LESSON 3

Tracking Shadows


ENGLISH HERITAGE

The Sun sets along the horizon at Stonehenge (which means "hanging stones"). Stonehenge was constructed outside of London from about 2400 B.C. to 1200 B.C.

INTRODUCTION

If you go to Stonehenge during the summer solstice, you will notice that the Sun always rises over a stone called the Heel Stone or Sun Stone. Why does this happen? Some scientists theorize that Stonehenge may have been an ancient astronomical observatory and calendar. Those who built it could tell when Earth arrived at a certain point in its yearly orbit around the Sun. Some scientists think that Stonehenge also may have been used to mark changing seasons and to predict eclipses. Still others believe that it was a temple for Sun worshipers who used the stones to mark significant points in the Sun's journey across the sky.

To begin this lesson, you will share with the class what you know about the Sun and Moon's apparent motion across the sky, as well as what causes day, night, and seasons. During Inquiry 3.1,

OBJECTIVES FOR THIS LESSON

Record the length and angle of shadows cast by a shadow stick at different times during the day.

Relate the length and angle of shadows to the apparent position of the Sun in the sky.

Model winter and summer shadows and compare the Sun's apparent position in the sky during each season.

Simulate Earth's rotation, and relate it to the Sun's apparent daily motion across the sky.

Create a working definition for the term "rotation."

you will record the Sun's position in the sky throughout the day by marking the location of shadows cast by a shadow stick. During Inquiry 3.2, you will use a computer program to analyze shadows and the path of the Sun throughout the year. During Inquiry 3.3, you will use a flashlight to simulate the rising and setting of the Sun. At the end of the lesson, you will use a small globe and the Sun's natural light to determine what changing shadows tell us about our planet Earth.

Getting Started

1. Be prepared to discuss with your class what you know about day, night, and the seasons.

2. In this lesson you will use a shadow stick to make general observations of shadows throughout the day. Do you know how shadow sticks were used in the past? Discuss your ideas with the class.

3. In a class discussion, describe shadows you have seen at home or school. What patterns did you observe in the shadows throughout the day? How might you study the patterns in shadow data firsthand?

4. You will be collecting shadow data outside. Before you do, read "How To View the Sun Safely." Discuss the Safety Tip with your teacher.

MATERIALS FOR INQUIRY 3.1

For you

- 1 copy of Student Sheet 3.1: Analyzing Shadow Data

For your group

- 1 Sun-Earth-Moon Board™
- 3 sheets of white paper, taped together
- 4 large binder clips
- 1 rod #1
- 1 rod #2
- 1 rod #3
- 1 piece of chalk
- 1 magnetic compass
- 1 student timer (or other timepiece)
- 1 metric ruler, 30 cm (12″)

SAFETY TIP

Never look directly at the Sun! It can cause permanent eye damage, or even blindness.

5. Look at Side A of the Sun-Earth-Moon (SEM) Board™. How might you use it to record shadows throughout the day? What would you need to keep constant to compare shadow patterns? How will you record your data? Discuss your ideas with the class.

Inquiry 3.1
Analyzing Shadows

PROCEDURE

1. Set your group's timer to the correct time of day.

2. Use Figure 3.1 and your teachers' guidance to position the board to get the best shadow data. If a class before yours used this board, keep it in the same location. Listen to find out which rod to use.

