11.3 Measuring Distances in Space

Astronomical units are used to measure distances within the solar system. Light-years are used to measure distances to all other bodies far beyond our solar system. Distances measured from Earth to some bodies can be determined using triangulation and parallax.

Words to Know

light-year
parallax
triangulation

As you learned in Chapter 10, astronomers believe that the age of the universe is 13.7 billion years. To help you put into perspective how much a billion is, imagine that you started counting to a billion right now. If you kept counting steadily at a number per second, day and night, it would take you 31 years, 259 days, 1 hour, 46 minutes, and 40 seconds before you were finally able to gasp out "1 billion!"

Not only is the universe astronomically old, it is also astronomically big, and the distances between its celestial bodies are astronomically far. In this section, you will learn about scales and techniques that astronomers have developed to measure the tremendous distances between those components.

Did You Know?

Imagine a pile of 100 copies of this textbook. If the total number of words in that pile represented the volume of the universe, Earth would not even be the dot on an *i*.

Just How Big Is Space?

It is not easy for most of us to imagine the truly immense scale of the universe. "Scale" refers to the size of an object compared with its surroundings or another object. Think of a flea trying to understand the size of a sports arena. Now imagine that the flea is surrounded by 100 sports arenas. If someone told the flea how vast the space was around it in all directions, the flea would find it extremely difficult to envision. For humans, trying to understand the size of the universe is just as difficult. If you did Conduct an Investigation 11–2C, Strolling Through the Solar System, modelling the relative sizes of the bodies in our solar system and the distance between them, you are probably beginning to get an idea of how challenging it is to describe scale in the universe.

Figure 11.20 shows the relative sizes of components in the universe, from quarks to galaxies.

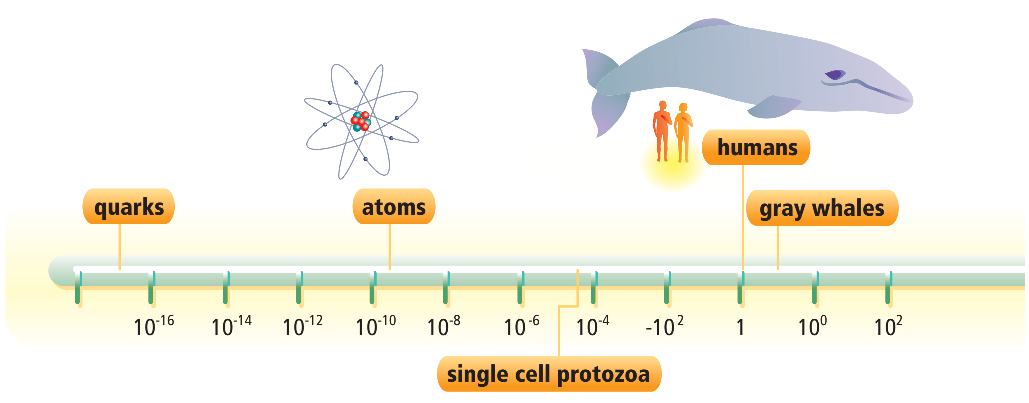


Figure 11.20 The relative size of components in the universe

11-3A 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.

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.		

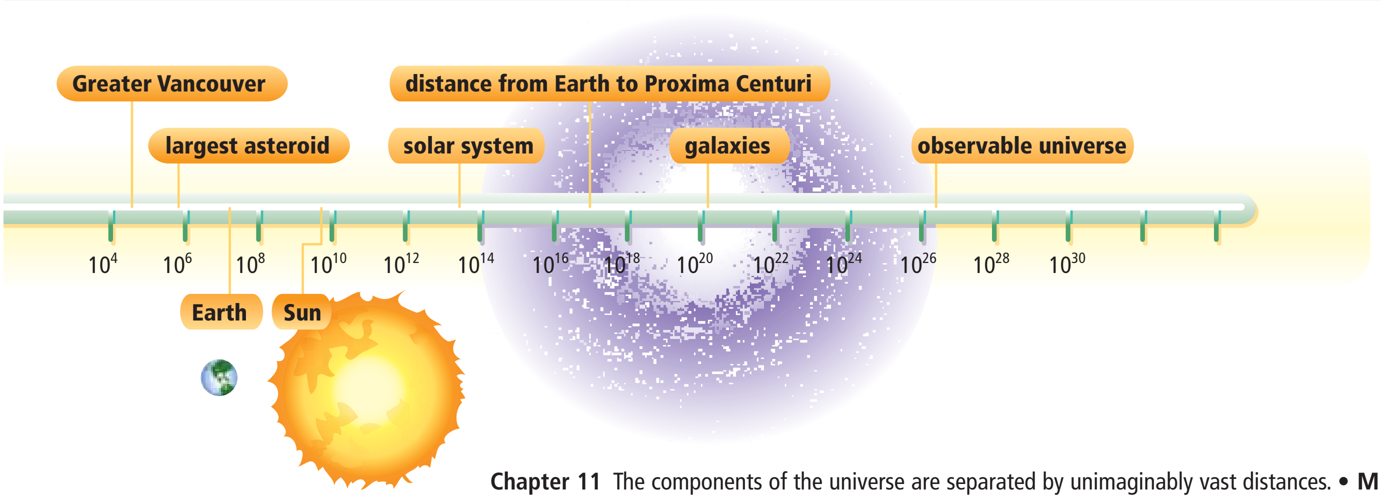
2. Use the compass to find out which part of your classroom faces due north. Then use the compass to determine the angle of the first object in relation to due north. Record this in the "Angle" column of your table. Remember that degrees increase in order clockwise from north.

