11.2 The Sun and Its Planetary System

Our solar system is full of planets, moons, asteroids, and comets, all in motion around the Sun. Most of these components are separated from each other by great distances. Each planet has its own distinct characteristics. Comets, icy debris, and dwarf planets travel at the outermost reaches of the solar system.

Words to Know

asteroid
axis
comet
moon
planet
revolution
rotation
solar system

When a star forms, its hot core remains surrounded by gas and dust that have not been pulled into the centre. Sometimes this leftover material just drifts off into space. In other cases, however, it remains in the nebula.

Gravity can set these particles into motion around the core (Figure 11.13A). The particles begin to gather in the centre of the spinning cloud. You can see a similar effect if you stir a glass of water that has a small amount of sand at the bottom. The more you stir, the more the sand gathers in the middle of the bottom of the glass. In the spinning cloud, tiny grains begin to collect, building up into bigger, rocky lumps called planetesimals (Figure 11.13B). If these planetesimals can survive collisions with each other, they may build up and eventually develop into full-fledged planets (Figure 11.13C). A **planet** is a celestial body that orbits one or more stars. Unlike a star, a planet only reflects the light radiated by its star. It does not generate its own light.

Astronomers believe this is how Earth and its seven fellow planets in our solar system formed. A **solar system** is a group of planets circling one or more stars.

Did You Know?

Astronomers once thought that our solar system was the only one that existed. Today we know that planetary systems are common. More than 200 planets have been discovered orbiting distant stars.

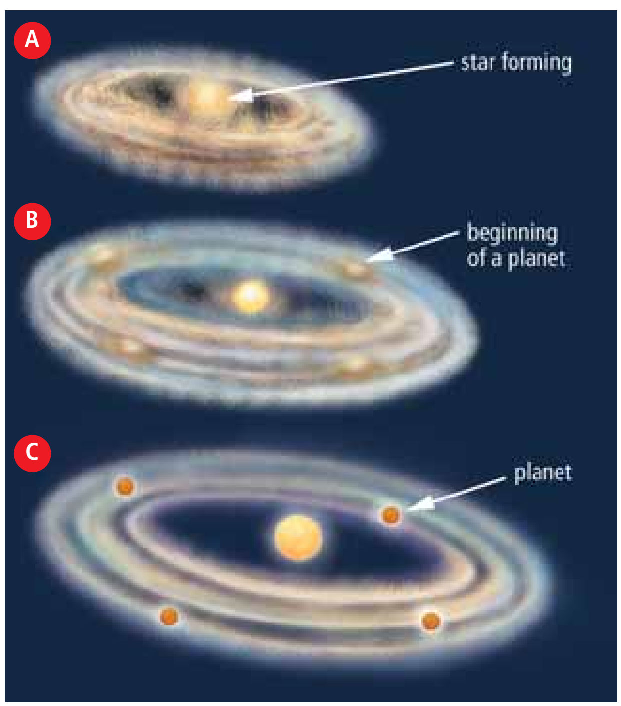


Figure 11.13 This model of planet formation is called the protoplanet hypothesis.

Each galaxy, as you learned in Chapter 10, spins like an enormous merry-go-round, around its central nucleus. Within the spinning Milky Way galaxy, our solar system is also rotating, moving at a speed of about 250 km/s. Within the solar system, all the planets are in motion, too, spinning like toy tops while orbiting the Sun. Earth spins on its **axis** (an imaginary line from the North Pole to the South Pole) at a speed of 1670 km/h, or 0.5 km/s. This is called its **rotation**. At the same time, it orbits the Sun at 30 km/s. This is called its **revolution**. The paths that Earth and the other planets take as they revolve around the Sun are elliptical, resembling long, slightly flattened circles.

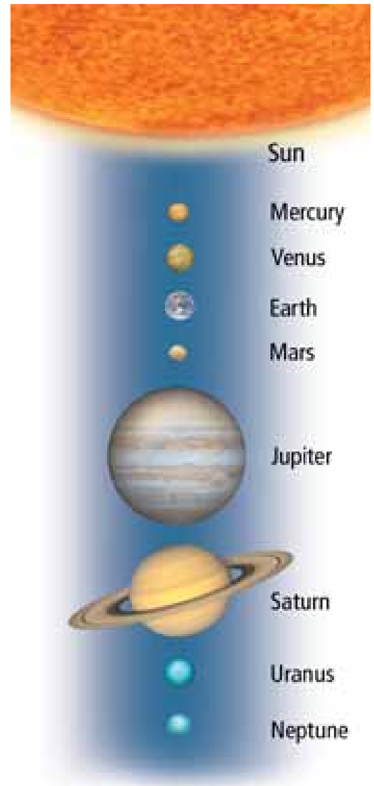


Figure 11.14 The order of planets in our solar system (not to scale)

The Formation of the Solar System

Our solar system formed more than 4.5 billion years ago. As the Sun burst into existence, the leftover material combined to form eight planets and numerous other smaller bodies: moons, asteroids, and comets.