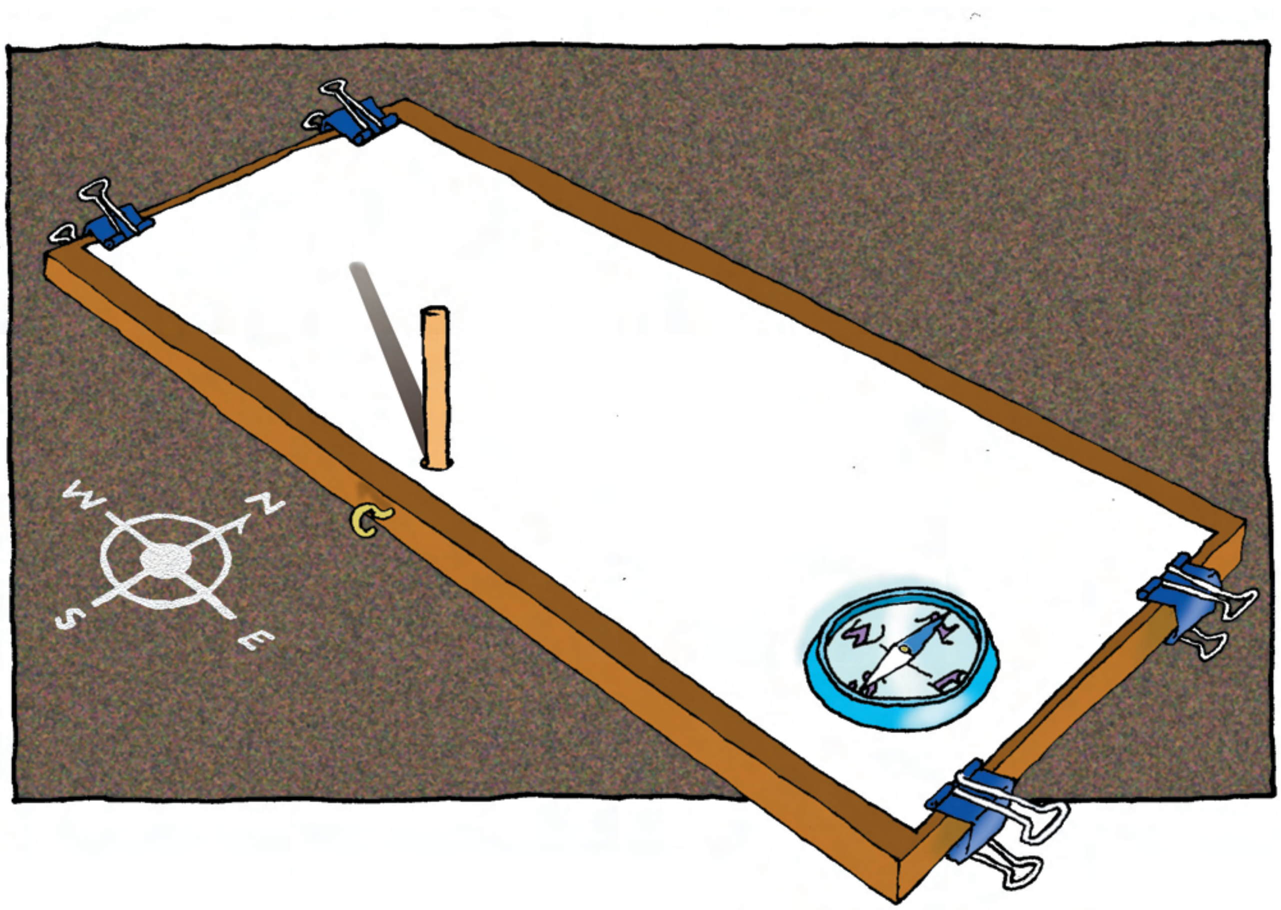

Figure 3.1 *Put the Sun-Earth-Moon Board in a flat, sunny place so that Side A is facing up. Turn the board so that the stick is in the middle of the southern edge of the board. Use your compass to find north. Use chalk to outline your board's position on the ground.*

3. Trace the shadow cast by the stick directly onto your SEM Board paper. Then write the time above, near, or inside the shadow, as shown in Figure 3.2.

4. Discuss what you think will happen to the shadow throughout the day.

5. Wait 10–15 minutes to record your next shadow. While you wait, read "Solar Noon." If you have time, read "The Anasazi: Ancient Skywatchers" as well. Discuss these readers with your group or class.

6. Record your second and final shadow. Do not take your board apart. Other classes may continue to add shadows to your board. During your next class you will analyze a full day's worth of shadows.

Figure 3.2 *Trace the shadow, then write the time.*

SOLAR NOON

Have you ever noticed that light from the Sun feels more intense when the Sun is high in the sky? The point at which the Sun is highest in the sky (and when shadows are shortest) is called "solar noon."

When the Sun first becomes visible in the morning, a given point on Earth receives sunshine at an extremely small angle. This means that the relative intensity of the Sun's radiation is small at this point. The more the light spreads out (or diffuses), the less intense the Sun's radiation is at a given point. By solar noon, however, when the Sun is highest in the sky, the sunshine is slanted the least, or is closest to being vertical. At the close of the day, the Sun's rays again strike Earth at a lesser angle.

But sometimes it is hotter at 3:00 P.M. than at solar noon. Why? A given point at the top of Earth's atmosphere receives more energy from the Sun at solar noon than at 3:00 P.M. or 4:00 P.M. Nonetheless, heat energy from the Sun collects in the atmosphere, on the surface of Earth, and in man-made objects on Earth's surface from the time the Sun rises until it sets. Earth's surface sends this heat energy back into the atmosphere. The amount of heat energy sent (radiated) by Earth's surface determines air temperature. This means that the afternoon—and not solar noon—is often the hottest part of the day.