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 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.



Light-years

If asked to give the distance from home to school, a student would probably answer by stating the number of blocks or even kilometres. These units are appropriate, because millimetres and centimetres would be meaningless for distances greater than a few metres. Astronomical units (AUs), as you read in section 11.2, are used to measure distances in the solar system. The AU, based on the distance between Earth and the Sun, is equal to 150 million km.

However, even AUs become meaningless for the *really* great distances that separate stars and galaxies throughout the universe. For example, the distance from Earth to the area at the edge of the solar system where comets are thought to originate is estimated to be between 50 000 and 100 000 AUs. If you multiply those figures by 150 million (the distance of 1 AU in kilometres), you can understand how quickly the numbers grow cumbersome.

As the distances to most stars from Earth are in the billions of AUs, astronomers have devised a different unit to talk about the enormous distances outside our solar system. That unit is called a **light-year**. Although it sounds like it describes time, a light-year is actually a measure of distance. It is the distance that light, which moves at 300 000 km/s, travels in a year. It is equal to about 9.5 trillion km.

Thus, when you look at the Andromeda galaxy in Figure 11.21, you are seeing a distance of 2.5 million light-years from Earth. Said another way, it has taken the light you are seeing from the galaxy 2.5 million years to travel through space and into your eyes.

Did You Know?

Light travels faster than anything else we know. The light reflected off the Moon reaches your eyes in a little over 1 s after it leaves the Moon's surface. The light from the Sun takes about 8.3 min to reach Earth. Light from the oldest stars (those formed shortly after the universe formed) has taken around 13.7 billion years to reach Earth.

Figure 11.21 The Andromeda Galaxy can be seen from Earth even with binoculars. It is one of the Milky Way's nearest neighbours, yet it lies 2.5 million light-years away.

Techniques for Indirectly Measuring Distance

As telescopes become larger and use more sophisticated technology, astronomers are increasingly able to see objects farther away. Telescopes cannot, however, directly determine the distance to objects in space. It is also not possible to physically measure such long distances. For these reasons, astronomers use a number of techniques to measure distances indirectly. Two such techniques have been used for thousands of years to determine distances on Earth: triangulation and parallax.