Not all the planets formed at the same time or in the same way. In the first 100 million years or so, the material closest to the young Sun developed into the planets Mercury, Venus, Earth, and Mars. These are called the inner planets or terrestrial (Earth-like) planets. They are relatively small and have solid cores and rocky crusts. Farther away, large clumps of gas, ice, and dust formed what are called the outer (or Jovian) planets: Jupiter, Saturn, Uranus, and Neptune. These planets are known for their large gaseous bands and cold temperatures. Figure 11.14 shows the relative location of these planets in the solar system.

The Sun

At the centre of the solar system lies our star, the Sun. The Sun contains more than 99 percent of all the mass of the solar system, equal to almost 100 times the mass of all the planets combined. Even though our Sun is just a main sequence star of average size, it would take about 110 Earths lined up side by side to reach the Sun's width. The composition of our star is mainly hydrogen gas, the most common element in space. As in all stars, nuclear reactions in the Sun's core cause hydrogen to fuse with helium. The tremendous radiated energy produced keeps Earth warm enough to support life.

Technology has enabled scientists to monitor the Sun over the past few decades from close range (Figure 11.15).

Figure 11.15 The Solar and Heliospheric Observatory (SOHO) satellite has been observing activities on the Sun since 1995.

Word Connect

The term "solar" comes from the Latin *solaris*, which means of the sun.

Features of the Sun

The Sun is a complex system of bubbling gases that occasionally sends out spectacular explosions and violent solar flares. It has no solid surface but many distinctive features, as shown in Figure 11.16.

