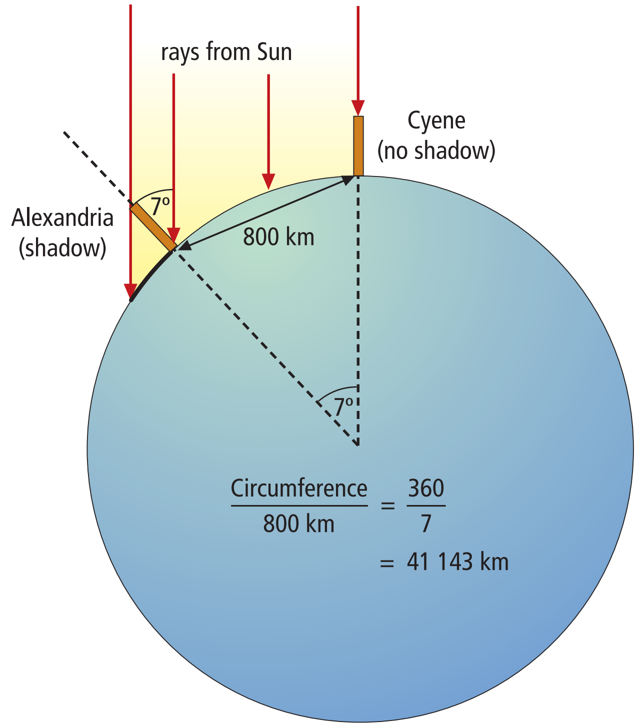


Figure 10.26 Eratosthenes used ratios, geometry, and astronomy to measure the diameter of Earth.

Ptolemy

Although Aristotle's model of concentric spheres around a spherical Earth explained much of what people saw in the sky, astronomers knew that Aristotle's model did not explain all the observed motions of the planets.

For example, if you observe and record the position of Mars every night over a period of weeks, you will see that its path creates a loop or S shape in the sky. This change of direction is called **retrograde motion**. Mars' eastward motion slows down and stops, then heads west for a few weeks. It then stops again and resumes its normal eastward motion (Figures 10.28 and 10.30 on the next page). Aristotle's spheres did not explain this strange behaviour.

Figure 10.27 Ptolemy

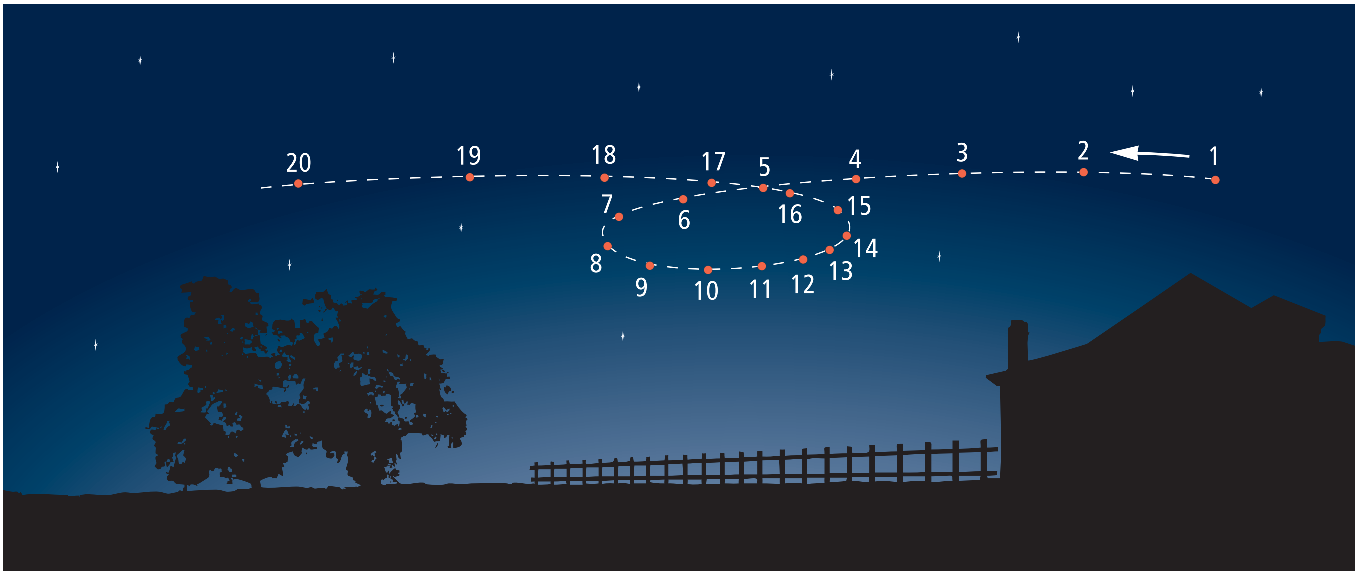


Figure 10.28 Position of Mars compared to the background stars during a period of retrograde motion. Each point represents the planet's new position every 10 days over the retrograde period.

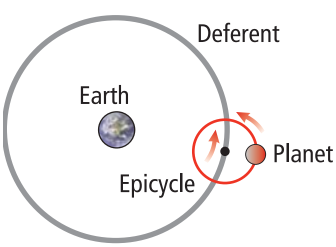


Figure 10.29 Ptolemy proposed that each planet revolved around a point on its orbit, called an epicycle, to explain its motion through the heavens.