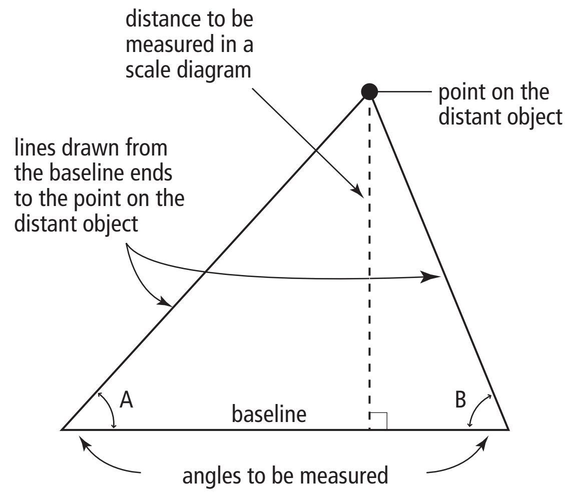


Figure 11.22 Triangulation to calculate a distance

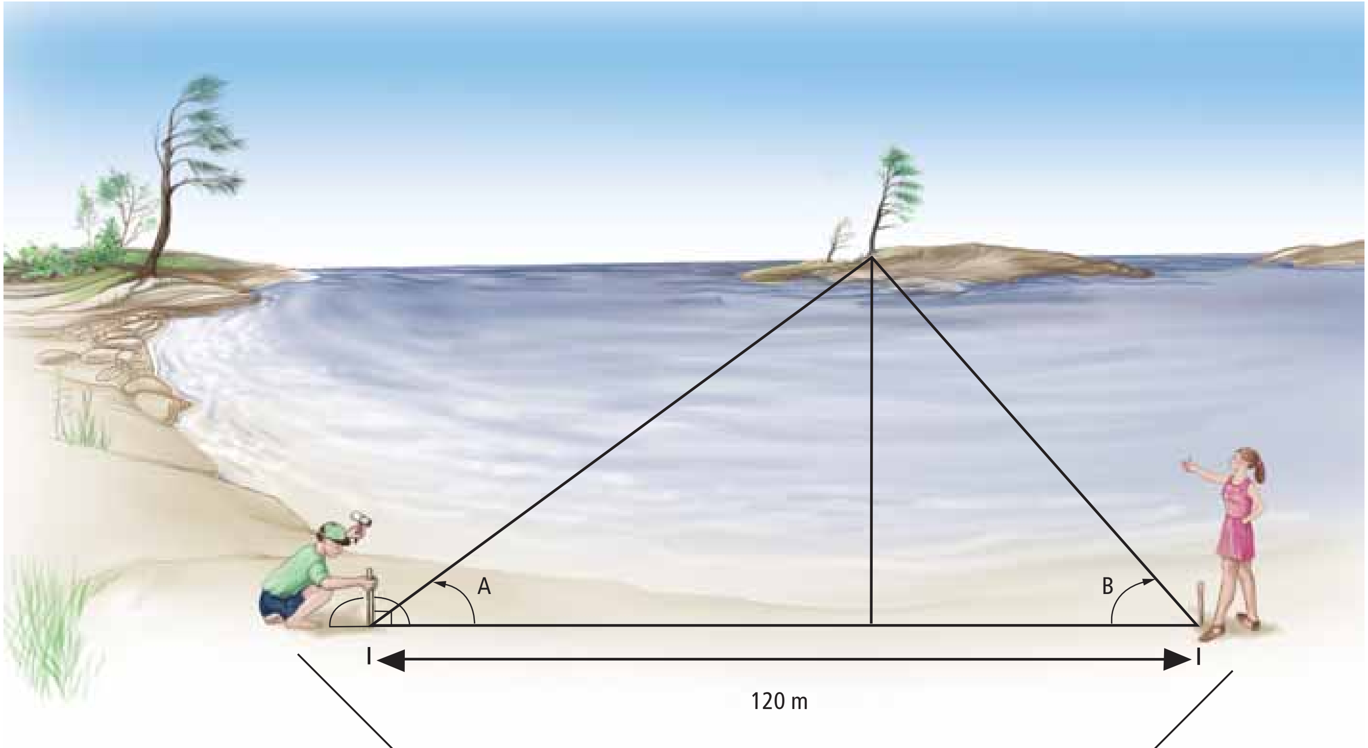
Triangulation

Imagine you are standing at the side of a lake and can see a small island in the distance. If you cannot reach the island, you have no way of directly measuring how far it is from where you are. The same problem confronts astronomers but on a far greater scale. How is it possible to determine the distance to stars and other objects in space if you are not able to reach them?

There is a solution, fortunately, and it involves using simple geometry. By measuring two angles and the length of a baseline, the distance to any object that is visible can be determined (Figure 11.22). This technique is called **triangulation**.

To use triangulation to determine the distance to the island from the shoreline, you would follow the steps below. These steps are illustrated in Figure 11.23 on the next page.

1. Measure a straight baseline along the shore. Remember, the longer the baseline, the more accurate the calculations. *Example:* 120 m
2. At one end of the line, use a protractor to measure angle A between the baseline and a particular point on the island, such as the bottom of a tree. *Example:* 75°
3. Move to the opposite end of the baseline and again measure angle B between the baseline and the same point on the same tree. *Example:* 65°
4. Using the two angles and the length of the baseline, construct a scale drawing.
5. On your scale drawing, mark a perpendicular line between the baseline and the tree. Measure the length of this line, and then calculate the actual distance according to the scale of the drawing. The distance to the tree will match the scale distance. *Example:* The scale distance was 8.2 cm. At 1 cm equal to 20 m, the true distance is 164 m (8.2×20).



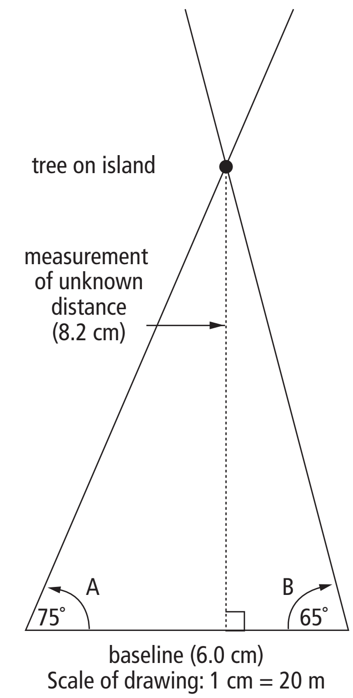


Figure 11.23 This example shows how you could use triangulation to calculate the distance from the shoreline of the lake to the island.