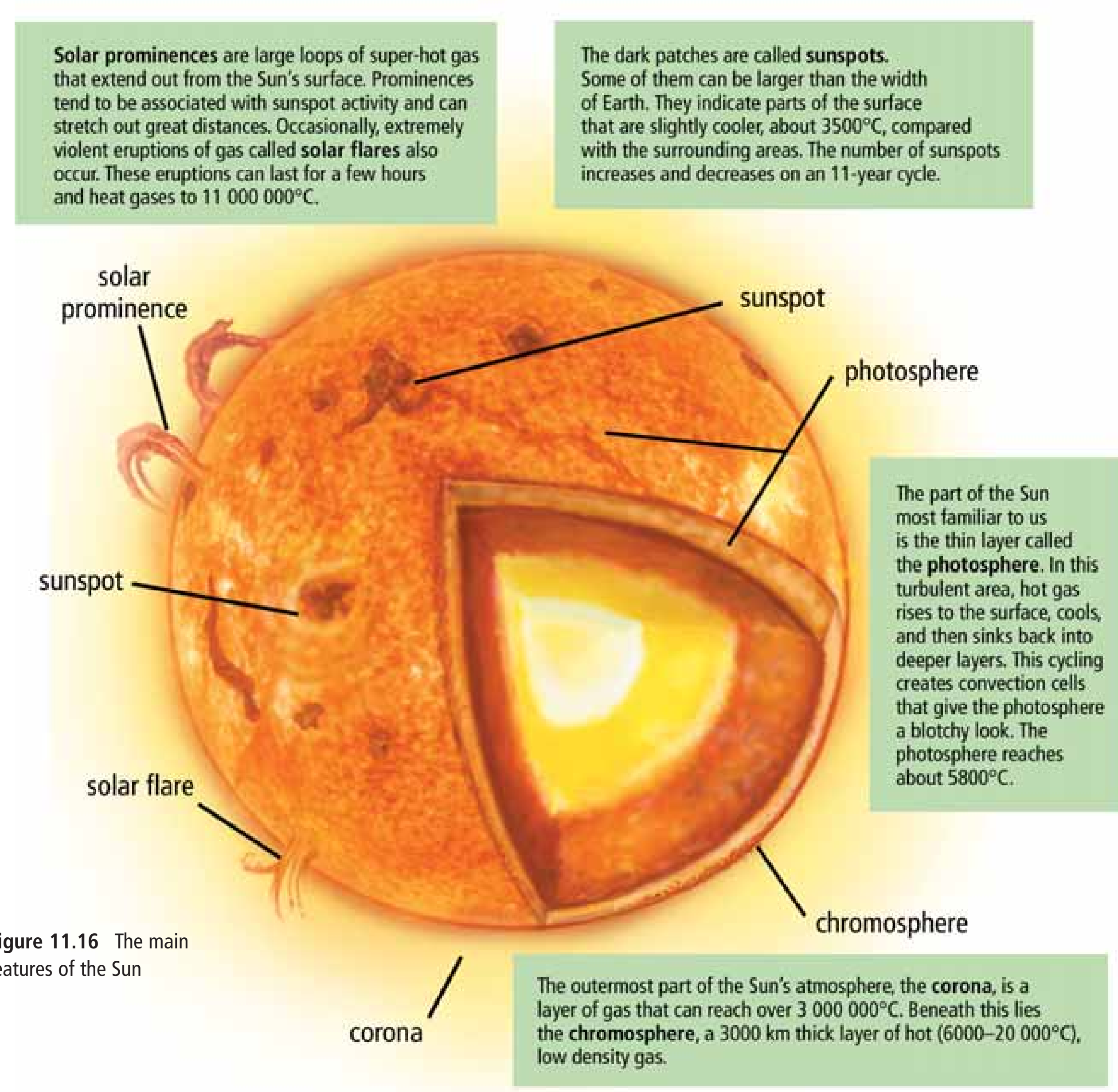


Figure 11.16 The main features of the Sun

internet connect

The SOHO satellite (**So**lar and **H**eliospheric **O**bservatory) monitors the Sun through a variety of wavelengths and even records movies about the Sun's activities. To find out more about SOHO and what we are learning about the Sun, visit **www.bcscience9.ca**.

Solar Wind

Sometimes the hot and energetic gases in the corona get ejected in a sudden burst. Gas is spewed out in every direction, similar to what happens when a soap bubble bursts. When these high-energy particles rush past Earth, they create an effect called the **solar wind**. Exposure to solar wind could be fatal for any organism living on Earth. Fortunately, Earth's magnetic field deflects the solar wind around the planet. Some of the particles enter Earth's atmosphere at the North and South Poles, where they collide with material in the atmosphere. The results are the extraordinary light shows in the sky we call the auroras, or the northern lights and southern lights (Figure 11.17). The solar wind can also generate large geomagnetic storms that can disable satellites and knock out power supplies on Earth.

Figure 11.17 The solar wind is responsible for creating the incredible displays of light we call aurora borealis and aurora australis.

Reading Check

1. How long ago did the Sun and planets form?
2. What are the two main materials that make up the Sun?
3. What is the name for the dark areas on the photosphere of the Sun?
4. Define solar wind.
5. (a) What are the names of the light phenomena that occur in the sky at the North and South Poles?
   (b) Explain why these lights occur.

Suggested Activities

Find Out Activity 11-2A on page 390
Find Out Activity 11-2B on page 391
Conduct an Investigation 11-2C on page 392

The Planets

To be considered a planet, a body must orbit one or more stars, be large enough that its own gravity holds it in a spherical shape, and be the only body occupying the orbital path.

Large distances keep our solar neighbourhood's family of eight planets well separated from each other. In fact, the planets lie so unimaginably far apart that kilometres are not a meaningful way of measuring distance, because the result is a huge, unwieldy number. Doing so would be like using millimetres to measure the longest hallway in your school or describing the cost of everything in pennies only. For this reason, astronomers devised another unit of measure for solar system distances. It is the **astronomical unit** (AU), and it is equal to the average distance between the Sun and Earth, about 150 million km. Therefore, Earth is 1 AU from the Sun, while Jupiter is 5.27 AUs from the Sun.

The planet profiles that follow here will give you a better idea of your planetary neighbours.

Word Connect

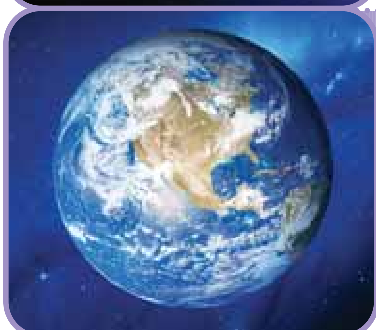
"Astronomical" is an adjective used to describe something that is of immense size.