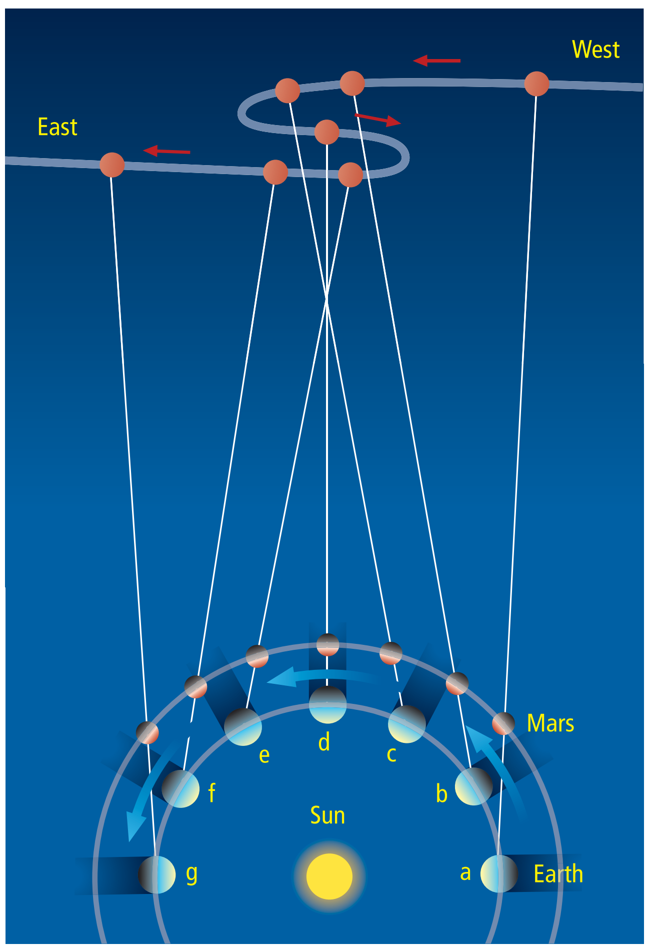


Figure 10.30 In some parts of Earth's orbit, for example between a and b, Mars appears to be moving more quickly than we are. In other parts, for example between c and d, Mars seems to be moving more slowly than we are. These observations cause Mars to seem to change directions—sometimes appearing to move from east to west and sometimes from west to east.

Ptolemy (83–168 C.E.), shown in Figure 10.27 on page 369, observed Mars closely and developed a model of the solar system to explain it. His model showed each planet attached to a crystal sphere with its centre at Earth. Ptolemy envisioned each planet not attached directly to its sphere, but attached to an off-centre wheel, which rotated as the sphere turned. This small wheel was called an epicycle (Figure 10.29 on page 370). This model was a convincing explanation for the observed motion of the planets, and was accepted for nearly 1500 years as part of the Aristotle/Ptolemy universe.

Around the time of Ptolemy, an instrument called an **astrolabe** was invented. Astronomers were able to use astrolabes to help them locate and predict the positions of the Sun, Moon, and stars. Using a compass and an astrolabe, they were able to describe the position of any celestial body in relation to the direction north as well as in relation to the horizon. Doing so helped them to make more accurate observations and to compare observations at different places and times. While this tool was important to astronomers in their study of the sky, mariners developed their own version of an astrolabe, to help them navigate using the Sun, Moon, and stars. A mariner's astrolabe worked much like a protractor. By lining it up with the horizon, a navigator could compare the positions of celestial bodies to positions in tables that were carried on the ship. In this way, the navigator could determine the position of the ship.

Did You Know?

An astrolabe used in the early 17th century was discovered near Isle aux Morts in south-west Newfoundland by Wayne Mushrow in 1981. The astrolabe is of Portuguese origin, is in excellent condition and working order, and has been designated as a provincial heritage treasure.

Suggested Activity

Find Out Activity 10-2B on page 374

Copernicus

Nicolaus Copernicus (1473–1543), shown in Figure 10.31, was a Polish astronomer, mathematician, physician, and priest, and he lived before the telescope was invented. He observed the night sky carefully using just his eyes, and proposed that the movements of celestial bodies that earlier astronomers had observed—the daily rotation of the heavens, the annual movement of the Sun through the ecliptic, and the periodic retrograde motion of the planets—could be explained in a simpler way by a model in which Earth rotated on its axis once daily and revolved around the Sun once a year (Figure 10.32). People of this time period still believed in the geocentric universe proposed by Ptolemy and Aristotle. It was a brave thing for Copernicus to suggest that this theory was not true.

Figure 10.31 Nicolaus Copernicus

Copernicus' model of a heliocentric universe set the stage for other scientists to better understand the universe and to propose their own theories based on his model. Some supporters of his heliocentric model paid dearly. Giordano Bruno agreed with the Copernican model. He suggested as well that the universe was immense and that there were other Suns like our own, with planets, possibly inhabited. In fact, he suggested that these beings may be superior to us. For an act that was viewed as blasphemy, Bruno went on trial, was found guilty, and was burned at the stake in 1600.

Figure 10.32 Copernicus' view of the solar system with the Sun at the centre

Galileo

Galileo Galilei (1564–1642), shown in Figure 10.33, was the first person to turn a small telescope toward the heavens and publicly report on what he saw. A **telescope** is an optical device that uses lenses to gather and focus light to provide a magnified view. His telescope was not very powerful—it made objects appear only 20 times closer. Most backyard telescopes today are more powerful than this. But it was powerful enough to show him never before seen views of several celestial bodies. He observed craters on the Moon, spots on the Sun, and four "stars" orbiting the planet Jupiter. The "stars" orbiting Jupiter turned out to be natural moons. Galileo also observed that Venus has phases, like our Moon does. This observation provided evidence for the heliocentric universe. Galileo reasoned that Venus could only have phases if it orbited the Sun (Figure 10.34).

Figure 10.33 Galileo Galilei

Did You Know?

The four large moons of Jupiter discovered by Galileo are now known as the Galilean Moons. These moons are easily seen using a small backyard telescope. A spacecraft sent in the 1980s to orbit Jupiter and learn new things about the planets and its moons was named *Galileo*, after the famous astronomer.