REFLECTING ON WHAT YOU'VE DONE

1. Get one copy of Student Sheet 3.1. For your group, get a full day's worth of shadow data.

2. Use your metric ruler to measure each shadow tracing. Record the times and shadow lengths on Table 1 on Student Sheet 3.1.

3. Plot your time and length data on Graph 1 on the student sheet. Connect the dots on your graph so that they form a curve.

4. Answer the following questions in your notebook:

   A. What shadow patterns did you observe?

   B. At what time of day did the shortest shadow occur? Where is the Sun in the sky at this time of day?

   C. At what times of day did the longest shadows occur? Where is the Sun in the sky at these times of day?

   D. If solar noon were the lowest point on your curve, how would you define the term "solar noon"?

   E. How could you use your graph to predict the length and location of a shadow for a particular time not plotted on the graph? Give an example and explain.

MATERIALS FOR INQUIRY 3.2

For you and your computer partners

1 transparency
1 set of fine-point transparency markers

Inquiry 3.2
Collecting Computerized Shadow Data

PROCEDURE

1. From <Go> on the Main Menu, select <Set Home Location>. Select <Lookup>. Select the city closest to your home location. Choose <OK>, and then click on <Set Home Location>.

2. If a grassy field is not already showing, select <Home> from the <Go> menu.

3. Check the time on your computer to make certain it is the same time as on your watch. If it is not, click on the time and change it.

4. Go to the <Labels> menu and select <None>.

5. Find the Sun in the sky. If you can't find it, left-click and drag your cursor around the screen until you find the Sun.

6. What does the Sun look like in the sky on your screen? In which direction are you looking? Discuss your observations with your partner.

7. Set the date to 06/01 (June 1) of this year. How high in the sky does the Sun get? At its highest point, click on the Sun, change your cursor to an arrow, and drag the arrow down to the horizon. What is the angle of separation (the measurement between the Sun's position in the sky and Earth's horizon)? See Figure 3.3 for an example. Tell this number to your partners.

8. Set the <Time Step Unit> (far right on the menu) to 003 minutes. Then click on the <Flow Time Forward> arrow to set the Sun in motion. From which direction does the Sun rise? In which direction does the Sun set? Hit the <Stop Time> button.

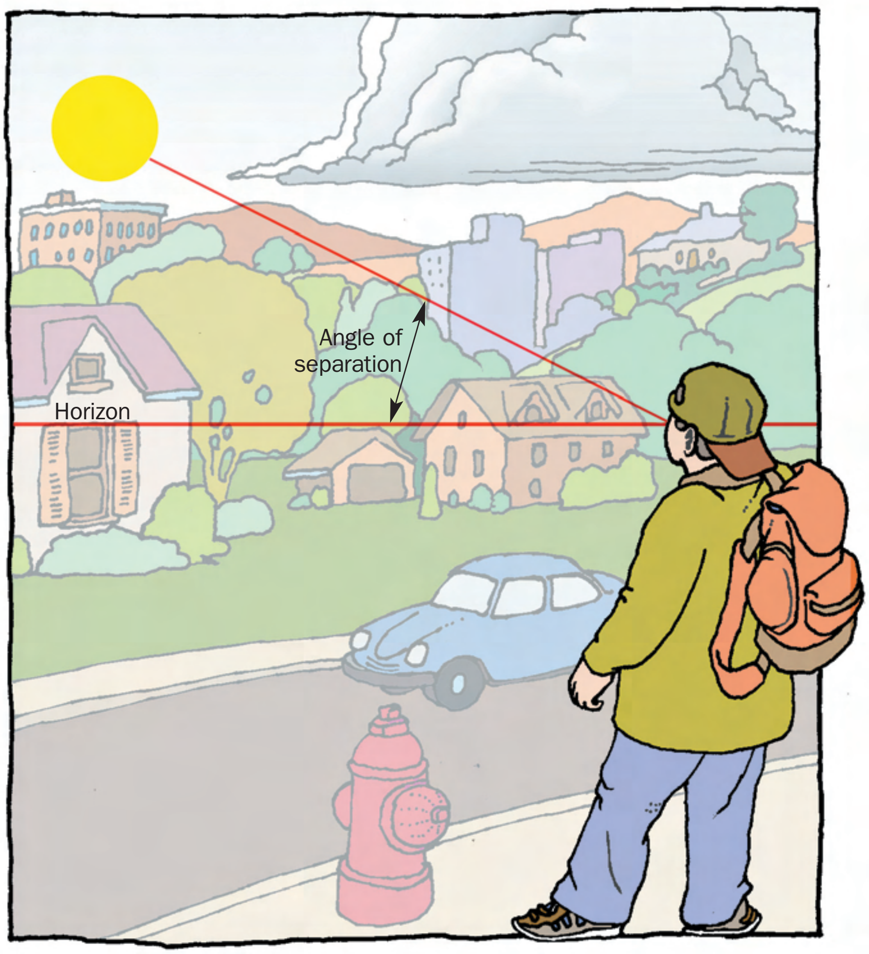

Figure 3.3 *The angle of separation can be thought of as the Sun's apparent position in the sky relative to the horizon, as viewed by an observer on Earth.*