Mercury

The closest planet to the Sun is also the smallest. Mercury is a rocky ball covered in meteor craters. It is slightly larger than our Moon and is about one-third the size of Earth. It does not have any significant atmosphere. Mercury experiences extraordinary differences between night and day temperatures on its surface (ranging from 400°C to –183°C). This constant cycle of extreme heating and freezing causes the rock of Mercury to expand and contract, forming immense cracks in the surface.

Venus

Venus is often called Earth's sister planet because of its similar size and composition to Earth. A notable difference, however, is the atmosphere. The atmosphere of Earth provides oxygen and nitrogen. Venus's atmosphere is almost completely carbon dioxide. Surface features of Venus cannot be seen through optical telescopes because the planet is shrouded in thick clouds. Sulphur mixes with moisture in the atmosphere to rain down as sulphuric acid. In 1990, the *Magellan* spacecraft began scanning the surface of Venus using a radar probe. It revealed that large portions of the planet are very flat, while other areas have volcanoes, lava flows, and cracks called rifts.



Earth

Our little blue planet, third from the Sun, is home to the only life yet discovered in the universe. Besides having a suitable atmosphere and temperature, Earth is the only place known to have water in three phases: liquid, solid, and gas. Water covers nearly three-quarters of Earth's surface. Earth's atmosphere is composed mostly of nitrogen and oxygen, components essential to life. Running water, atmospheric effects, and plate tectonics together constantly shape the surface of Earth.

Mars

Mars is often called the red planet because the iron in its surface rocks gives it that colour. Despite being half the size of Earth, Mars has about the same amount of surface area. Several extraordinary features mark its surface, such as a volcano that is three times higher than Mount Everest and an 8 km deep canyon that would stretch from Vancouver to Toronto. Mars has a very thin atmosphere of carbon dioxide and can experience winds of more than 900 km/h. Dust storms can cover the whole planet and last for weeks. Mars has two polar ice caps.

Planet	Average Distance from Sun (AU)	Radius (km)	Mass (relative to Earth)	Average Surface Temperature (°C)	Period of Rotation (relative to 1 Earth day)	Period of Revolution (relative to 1 Earth year)
Mercury	0.39	2 440	0.06	179	58.90	0.24
Venus	0.72	6 052	0.82	467	244.00	0.61
Earth	1.00	6 378	1.00	17	1.00	1.00
Mars	1.52	3 397	0.11	-63	1.03	1.70

Jupiter

The largest planet in the solar system is Jupiter. It has a mass 2.5 times greater than that of all the other planets combined. Its "Great Red Spot" has been visible from Earth for more than 300 years. This spot, as large as three Earths, is a storm raging in the clouds of hydrogen and helium that form the planet's outer layers. Despite its immense size, Jupiter has the shortest day of any of the planets, turning once on its axis every 10 hours. If it were only 100 times more massive, Jupiter might have formed into a small, faint star.

Saturn

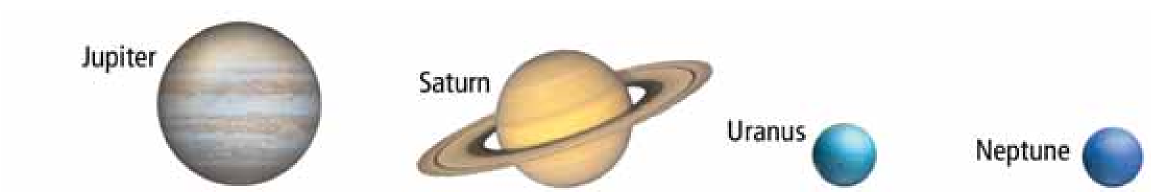
Saturn, another gas giant, is easily identified by its elaborate system of rings. Its rings are formed from ice particles rather than rocky chunks. Those particles range in size from specks of dust to the size of houses. The rings are 250 000 km wide but can be as thin as 10 m. A sheet of paper the size of a city would have the same thickness-to-width ratio as Saturn's rings. The planet itself is composed mainly of hydrogen and some helium.