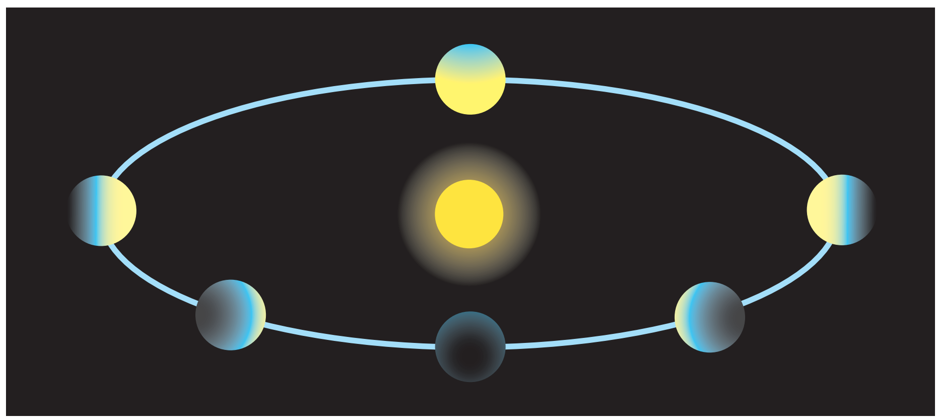


Figure 10.34 The planet Venus will show phases like the Moon only if it orbits the Sun as shown in this drawing. This phenomenon is what Galileo observed.

Galileo published his observations and conclusions (Figure 10.35). At the time, the Catholic Church was a very powerful institution in Italy, where Galileo lived. The Church taught that the Sun revolved around Earth, and put Galileo on trial for his theory of a heliocentric universe, found him guilty, and imprisoned him for the rest of his life.

The impact Copernicus and Galileo had on astronomy was very important. Now that the Sun was placed at the centre of our solar system, other astronomers could work to understand the motions of the planets using careful observation and mathematics. Improvements in the telescope would open up the heavens to astronomers, showing them new celestial bodies and strange objects never imagined.

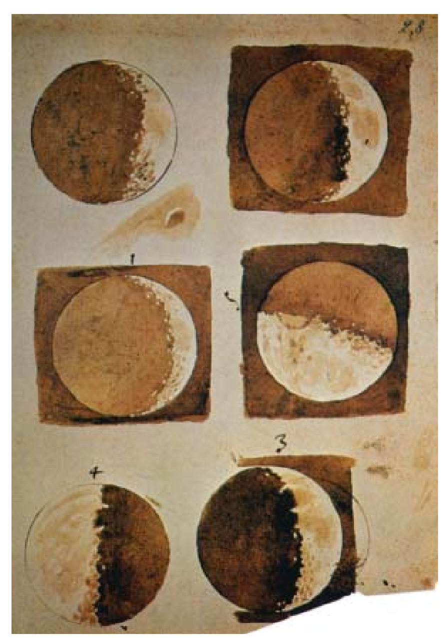


Figure 10.35 Drawing of the Moon as seen by Galileo through his telescope

Explore More

The contributions of Galileo had a significant impact on science. Follow the links at **www.discoveringscience9.ca** to learn more about how he made these discoveries and how they impacted society and his life.

Reading Check

1. What does the term "geocentric" mean?
2. What are astrolabes used for?
3. Compare and contrast Aristotle's and Copernicus' models of the universe.
4. What piece of evidence led Galileo to believe that the universe was heliocentric?

10-2A Build Your Own Telescope

Find Out ACTIVITY

In a refracting telescope, an objective lens gathers light from a distant object and focusses the image in the telescope. The light of the image is then magnified by an eyepiece lens, which is where you see the image with your eye. In this activity, you will build your own refracting telescope.

Safety

- Handle scissors carefully.
- Glass lenses are breakable. Handle them carefully.

Materials

- ruler
- pencil
- one toilet paper tube (approximately 4 cm in diameter)
- one paper towel tube (approximately 4.3 cm in diameter)
- scissors
- two convex lenses (approximately 4.5 cm in diameter)
- clear adhesive tape
- metre stick
- page of small-print text (such as the page of a newspaper or magazine)

What to Do

1. Use the ruler and pencil to mark a line about 2.5 cm from one end of the toilet paper tube. Do the same on the paper towel tube.
2. With the scissors, carefully cut an opening in each tube along the line you drew, but only halfway around.
3. Insert one of the lenses into the opening you made in the toilet paper tube. Use the tape to secure the lens to the outside of the tube. Repeat this step for the paper towel tube.
4. Slide the empty end of the toilet paper tube (the end without the lens) into the empty end of the paper towel tube.
5. Have a partner hold the page of text about 1 m away from you. Look through your telescope at the page. To focus the image, slide the inner tube back and forth inside the outer tube.
6. Test your telescope by having your partner hold the page at different distances from you.
7. Repeat step 6 until you cannot see a clear image. Measure this distance using the metre stick and record the number.

What Did You Find Out?

1. What did you notice about the image you observed when you were 1 m from the page?
2. Explain what you had to do to the telescope to make the image clearer when you were:
   (a) closer to the page
   (b) farther from the page
3. What was the maximum distance at which you could still see a clear, magnified image?
4. Suggest a change to the design of the telescope that would allow you to see a clear image of the page from farther away.

10-2B Pointing in the Right Direction

Find Out ACTIVITY

The astrolabe is a device that was used by early astronomers to pinpoint the locations of objects in space. The instrument itself has had various forms and has been in use for more than 2000 years. In this activity, you will use an astrolabe to determine the angle and height of objects in different positions around your classroom.

Safety

Never look directly at the Sun in this or any other activity.

Materials

- astrolabe
- directional compass
- pen
- paper

What to Do

1. Copy the table shown below into your notebook. (Your teacher will pick the target objects you should use.)

Object	Angle	Height
1. Example: Top hinge of door		
2.		
3.		
4.		

2. Use the compass to find out which part of your classroom faces due north. Then use the compass to determine the angle of the first object in relation to due north. Record this angle in the "Angle" column of your table. Remember that an angle farther from north will measure a greater number of degrees.

3. Use the astrolabe to determine the height of the object. Make your measurement from a sitting position at your desk. Record this value in the "Height" column of your table.

4. Repeat steps 2 and 3 for three more objects assigned by your teacher.

What Did You Find Out?

1. Describe the difficulties of locating objects using this technique.
2. What could be done to improve this way of measuring?
3. Compare your coordinates (angle and height measurements) with those of a classmate. Why are they different?
4. How does the time of day you take a measurement of an object in the sky using an astrolabe affect the ability of someone else to find the same location?
5. Write a general rule about the accuracy of using an astrolabe to share the location of objects in the sky.