9. Divide your transparency in half as shown in Figure 3.4, and write 06/01 on the top half of the transparency.

10. Set the time on the computer screen to 8:00 A.M.

11. Use the cursor to click and drag the scene up, so that half of your screen is grass. Focus on the taller tree to the right of the "S" (South) compass mark.

12. Place the transparency on the computer screen. (Use masking tape to secure it if you are allowed.) Trace the taller tree onto the top half of the transparency.

13. On the transparency, draw the tree's shadow. Mark 8:00 A.M. next to the shadow, as shown in Figure 3.4. In your notebook, draw the tree and its shadow and indicate the date and time as well.

14. Set the <Time Step Unit> button to hours. Change it to read 001 hours.

15. Click on the <Single Step Forward> button. On the same tree on the transparency, trace the shadow for 9:00 A.M. Draw the shadow in your notebook.

16. Click the <Single Step Forward> button again. Trace the shadow of the tree. Repeat this step until you have traced all of the shadows for the full day. Label the time for each shadow. When the shadow is the shortest, measure the Sun's angle of separation.

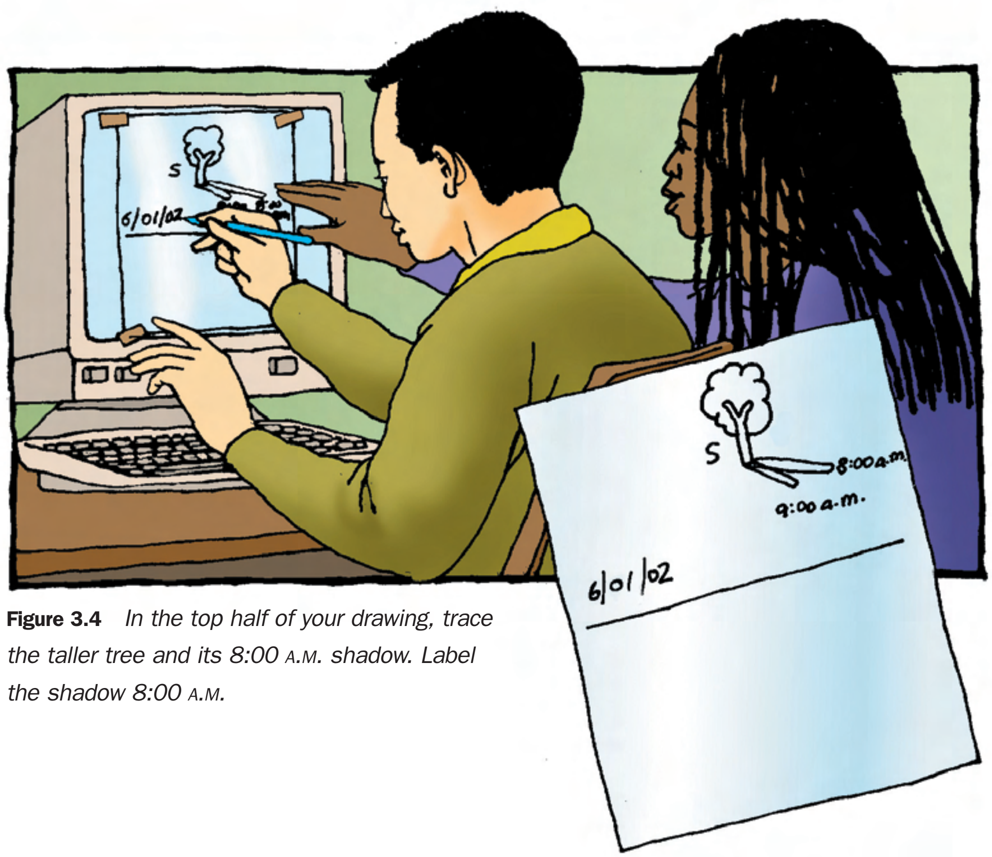

Figure 3.4 *In the top half of your drawing, trace the taller tree and its 8:00 A.M. shadow. Label the shadow 8:00 A.M.*

17. Move your transparency up so the bottom half is now over the "S" tree. Set the date on the screen to 12/01 (December 1) of this year. Set the time to 8:00 A.M. Then repeat Steps 13–16. Record all your new shadows on the bottom half of the transparency. Keep a record of your shadows in your notebook as well.