Uranus

Uranus is the fourth most massive planet in the solar system. A gas giant, it has a similar composition to Jupiter and Saturn, including a ring system composed of ice and dust. The planet gets its distinctive blue colour from the methane gas in its atmosphere (methane absorbs red light). Uranus has an unusual rotation in that it is flipped on its side. As a result, it appears to be rolling through its orbit around the Sun.

Neptune

Neptune is the outermost planet and the third most massive. Its composition is similar to that of Uranus, and it has the same dark blue colour. Like the other three gas giants, Neptune has a ring system, but it is very faint. When the *Voyager 2* spacecraft flew by Neptune in 1989, it discovered a large, blue, Earth-size patch on Neptune's surface. The patch, similar to Jupiter's Great Red Spot, was likely a storm in the clouds of Neptune's atmosphere. When the planet was viewed again in 1994 through the Hubble Space Telescope, the spot was gone. A new dark spot has since appeared in the northern hemisphere.



Planet	Average Distance from Sun (AU)	Radius (km)	Mass (relative to Earth)	Average Surface Temperature (°C)	Period of Rotation (relative to 1 Earth day)	Period of Revolution (relative to 1 Earth year)
Jupiter	5.27	71 492	317.8	–150	0.41	11.9
Saturn	9.54	60 268	95.2	–170	0.45	29.5
Uranus	19.19	25 559	14.5	–215	0.72	84.0
Neptune	30.06	24 764	17.1	–215	0.67	165.0

Other Solar System Bodies

Keeping the eight planets company in our solar system are numerous other small bodies.

Moons

All the planets except Mercury and Venus have one or more orbiting companions. Astronomers call these "satellites." (These are not the same as the human-made satellites that are sent into orbit around Earth to provide communication services, mapping, and surveillance.) Our satellite has been named the Moon, and so we usually refer to other planets' orbiting companions as **moons** too. So far, more than 150 moons have been detected in the solar system.

Asteroids

Asteroids are small bodies that are believed to be leftover remains of the formation of the solar system. Most asteroids orbit the Sun in a band between Mars and Jupiter (Figure 11.18). Asteroids range from the size of sand grains up to the 1000 km wide Ceres.

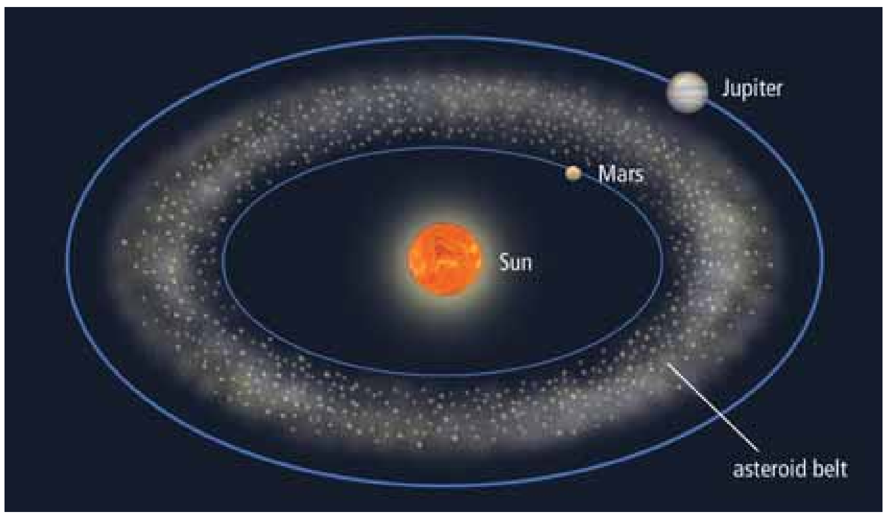


Figure 11.18 Thousands of asteroids orbit in the asteroid belt.