a. *Create a baseline.* Mark off a long, straight line, 120 m long, just up from the shore. The end of the baseline where you start measuring can be marked with a stake.

b. *Measure the angles from the ends of the baseline.* Stand at one end of the baseline, facing the island, and imagine a straight line extended to a point on the island (for example, to a tall tree). Then, measure angle A between that line and the baseline, and record it. At the other end of the baseline, repeat the procedure for angle B. Suppose the two angles you record are 75° for angle A and 65° for angle B.

c. *Make a scale drawing of the imaginary triangle.* First, choose an appropriate scale (in this case, 1 cm = 20 m), and draw the baseline. Then, using a protractor and a ruler, draw a line from each end of the baseline at the angles you recorded. The point at which the two lines cross is the position of the object (in this example, the tree). The shortest distance from that point to the baseline (the dotted line) represents the distance between the shore and the tree on the island. In this case, the line measures 8.2 cm, or 164 m in real life.

Parallax

Try this: extend your arm and hold up your thumb. As you look with your left eye only, line your thumb up against an object on the far wall, such as a light switch or the corner of a window. Without moving your thumb, now look with your right eye only. The apparent shift of your thumb against the stationary (meaning unmoving) background is called **parallax**. It is caused by the change in position of observation. This same principle applies to stars that are viewed from Earth. When a nearby star is viewed from Earth, it appears to shift against the background of the much more distant and seemingly stationary stars. Observers at two different locations on Earth can measure the angles of sight from a baseline and then calculate the distance to the star using triangulation (Figure 11.24).

As noted above, the longer the baseline, the more accurate a triangulation calculation will be. A triangle with a short baseline is narrow and tall, which makes the angles very wide and difficult to measure. A triangle with a long baseline will have more noticeable angles that are easier to measure accurately. Therefore, to create the largest baseline possible, astronomers use the width of Earth's orbit to achieve the most accurate distance measurements to objects in space (Figure 11.25). Because it takes Earth a year to fully orbit the Sun, measurements from each end of the baseline must be taken six months apart, when Earth reaches its farthest points on opposite sides of the Sun.

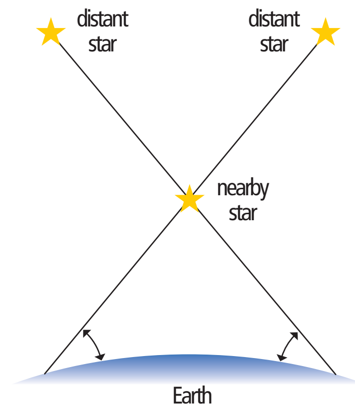


Figure 11.24 Using the effect of parallax to triangulate a star's distance from Earth

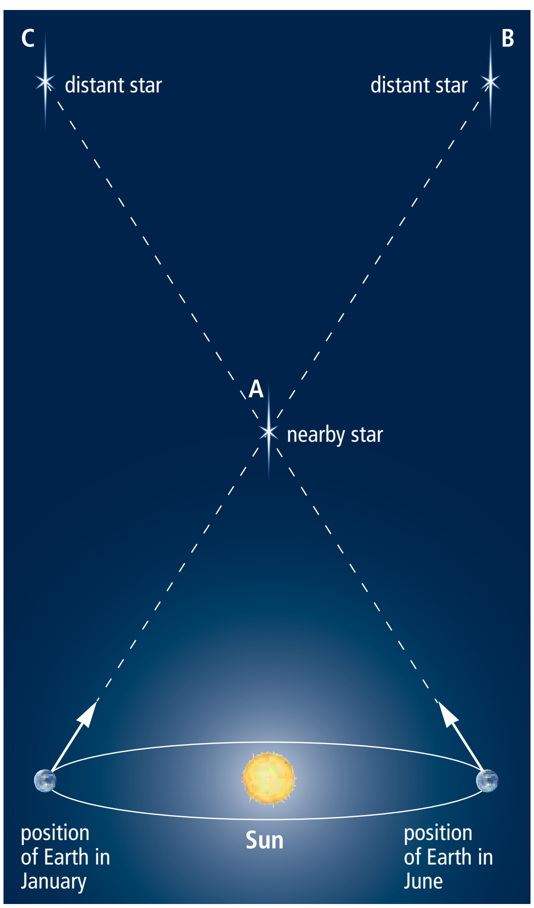


Figure 11.25 Calculating a star's distance from Earth using parallax and triangulation. In January, the nearby star (A) appears to line up with star B. In June, it seems to line up with star C. The distance that star A appears to move in the sky (the apparent distance between stars B and C) is its parallax. This provides the angles needed for using triangulation.