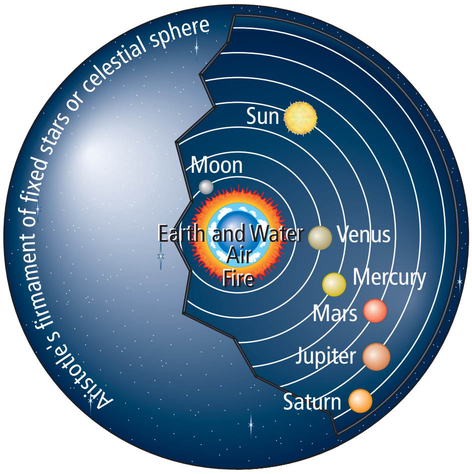
Check Your Understanding

Checking Concepts

1. How have fisherman, hunters, gatherers, and farmers used the positions of the stars to help them?
2. What observations led Aristotle to believe that the Earth was a sphere?
3. What does heliocentric mean when used to describe a model of the solar system?
4. There were several early astronomers who made significant contributions to our current understanding of Earth and space. Summarize the theories of the following astronomers.
   (a) Aristotle
   (b) Aristarchus
   (c) Ptolemy
   (d) Copernicus
   (e) Galileo

Understanding Key Ideas

5. How could you prove that Earth is not flat?
6. Look at the figure of Aristotle's model of the solar system. Describe at least three parts of the model that we now know are not correct.



7. How does a mariner determine the position of his or her ship?
8. How did the model of the universe proposed by Copernicus differ from the model proposed by Ptolemy?
9. What celestial bodies were revealed when Galileo turned his telescope to the heavens?
10. Compare and contrast a geocentric model with a heliocentric model of the solar system.

Pause and Reflect

In this section, you have learned about how early astronomers evolved theories to explain our understanding of the universe. The study of astronomy is complex. It combines many types of scientific study along with influences from religion and society. Give examples of how either religious or societal views have affected the acceptance or rejection of models to explain how our universe is organized.

10.3 Standing on the Shoulders of Giants

By the 16th century, people understood that the Sun was at the centre of the solar system and the planets revolved around it. Astronomers then set to work to explain the motions of the planets and understand what causes them. Johannes Kepler and Sir Isaac Newton formulated the laws required to explain these motions and to understand mathematically how gravity works. These laws form an important part of the model of the solar system used by astronomers today.

Key Terms

ellipse
orbit

The research done by scientists such as Aristarchus, Eratosthenes, Copernicus, and Galileo laid the foundation for those who followed. Once people understood that the Sun was at the centre of the solar system and the planets revolved around the Sun, the next astronomers could use new technologies available to them to make accurate observations and add details to this model. These astronomers—Kepler, Brahe, and Newton—were the first true astronomers/physicists, or astrophysicists. They tried to explain the observed motions of the celestial bodies using mathematics. To do so, they had to invent new methods, look for patterns, and express new laws. The work of these astronomers resulted in a greater understanding of why the planets move the way they do. In addition, scientists found that these new laws of motion could be used when studying any objects in the universe.

Kepler, Brahe, Newton, and others helped to develop our modern understanding of the solar system. They could not have made their important discoveries, however, without the work of early astronomers and inventors. Newton once wrote of his accomplishments: "If I have seen further it is by standing on the shoulders of giants."

Figure 10.36 Johannes Kepler

Johannes Kepler

Johannes Kepler (1571–1630), shown in Figure 10.36, was a German mathematician, astronomer, and astrologer.

Kepler was familiar with the Copernican model of planetary motion. With the Sun at the centre of the solar system, the planets moved in circular **orbits**, or paths around the Sun. He knew that he could describe the motions of the planets more accurately and learn more about the solar system by using new technologies to make very accurate observations, then analyzing the data using mathematics. Since Kepler had little experience making astronomical observations, he sought help from someone who was known for his astronomcal observations—Tycho Brahe.

Tycho Brahe

Tycho Brahe (1546–1601), shown in Figure 10.37, was a Danish nobleman. Tycho used instruments in a new observatory to make very accurate observations of the positions of the planets. Kepler helped him to make these observations. Kepler then used their data to develop his theories of planetary motion.

Kepler worked for weeks using the data from the observations of Mars' orbit, trying to develop mathematical formulas that would match the motion he and Tycho Brahe observed. When he used a circular orbit for Mars, he got no match. He tried using an **ellipse** for the orbit, and it worked (Figure 10.38). He was able to predict the motion using mathematics.

Figure 10.37 Tycho Brahe

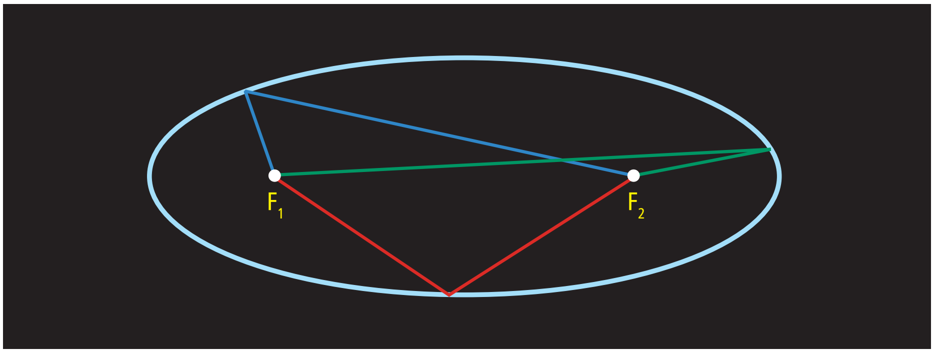


Figure 10.38 In an ellipse, the distance from one focal point (F_1) to a point on the edge and then to the other focal point (F_2) is the same no matter which point on the edge of the ellipse you choose.

Kepler developed three laws of planetary motion:

1. All planets move in ellipses, with the Sun at one focus.
2. Planets sweep out equal areas of their elliptical orbit in equal times. This law means that the speed of a planet as it revolves around the Sun is not constant. As the planet gets closer to the Sun, it speeds up; when it gets farther away, it slows down (Figure 10.39).