Comets

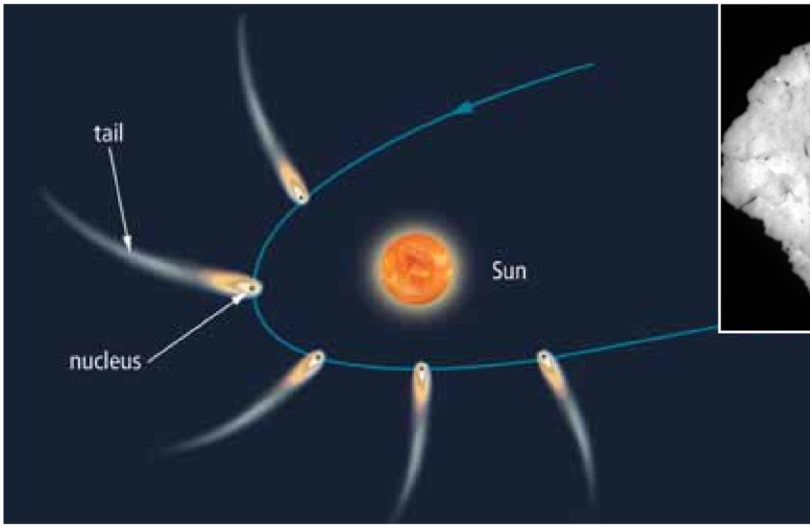
In the past, **comets** were often referred to as "dirty snowballs," composed of ice, rock, and gas. Information collected by space probes, however, has shown that comets consist of far more rocky material than originally suspected. They hurtle through space, originating from the Kuiper Belt and the Oort Cloud. Every once in a while they are bumped into the inner solar system. Once a comet feels the effect of sunlight, we can see its trail of gas and dust streaming behind it (Figure 11.19 on the next page).

Did You Know?

The Earth's Moon is 10 times more massive than the mass of all the asteroids in the asteroid belt combined.

Trans-Neptunian objects

Objects that circle the Sun beyond the orbit of Neptune are called trans-Neptunian objects. The Kuiper Belt is a flat disk of millions of small bodies orbiting the Sun. The Kuiper Belt is thought to be composed of fragments of material left over from the formation of the solar system (similar to the collection of dust around the edges of a swept patio).



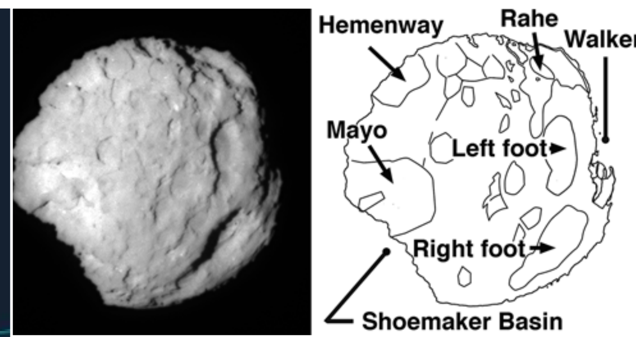


Figure 11.19 The path of a comet around the Sun. Notice how the comet's tail always points away from the Sun. Inset: Image of the surface of Comet Wild 2, taken from NASA's *Stardust* spacecraft.

Orbiting in this cloud of material are small bodies similar in composition and size to the former solar system planet, Pluto. Astronomers refer to these bodies as dwarf planets. The largest Kuiper Belt object is Eris. It is almost 400 km wider than Pluto and has its own moon. In 2006, the International Astronomical Union promoted Eris to dwarf planet status. At the same time, Pluto was demoted to dwarf planet as well. That ended Pluto's 76-year history as the solar system's ninth planet.

Astronomers currently suggest that at least 23 objects orbiting in the Kuiper Belt may be considered planets. As technology improves, more will undoubtedly be discovered.

Oort Cloud

At the farthest reaches of the Sun's gravitational influence lies a spherical cloud of small icy fragments of debris called the Oort Cloud. Along with the Kuiper Belt, the Oort Cloud is thought to be a source of comets. It is between 50 000 and 100 000 AU away from the Sun. The Oort Cloud is roughly one-quarter of the distance to the next nearest star to us, Proxima Centauri.

Reading Check

1. What are the two groups into which we divide planets?
2. Name two planets that do not have moons.
3. Where is the asteroid belt?
4. How many planets in the solar system have liquid water, ice, and clouds?
5. Describe the objects that are found in both the Kuiper Belt and the Oort Cloud.