Suggested Activity

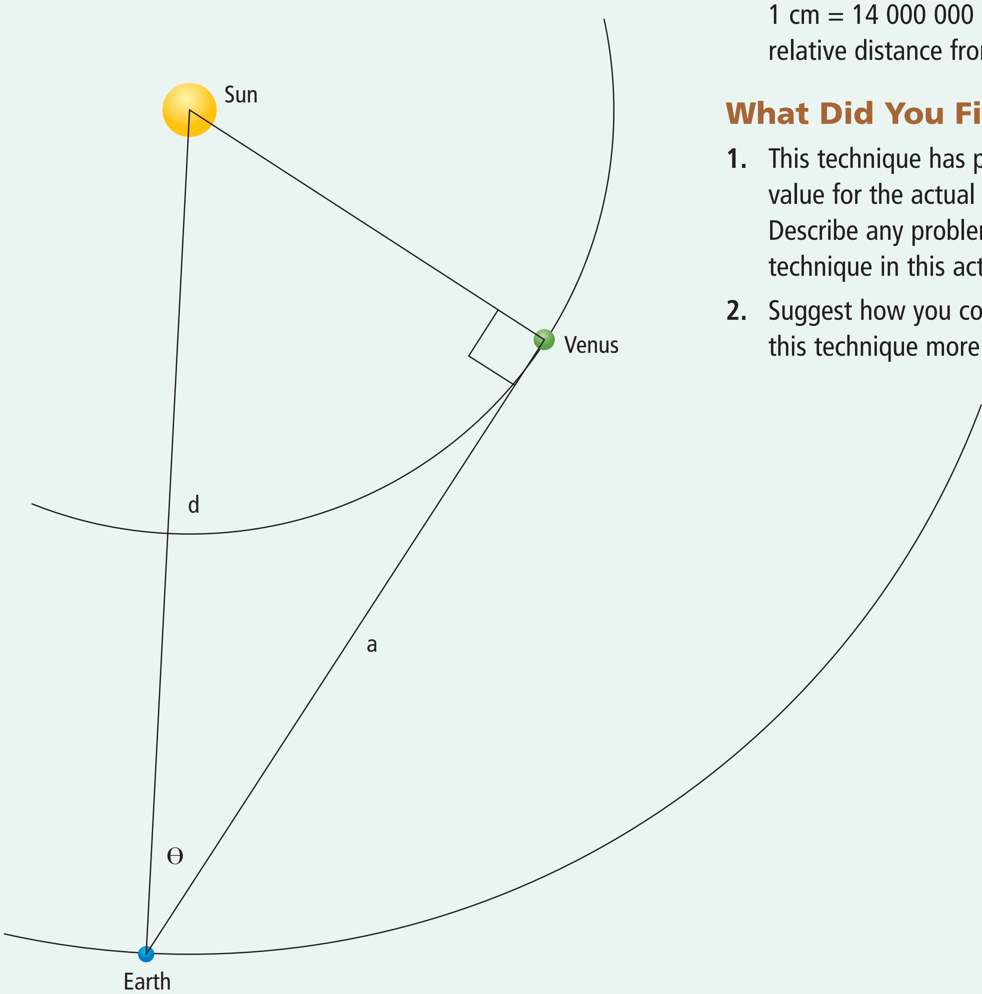
Find Out Activity 11-3B on page 402

11-3B How Close Is the Sun?

Find Out ACTIVITY

The effect of parallax is used to find the distance to stars that are reasonably close to Earth. You might think that finding the distance to the nearest star to us, the Sun, would be easy. In reality, however, the Sun is too close to allow us to determine an accurate distance using parallax.

To solve this problem, astronomers had to combine a new technology with an ancient technique: radar and trigonometry. Radar signals travel at the speed of light. Astronomers can measure the amount of time it takes for a signal to bounce off an object and return to the transmitter. The distance can then be calculated. However, astronomers could not just aim for the Sun, because its surface provides nothing solid from which to reflect a signal. For that reason, they bounced the signal off the nearby planet Venus and used trigonometry to calculate the distance. In this activity, you will simulate the calculation of the distance to the Sun.



Materials

- pen
- paper
- calculator
- ruler
- protractor

What to Do

1. On the diagram shown here, use the ruler to measure the distance from Earth to Venus in centimetres. Record this number in your notebook and label it "a".
2. Use the protractor to measure the angle Θ. Record this value.
3. The distance to the Sun, d, can be calculated using the formula: $d = \frac{a}{\cos \theta}$. Use the calculator to determine the distance to the Sun on the diagram.
4. Multiply your calculated value using the scale 1 cm = 14 000 000 km. This value will give you the relative distance from Earth to the Sun.

What Did You Find Out?

1. This technique has provided an extremely accurate value for the actual distance from Earth to the Sun. Describe any problems you experienced using the technique in this activity.
2. Suggest how you could make your calculation using this technique more accurate.

11-3C How Wide Is the Sun?

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Measuring
- Evaluating information
- Working co-operatively

Safety

- NEVER look directly at the Sun under any circumstances.