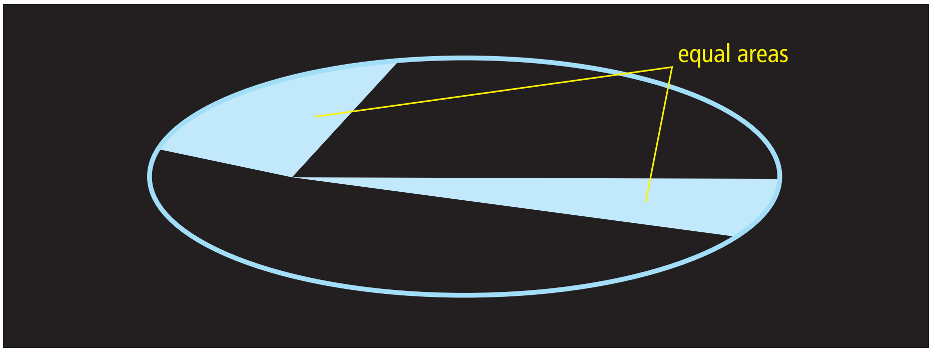


Figure 10.39 As a planet revolves around the Sun, its speed is not constant but the area it sweeps out in a given time is constant.

3. The time a planet takes to revolve around the Sun is directly related to how far away it is from the Sun.

These three laws are still used today to describe and predict the motions of any two celestial bodies where one is orbiting the other.

Did You Know?

A mission to use a telescope in orbit around Earth to search for Earth-sized planets is planned for launch in 2009. The mission is named after Johannes Kepler. It will monitor the brightness of over 100 000 stars over a period of time and watch for a slight dimming of any star. If a star gets slightly dimmer, that will indicate that a planet has moved in front of the star.

Suggested Activity

Find Out Activity 10-3C on page 384

Figure 10.40 Sir Isaac Newton

Sir Isaac Newton

Sir Isaac Newton (1643–1727), shown in Figure 10.40, was considered to be the most influential scientist who ever lived. He was a mathematician, an astronomer, and a physicist. Newton developed three laws to describe and predict motion, and explained how celestial bodies move through the universe.

Although it was widely understood that there was a force that caused objects to fall to Earth (gravity), Newton was the first to show mathematically that the force of gravity extends far beyond the surface of Earth, and affects all celestial bodies, causing them to remain in orbit around larger bodies. He published a book that explained the mathematics behind this theory. Moons revolve around planets, and planets revolve around the Sun in elliptical orbits. They are held in these orbits by gravity. We use Newton's laws when we calculate how to send people to the Moon or spacecraft to the planets. These same laws govern the motion of stars throughout the Milky Way galaxy.

Newton was interested in many areas of science. He discovered that light, when shone through a prism, is broken up, or refracted, into a spectrum of colours. He also showed that this spectrum could be reassembled into white light again when passed through a second prism. He also invented the reflecting telescope—a telescope that uses a curved mirror to focus the light to a point at an eyepiece (Figure 10.41). His reflecting telescope could be larger and allow more precise observation than the telescopes of his time that used lenses to focus the light. Newton's design for a reflecting telescope is used today and is called the Newtonian design.

Figure 10.41 Newton made his observations of the solar system using a simple reflecting telescope like this one.

Scale of the Solar System

Since the time of Johannes Kepler, Tycho Brahe, and Isaac Newton, many other astronomers have contributed to our understanding of the solar system. The basic model we use to represent it has not changed since Newton's time, but astronomers have learned more about the planets and their orbits. We now know that all the celestial bodies in the solar system orbit the Sun in elliptical orbits. They are held in these orbits by the gravity of the Sun. In turn, the planets rotate on their axes, which causes day and night.

The planets Mercury, Venus, Mars, Jupiter, and Saturn are visible without a telescope, and have been observed for many years (Figure 10.42). The planet Uranus is barely visible to the naked eye. Because it is so far away from the Sun, it also appears to move very slowly. Astronomers had noticed it, but had thought it was a star. In 1781, William Herschel, observing with a telescope, recognized Uranus as a planet in our solar system.

Neptune is so far from Earth that it cannot be seen with the naked eye. Astronomers noted that the orbit of Uranus was not a perfect ellipse and reasoned that there might be another planet nearby that was exerting a gravitational force on Uranus. In 1846, astronomers used mathematical formulas to predict where that new planet must be. Using telescopes, Neptune was found almost exactly where predicted.