11-2A 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

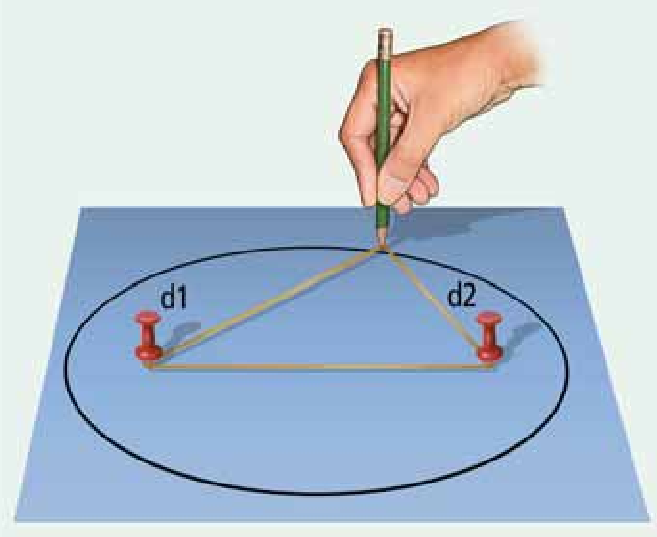
1. Tape the cardboard squares on top of each other and tape the paper on top.
2. Draw a 20 cm line horizontally across the middle of the paper. Stick the two pushpins on the line about 5 cm apart. These two points are the foci (singular: focus).
3. Loop the string over the pushpins. Using the pencil, 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.



11-2B 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 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 (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.

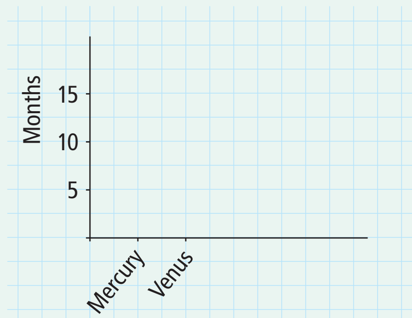
   Example:

   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?

11-2C Strolling Through the Solar System

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), baby powder, coarse and fine-grained sand, salt, cake sprinkles, and small candies or cake decorations
- 10 index cards
- clear adhesive tape
- 10 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, asteroid belt, 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)
Asteroid belt	< 1 000		Baby powder
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.

Inquiry Focus

Solar System Object	Actual Distance from Sun (km)	Scale Distance from Sun (m)	Distance from Previous Planet (m)
Sun			
Mercury	58 million	1.16	
Venus	108 million	2.16	1.00
Earth	150 million	3.00	0.84
Mars	228 million	4.56	1.56
Asteroid belt	~ 400 million	~ 8.00	
Jupiter	778 million	15.56	11.00
Saturn	1 430 million	28.60	13.04
Uranus	2 870 million	57.40	28.80
Neptune	4 500 million	90.00	32.60

Analyze

1. Solar system objects are typically described as inner and outer. Based on your scale models, describe what you notice about the:
   (a) size of the inner planets compared with the outer planets
   (b) 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 following table into your notebook and complete it. Use a scale of 1 m = 50 million km to calculate the scale distance (in metres) for each of the features listed.

Feature	Distance from Sun (million km)	Scale Distance (m)
Kuiper Belt	14 900	
Oort Cloud	7 450 000 000	
Proxima Centauri (nearest star to our Sun)	39 920 000 000	

2. Based on your scale model, explain why it seems unlikely that humans will ever journey outside the orbit of Neptune.

Science Watch

Canada's Suitcase Satellite Searches for Other Earths

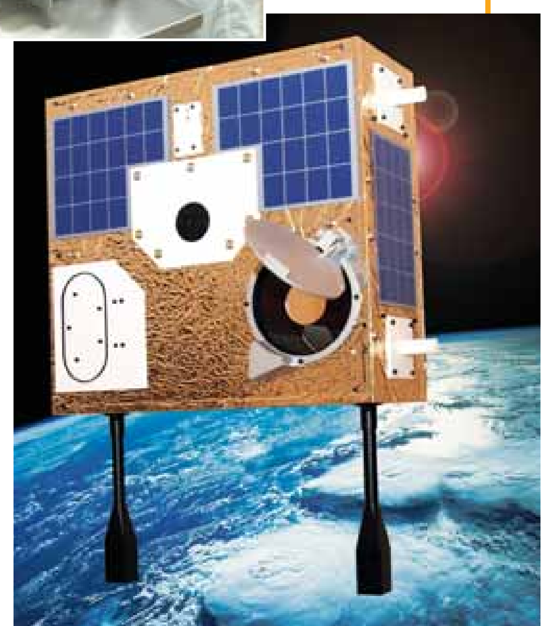
Searching for extra-solar planets (that is, planets that are not in our solar system) is extremely difficult. Unlike stars, planets do not give off their own light. They only reflect light from the star around which they orbit. Furthermore, the light that does reflect off them has to travel great distances in space before we can hope to detect it here on Earth. This challenge is where Canada's first space telescope comes in. The *MOST* (**M**icrovariability and **O**scillations of **St**ars) telescope monitors the slight variations in brightness of stars. When a planet orbiting a distant star passes between Earth and the star, the star's light dims very slightly. The change in brightness is similar to what might be detected if a mosquito flew in front of a 400 Hz streetlight viewed from a distance of 1000 km!