Materials

For each group:

- metre stick
- 2 squares of cardboard (20 cm × 20 cm), one with a 1 cm diameter hole
- white paper (6 cm × 6 cm)
- aluminum foil (4 cm × 4 cm)
- clear adhesive tape
- pin, or mechanical pencil
- ruler
- pencil
- calculator

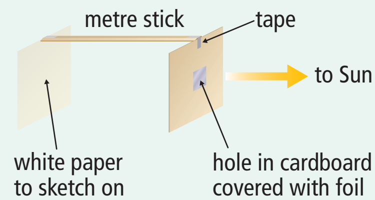
The Sun is about 150 million km away from Earth. In this activity, using a simple tool and some straightforward arithmetic, we can produce a very accurate calculation of the diameter of the Sun.

Question

How can you determine the diameter of the Sun?

Procedure

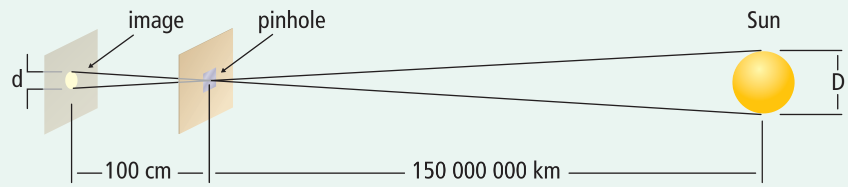
1. Use the metre stick, cardboard, paper, aluminum foil, and tape to assemble the apparatus shown here.



Step 1

2. Using the pin, carefully poke a small hole in the aluminum foil.
3. Move outdoors. Steadying the apparatus against your stomach, aim the aluminum foil end toward the Sun. Try to capture the image of the Sun's disk in focus on the white paper.
4. Have your partner use a pencil to mark the diameter of the Sun's image on the white paper.
5. Repeat step 4 two or three more times.
6. Measure the diameters you have marked off and calculate an average diameter.

Analyze



1. To calculate the Sun's diameter, use the average diameter you have measured in the following formula.

$$\frac{d}{100\text{ cm}} = \frac{D}{150\ 000\ 000\text{ km}}$$

d = diameter (cm)

D = Sun's diameter (km)

2. Your teacher will provide you with the accepted value. Use that to calculate your percent error.

$$\%\text{ error} = \frac{\text{actual diameter} - \text{calculated diameter}}{\text{actual value}} \times 100\%$$

Conclude and Apply

1. (a) What was your calculated percent error?
   (b) Do you think your percent error is reasonable? Explain.
2. What do you think were sources of error in this activity?
3. Suggest ways the activity could be improved to lower your percent error.

Science Math connect

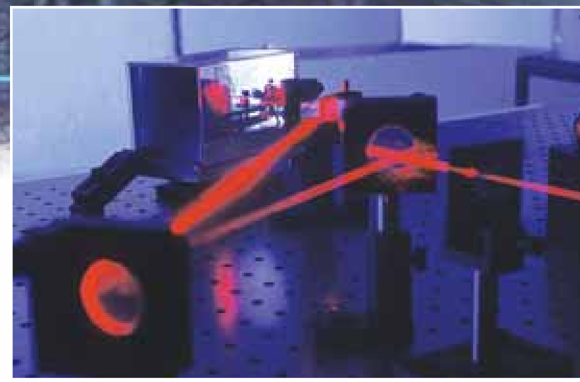
Way Faster Than a Speeding Bullet—the Speed of Light

From ancient times, the speed of light was considered to be infinite and unmeasurable. Not until the invention of the telescope did the ability to finally determine this elusive number seem possible. In the late 1600s, Danish astronomer Ole Rømer used a telescope and the orbit of Jupiter's moon Io to calculate light speed. Even with that very early technology, his calculated speed turned out to be off by only about 25 percent.

Light from the Cat's Eye Nebula has taken 3000 years to reach Earth.

About a century later, another scientist further refined the speed of light calculation. English astronomer James Bradley reasoned that the light from a star would strike Earth at an angle. This angle could then be determined by comparing the speed of light with the speed at which Earth was travelling. His calculation yielded a speed of light equal to 298 000 km/s.

Finally, what we know today to be the true speed of light was determined in 1887 by Albert Michelson and Edward Morley, two American scientists. They were actually looking for the speed at which Earth travels through a substance then called "ether." Ether was believed to be the material necessary for light to travel through. Michelson and Morley invented a device called an interferometer, which involved splitting a beam of light into two parts and then reflecting the parts off mirrors. The result was an incredibly accurate calculation of light speed. The experiment also proved that the mystical material called ether did not exist.



A device like the one shown in the figure helped scientists in the late 1800s determine accurate values for the speed of light.