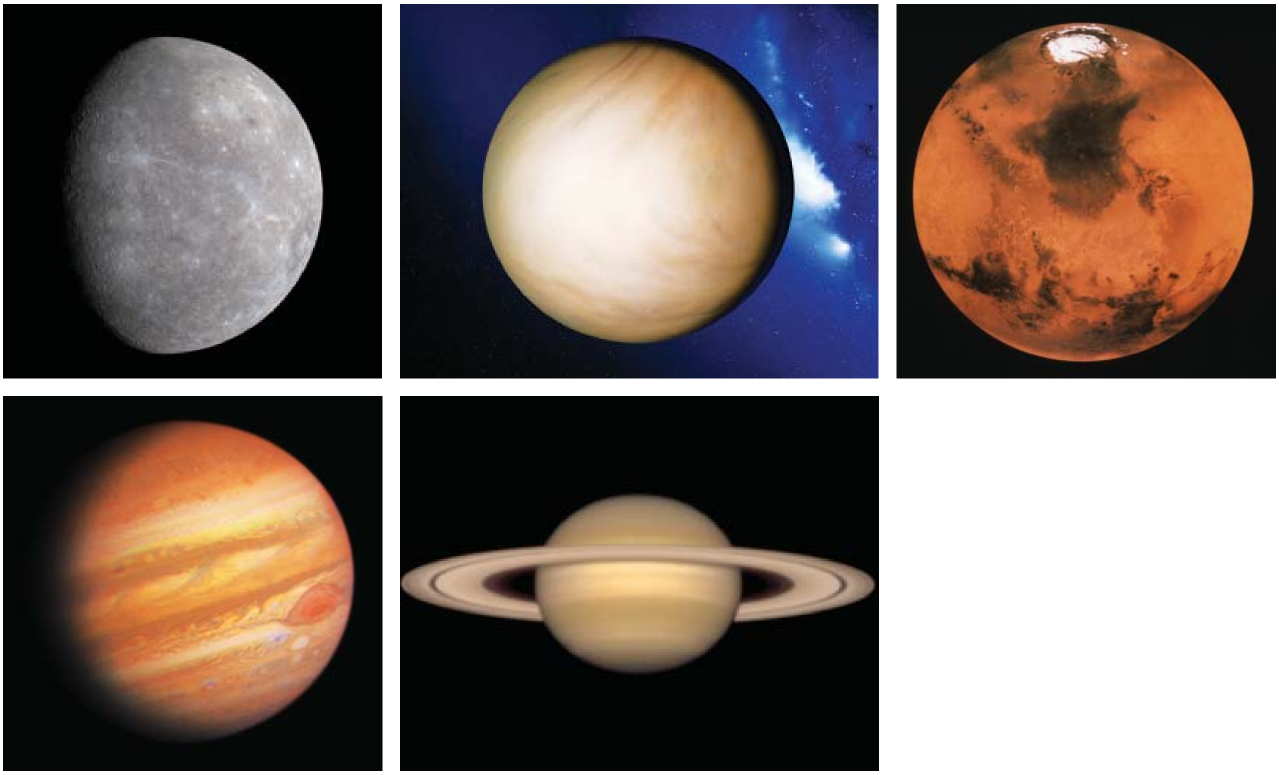


Figure 10.42 The planets, Mercury, Venus, Mars, Jupiter, and Saturn, as seen with powerful telescopes. From Earth, these planets can be seen without a telescope. They look like bright stars, but follow a different path in the sky.

The planets in order out from the Sun are shown in Figure 10.43.

The planets closest to the Sun—Mercury, Venus, Earth, and Mars—are called the inner planets. They are relatively small and have solid cores and rocky crusts. You could stand on any of these planets. Farther away are the outer (or Jovian) planets: Jupiter, Saturn, Uranus, and Neptune. These planets are known for their large gaseous atmospheres, cold temperatures, and lack of a solid surface.

The distances between the planets are immense. Most of the solar system is empty. As you will discover in Core Lab Conduct an Investigation 10-3B, the planets are very small and the space between them is very large.

Suggested Activity

Core Lab Conduct an Investigation 10-3B on page 382

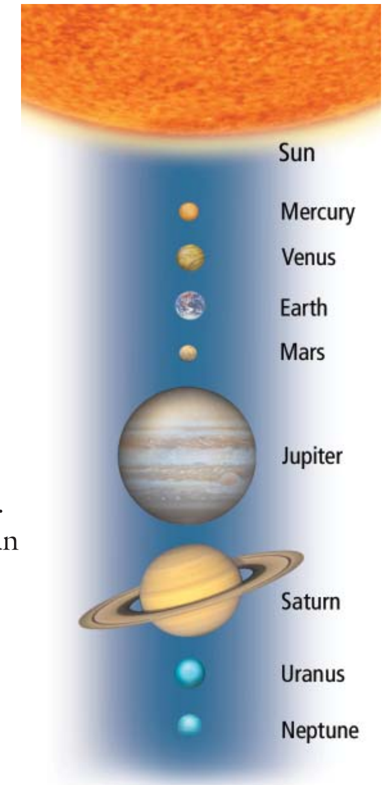


Figure 10.43 The order of planets in our solar system (not to scale). Since each of the planets rotates around the Sun, they never appear aligned as shown here.

Reading Check

1. What is the Copernican model of planetary motion?
2. What three laws of planetary motion did Kepler develop?
3. What force keeps planets orbiting around the Sun?
4. What are the two groups into which we divide planets?

10-3A The Length of the School Year on Different Planets

Find Out ACTIVITY

Earth takes 12 months to orbit around the Sun once. Students spend about 75 percent of their year, or 9 months, in school. Although that may seem like a long time, it could be longer if you were a student on another planet.

In this activity, you will determine the length of school years on other planets.

Materials

- pencil
- paper
- calculator
- graph paper

What to Do

1. Copy the following table into your notebook.

Planet	Period of Revolution (relative to 1 Earth year)	School Year Earth (months)
Mercury	0.24	2.16
Venus	0.61	
Mars	1.70	
Jupiter	11.90	
Saturn	29.50	
Uranus	84.00	
Neptune	165.00	

2. Calculate the school year on each planet relative to a school year on Earth.

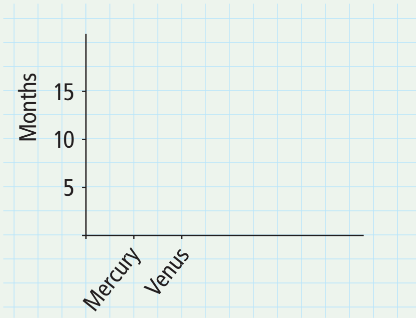
   Example:

   Earth school year = 9 months

   Mercury year (relative to Earth's) = 0.24 Earth years

   Mercury school year = 0.24 × 9 months
   = 2.16 months

3. Draw a graph of your data. Plot the planet names on the *x*-axis and the number of months on the *y*-axis:



4. Connect the points with a best-fit straight line.

What Did You Find Out?

1. What did you notice about the length of the school year as you moved farther from the Sun?
2. What does the slope of the line tell you about change in the length of the school year as you move from one planet to another?

10-3B Strolling Through the Solar System

Core Lab

SkillCheck

- Classifying
- Measuring
- Modelling
- Evaluating information

Safety

- Never eat anything in the science room.

Materials

- materials to model the Sun and planets: ball bearing, or similar-sized ball (~28 mm diameter), coarse- and fine-grained sand, salt, cake sprinkles, and small candies or cake decorations
- 9 index cards
- clear adhesive tape
- 9 sticks (at least 15 cm long)
- measuring tape (100 m)

Posters of planets in our solar system show fantastic images of the eight planets. What the posters do not show is how large the distances are between the planets. In this activity, you will create a model of the solar system that adopts a fairly realistic scale for size and distance.

Question

What are the relative distances between planets in the solar system?

Procedure

Part 1 How Do the Sizes of the Planets Compare?