Affectionately called the "Humble Space Telescope," Canada's *MOST* satellite is only about the size of a suitcase. The satellite orbits Earth from pole to pole at an altitude (height above Earth) of 820 km. It takes about 100 minutes for *MOST* to circle the planet. This altitude allows the satellite to remain focussed on its target star. The *MOST* program hopes to detect and analyze light reflecting from planets orbiting nearby stars as well as determine ages and compositions of the oldest stars closest to our solar system.

MOST sends data to the University of British Columbia for interpretation. Astronomers hope that this information can lead to answers to questions such as: How does our Sun compare with other stars? How do the planets in our solar system compare with planets in other solar systems? and even, How were planets able to form at all?

The next few years promise to be exciting times for Canada's space telescope, filled with wonderful new discoveries about solar neighbourhoods close to our own.

Dr. Jaymie Matthews, principal investigator with the *MOST* project.



Costing 1/150 of the Hubble Space Telescope, Canada's *MOST* satellite has helped astronomers detect the presence of planets orbiting stars many light-years from our solar system.

Questions

1. Why is finding planets that orbit distant stars so difficult?
2. How does *MOST* detect planets?
3. State two of the questions that astronomers hope the *MOST* satellite will answer.

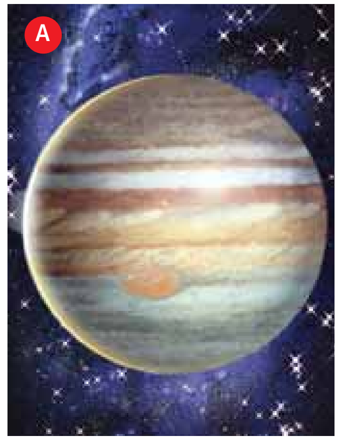
Check Your Understanding

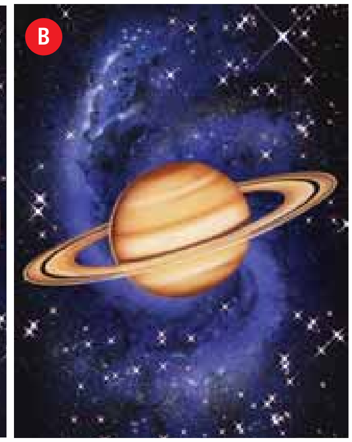
Checking Concepts

1. Why is most of the mass of the solar system contained in the Sun?
2. Briefly describe the protoplanet theory of planet formation.
3. What name is given to a group of planets that orbit a star?
4. Why do sunspots appear as dark areas on the Sun's surface?
5. What is solar wind?
6. Describe two differences between the inner and outer planets.
7. Name a planet that has no atmosphere.
8. Where is the Kuiper Belt found?
9. Describe the composition of a comet
10. Describe the materials that both the Kuiper Belt and the Oort Cloud contain.

Understanding Key Ideas

11. An astronomical unit (AU) is the average distance between Earth and the Sun. Explain why the distances between bodies in the solar system are measured using AUs.
12. Compare and contrast the following terms.
    (a) planet and solar system
    (b) rotation and revolution
    (c) comets and asteroids
13. Is it possible for an object in space to revolve but not rotate? Explain.
14. Describe the shape of the paths of planets that orbit the Sun.
15. Although asteroids orbit as planets do, why are asteroids not considered to be planets?
16. Explain why the frozen debris found in the Oort Cloud, more than 50 000 AU away from the Sun, is still considered part of the solar system.
17. The photographs that follow show parts of the most recognizable features of three planets in our solar system. Name the planets and the features.





Pause and Reflect

The protoplanet hypothesis suggests that all the planets formed from the same rotating cloud of gas and dust at about the same time. Astronomers studying our solar system have found several pieces of evidence in support of this idea.

- All planets revolve in the same direction around the Sun (counterclockwise).
- Most planets rotate in the same direction (counterclockwise).
- Almost all the planets orbit the Sun on the same plane (an imaginary line drawn out from the Sun's equator).

Explain how each of these ideas supports the protoplanet hypothesis.