As you have probably realized while reading this chapter and Chapter 10, distances in space are so enormous that they exceed the bounds of our current technology. At least by knowing the speed of light, astronomers have a practical unit with which to measure the universe's vast distances. Even our *nearest* neighbouring star outside our solar system, Proxima Centauri, is more than 40 trillion (4.0×10^{12}) km away. Expressed in light-years, that distance is 4.2 light-years, which is a much more manageable figure. A light-year is about 9.5 trillion km (a trillion kilometres is a million million kilometres).

Questions

1. Imagine we wanted to send a signal at the speed of light to Canis Major dwarf, one of the nearest galaxies to ours, the Milky Way. If Canis Major dwarf is 25 000 light-years from Earth, how much time would pass between the time our signal was sent and the time we received a reply?
2. Astronomers have found a neutron star that is 855 trillion km from Earth. How many years does it take for light from there to reach Earth?
3. James Bradley calculated the speed of light to be 298 000 km/s. Using the following formula, determine the percent error of that calculation. (Recall that the actual speed of light is about 300 000 km/s.)

$$\text{Percent error} = \frac{(\text{actual speed of light}) - (\text{calculated speed of light})}{(\text{actual speed of light})} \times 100\%$$

Check Your Understanding

Checking Concepts

1. What is an astronomical unit?
2. Define a light-year.
3. Explain how you would use triangulation to determine the distance to an object on Earth's surface.
4. Why do you need to have a baseline to make a triangulation measurement?
5. Describe what parallax means.
6. Why are kilometres usually not used to indicate distances in space?

Understanding Key Ideas

7. Why are the distances between bodies in the solar system not measured in light-years?
8. Why is it best to use a long baseline when determining distances using triangulation?
9. Explain why parallax is not a good technique for determining distances of stars that are extremely far away (that is, greater than 500 light-years).
10. A student is trying to determine the distance from where she is standing to a tall tree in a field nearby. She collected and recorded the following data:

    Angle A = 45°
    Angle B = 62°
    Baseline = 10 m
    Scale: 1 cm = 5 m

    In your notebook, draw a scale model using these figures and calculate the distance to the tree.
11. Parallax and triangulation are considered to be indirect measurement techniques. Why are such techniques used to measure distances in space?

Pause and Reflect

Our closest neighbouring star after the Sun is Proxima Centauri. It is a small red dwarf star less than $\frac{1}{100}$ as bright as the Sun. It would take 10 stars the size of Proxima Centauri to equal the mass of the Sun. The distance to the star is 4.2 light-years, relatively close compared with distances to other objects. Imagine humans sent explorers in a spacecraft to observe a solar system discovered around Proxima Centauri. Describe the difficulties that we on Earth would have in communicating with the spacecraft as it travelled farther from Earth and eventually arrived at the star.

Prepare Your Own Summary

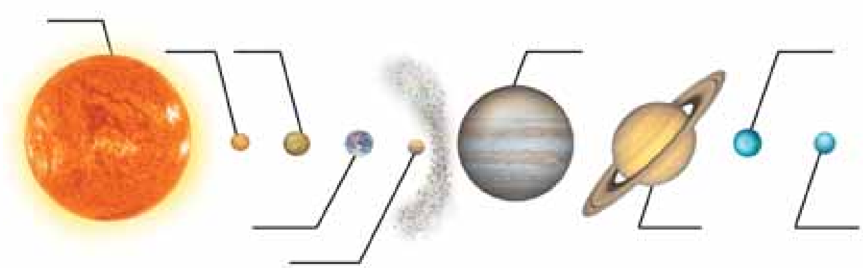
In this chapter, you learned about several components of space. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 12 for help with using graphic organizers.) Use the following headings to organize your notes:

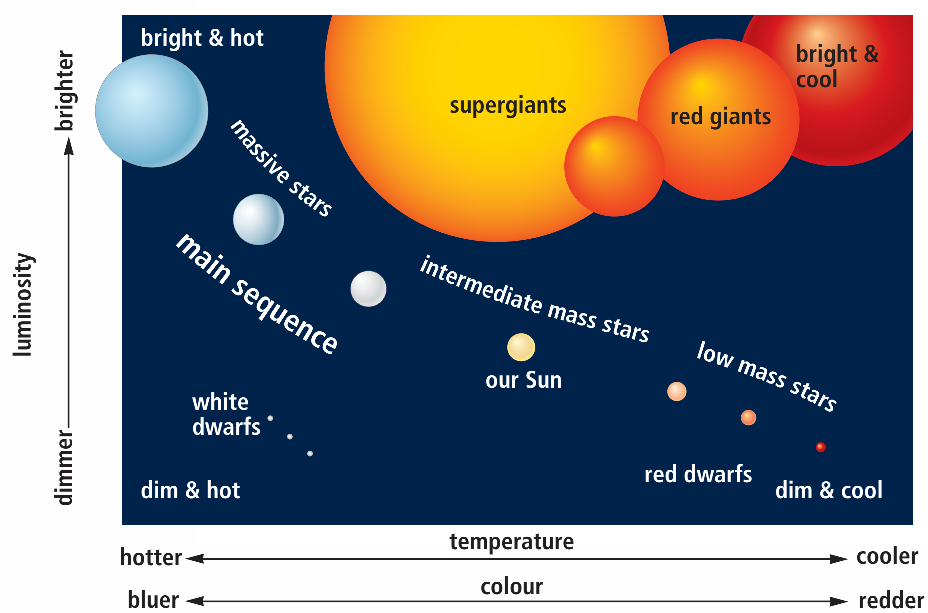
1. Life Cycles of Stars
2. Analyzing the Composition of Stars
3. The Solar System
4. Measuring Distances in Space