1. Prepare the Sun and each planet using the dimensions shown in the table below. Use the tape to stick the material to the index cards.

Solar System Object	Actual Diameter (km)	Scale Diameter (mm)	Model Material
Sun	1 400 000	28.00	Ball bearing
Mercury	4 900	0.10	Grain of fine-grained sand
Venus	12 100	0.24	Grain of salt
Earth	12 800	0.25	Grain of salt
Mars	6 800	0.14	Grain of coarse-grained sand (half the salt-grain size)
Jupiter	143 000	2.90	Cake decoration of appropriate size
Saturn	120 000	2.40	Cake decoration of appropriate size
Uranus	51 800	1.00	Cake decoration of appropriate size
Neptune	49 500	0.99	Cake decoration of appropriate size

Part 2 How Do the Distances to the Planets Compare?

2. Use the tape to attach the sticks to the index cards you used for your models. You will be sticking your models in the ground.
3. Take the planet models you made in Part 1 to a playing field outside. Place the model of the Sun at the goal line of the playing field. All measurements will be made from this point.
4. Using the measuring tape and the table below, determine the scale distance of the objects in the solar system. Place each model in the correct position relative to the Sun.

Solar System Object	Actual Distance from Sun (km)	Scale Distance from Sun (m)	Distance from Previous Planet (m)
Sun			
Mercury	58 million		
Venus	108 million		
Earth	150 million		
Mars	228 million		
Asteroid belt	~ 400 million		
Jupiter	778 million		
Saturn	1 430 million		
Uranus	2 870 million		
Neptune	4 500 million		

Analyze

1. The planets are typically described as inner (Mercury, Venus, Earth, and Mars) and outer (Jupiter, Saturn, Uranus, and Neptune). Based on your scale models, describe what you notice about the following:
   (a) the size of the inner planets compared with the outer planets
   (b) the distances to the outer planets compared with the inner planets
2. How do the distances between the inner planets compare with the distances between the outer planets?

Conclude and Apply

1. Copy the table at the left into your notebook and complete it. Use a scale of 1 m = 50 million km to calculate the scale distance (in metres) to Proxima Centauri (the nearest star to the Sun). The real distance from the Sun to Proxima Centauri is 30 000 000 000 million km.
2. Based on your scale model, explain why it seems unlikely that humans will ever journey outside the orbit of Neptune.

10-3C Easy Ellipses

Find Out ACTIVITY

Almost 400 years ago, Johannes Kepler, a German astronomer, concluded that all the planets orbit the Sun in ellipses, not circles. His studies helped explain the often confusing paths of the planets relative to each other.

In this activity, you will construct a number of different-sized ellipses.

Materials

- 2 cardboard squares (30 cm × 30 cm)
- blank piece of paper (28 cm × 21.5 cm)
- ruler
- clear adhesive tape
- pencil
- string (or thread) about 20 cm long
- 2 pushpins

What to Do

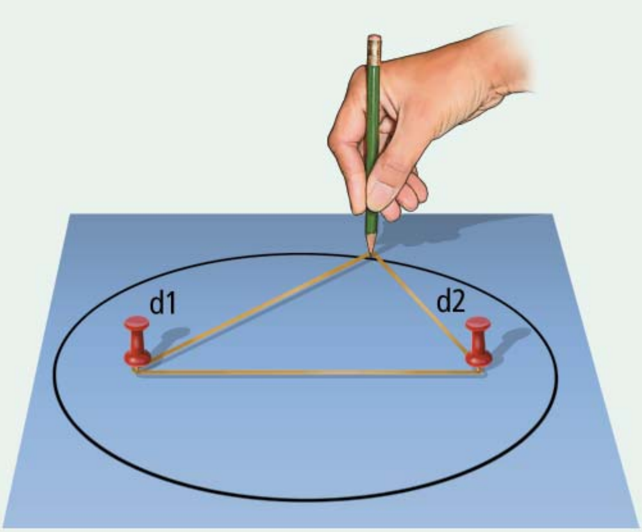
1. Tape the cardboard squares on top of each other and tape the paper on top.
2. Draw a 20 cm line horizontally across the middle of the paper. Stick the two pushpins on the line about 5 cm apart. These two points are the foci (singular: focus).
3. Loop the string over the pushpins. Using the pencil, pull the thread outward over the paper.
4. Keeping the string tight, drag the pencil upright around the pushpins so that it draws a smooth line on the paper.
5. Put three dots on the ellipse at three different points and label them A, B, and C.
6. Measure the distance from each dot to one focus (d1) and then to the other focus (d2). Record the measurements in a table (like the one below) in your notebook.

Point	d1 d2	Sum of Distances
(d1 + d2)		
A		
B		
C		

7. Add up the two distances from each point and record the sums in the table.

What Did You Find Out?

1. What do you notice about the sum of the distances for each point on your ellipse?
2. State what happens to the shape of the ellipse if you move the pushpins (foci):
   (a) farther apart?
   (b) closer together?
3. Calculate the sum of distances for another ellipse.
4. Describe the shape that results when you put the two pushpins together.
5. Write a general rule for the sum of distances from any point on an ellipse.



Check Your Understanding

Checking Concepts

1. What is an astrophysicist?
2. How does a planet's speed change as the planet gets closer to the Sun in its eleptical orbit?
3. What do Kepler's laws tell us about the motion of any planet that is orbiting the Sun? Use these headings to organize your answer:
   (i) Shape of the orbit
   (ii) Speed of the planet
   (iii) Time to complete one orbit
4. Describe the main contributions made by Sir Isaac Newton to our study of the universe.
5. What effect does gravity have on celestial bodies?
6. What causes a planet to have day and night?
7. Name the five planets visible in the sky without the use of a telescope.
8. Describe two differences between inner and outer planets.

Understanding Key Ideas

9. How did Kepler and Brahe work together to develop theories of planetary motion?
10. Summarize Kepler's mathematical explanation of how to predict planetary motion.
11. What is the relationship between a planet's distance from the Sun and the time it takes to revolve around the Sun?
12. Describe the shape of the paths of planets that orbit the Sun.
13. What were the advantages of the Newtonian telescope over other telescopes being used in Newton's time?
14. What observations by astronomers led to the discovery of Neptune?

Pause and Reflect

In this section, you learned how astronomers used mathematics to explain the motions of celestial bodies. The contributions of Johannes Kepler, Tycho Brahe, and Sir Isaac Newton have influenced our modern understanding of the universe. Summarize the laws that we use today to explain the motions of the planets and how gravity works.

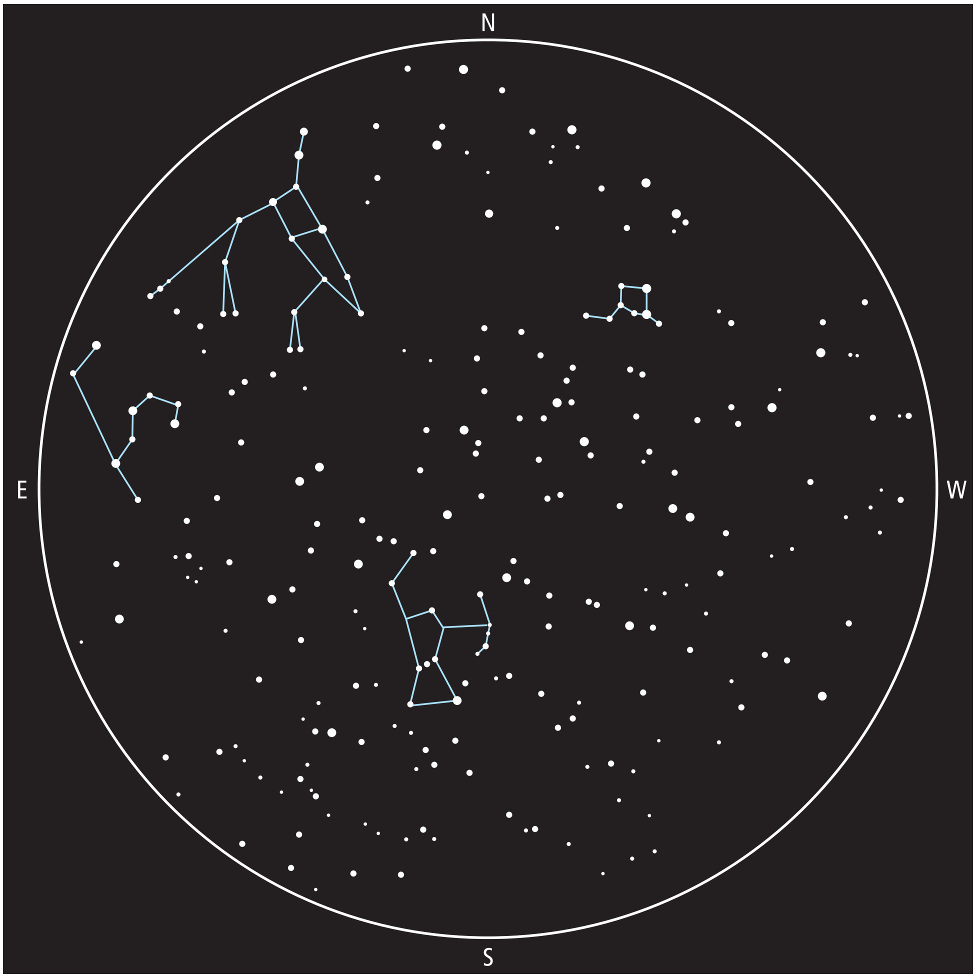
Prepare Your Own Summary

Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 8 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Constellations and Stars
2. Contributions of Ancient Greek Astronomers
3. Heliocentric Model of the Universe
4. Galileo's Invention of the Telescope
5. Contributions of Kepler and Newton to Astronomy

Checking Concepts

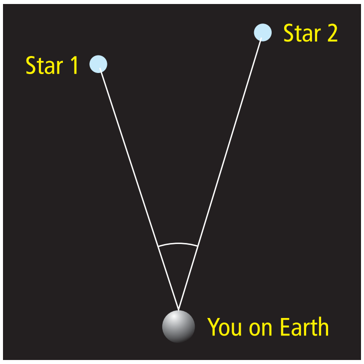
1. What is the name of each constellation shown below?
2. What is an asterism? Give an example.
3. Describe how astronomers record the magnitude of a star.
4. If you were to watch a night sky for many hours, which direction would the stars appear to move?
5. What is a circumpolar constellation?
6. Draw a diagram illustrating Aristotle's view of the universe.
7. What observation supports the belief that Earth is round?
8. Draw a diagram showing Copernicus' view of the solar system.
9. What contributions by Galileo led to our current understanding of astronomy?



10. What laws can an astronomer use to predict the motion of a celestial body orbiting another celestial body?
11. Sir Isaac Newton is often considered the most influential scientist who ever lived. Explain why this might be the case.
12. Astronomers like Kepler, Brahe, and Newton made contributions to the model of the universe that we use today. What do we know about the universe today that came from the investigations of these scientists?

Understanding Key Ideas

13. Compare and contrast the terms "celestial body" and "constellation."
14. Using the diagram below, summarize how you would estimate the angular dimensions between the two stars.



15. Why are the inner planets only visible around sunset or sunrise, but some of the outer planets are visible at other times of the night?
16. Compare Aristotle's view of the universe with the model proposed by Aristarchus.
17. How did Ptolemy explain the movement of Mars in the sky?
18. If a debate were to occur between two astronomers, one of them believing that the universe is geocentric and the other believing that the universe is heliocentric, what are some of the major points each speaker could make to support his or her point of view?
19. Explain why landing a spacecraft on a Jovian planet would be very difficult.
20. Sir Isaac Newton once wrote, "If I have seen further it is by standing on the shoulders of giants." Choose three astronomers and summarize how they contributed to Newton's ability to "see further."

Pause and Reflect

Detailed records of astronomical observations have been kept since ancient times. Throughout time, many different astronomers have contributed to increasing our knowledge about the universe. Draw a time line that documents the astronomers from ancient times to the classic astronomy era (about 1750 C.E.).