Checking Concepts

1. What is the process that creates energy in stars?
2. At which stage in a star's life will it turn into a supernova?
3. How old is the solar system?
4. Draw a labelled cross-section of the Sun's outer atmosphere. Label the chromosphere, photosphere, sunspots, and prominences.
5. How does the temperature of sunspots compare with temperatures in the rest of the photosphere?
6. How can storms on the Sun affect people on Earth?
7. What name do astronomers give to the average distance between the Sun and Earth?
8. Why do we refer to the inner planets as "terrestrial"?
9. Describe characteristics all the Jovian planets share.
10. Copy and complete the diagram of the solar system shown below, labelling the key parts.
11. Why does a comet's tail always point away from the Sun?
12. Why are light-years used to measure distances in space?

Solar system, Question 10





Hertzsprung-Russell diagram, Question 15 on the next page

Understanding Key Ideas

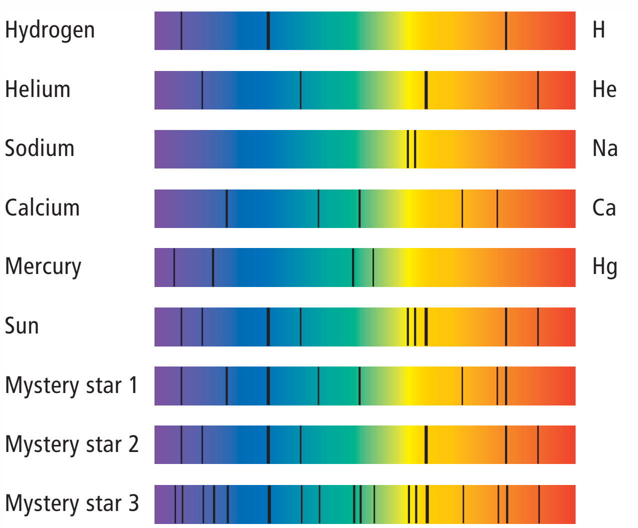
13. (a) Explain why black holes are invisible.
(b) If black holes are invisible, how do astronomers know they exist?

14. What would an astronomer conclude if he or she observed that the spectrum of a star had shifted to the blue end?

15. Use the data below and the Hertzsprung-Russell diagram on page 406 to classify the following stars. Write your answers in your notebook.

Star	Temperature (degrees kelvin)	Luminosity (Sun = 1)	Star Classification
Shanstar	25 000	500	
A Britt Aquarii	3 000	0.1	
Tash Bojube	30 000	0.0001	
Chris Centaura	4 000	10 000	
Joycmarg 1123	5 000	50 000	

16. You have learned that each element has its own distinct spectral pattern and that the chemical composition of stars can be determined by analyzing their spectra. The figure below shows the spectral pattern of five elements. Refer to the figure to answer the following questions.
(a) What elements can you detect from the Sun's spectrum?
(b) What elements are found in both the Sun and the unknown stars?



17. Imagine a new planet has been discovered between Saturn and Uranus. Describe the characteristics you would expect this planet to have.

18. Explain why landing a spacecraft on the surface of a Jovian planet would prove to be very difficult.

19. Imagine you are in your spacesuit, holding a tin can of pop (the melting point of tin is 232°C). Give as many reasons as you can for why you would not likely be able to open the can on Mercury or Venus.

20. Trans-Neptunian objects are believed to be debris left over from the formation of the solar system. Some objects are larger than Pluto. Why are these objects considered to be part of our solar system?

21. An astronomer trying to use parallax to determine the distance to a star notices the star did not change position when observed from two different locations. What should the astronomer conclude from this observation?

Pause and Reflect

When we consider the impressive size of the universe, it is easy to see why humans may consider themselves insignificant. What is so amazing is that, even from this small speck in the corner of the universe, we have been able to figure out so much, see great distances, and look so far back in time. Unstoppable curiosity and constant advances in technology have allowed humans to uncover as many new questions about space as they have answers. Write a brief paragraph explaining how humankind's understanding of space is connected to our ability to improve our technology. Consider what limits there might have been to our knowledge of space if we had not progressed beyond the simple telescope.