REFLECTING ON WHAT YOU'VE DONE

1. Discuss your observations with the class.

2. Discuss the following questions:

   What patterns do you observe in the shadow data overall? What do you think causes these patterns?

   What differences do you observe between the summer and winter shadow data? What patterns do you observe in the Sun's angle of separation? What do you think causes these patterns?

MATERIALS FOR INQUIRY 3.3

For you

1 copy of Student Sheet 3.3: Graphing the Sun's Path in Winter and Summer
2 markers, pens, or pencils (different colors)

For your group

1 Sun-Earth-Moon Board™
1 "Modeling Shadows" sheet
4 large binder clips
1 rod #1
1 Mini Maglite®
2 AA batteries
1 piece of string, 50 cm
1 super jumbo plastic straw
1 metric measuring tape
1 foam sleeve (optional)

Inquiry 3.3
Modeling Winter and Summer Shadows

PROCEDURE

1. Use binder clips to attach the two-sided "Modeling Shadows" sheet to Side A of your SEM Board so that the Winter side faces up.

2. Place rod #1 in the hole.

3. Tie one end of the string to the hook on your board. Tie the other end to your Mini Maglite®, as shown in Figure 3.5. There should be 30 cm from the hook to the head of the Mini Maglite when the string is pulled tight.

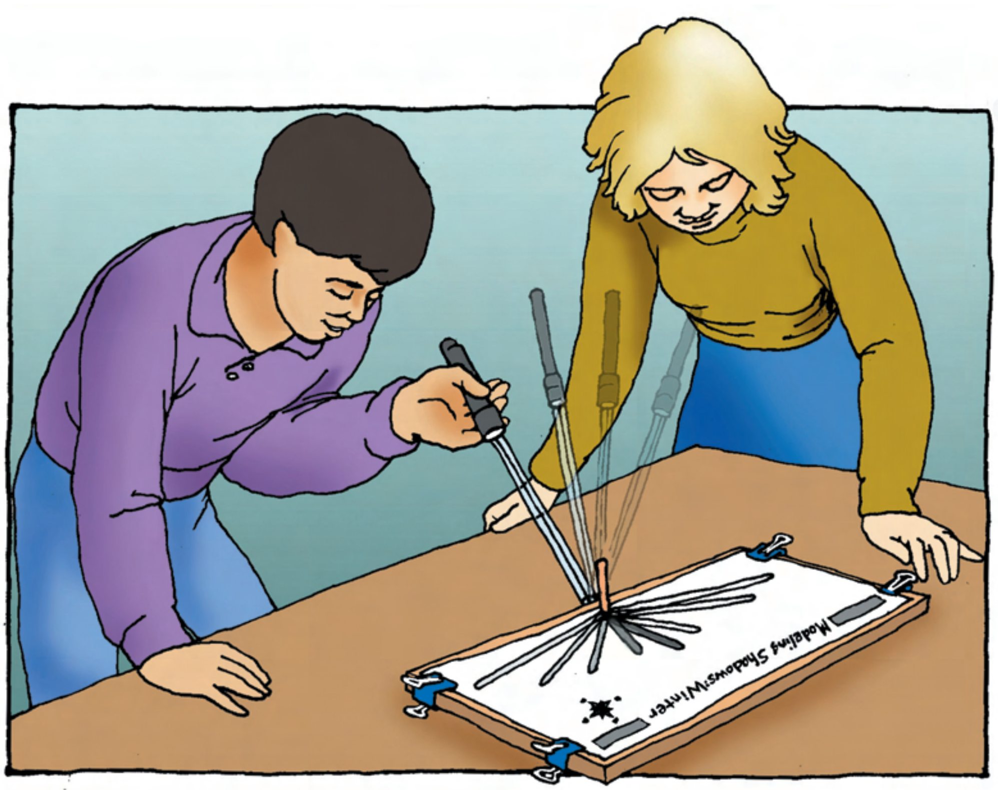

Figure 3.5 *Tie the Mini Maglite® to the string. Attach the string to the hook on the board. Keep the string pulled tight at all times, so that your Mini Maglite® travels in an arc across the "sky."*

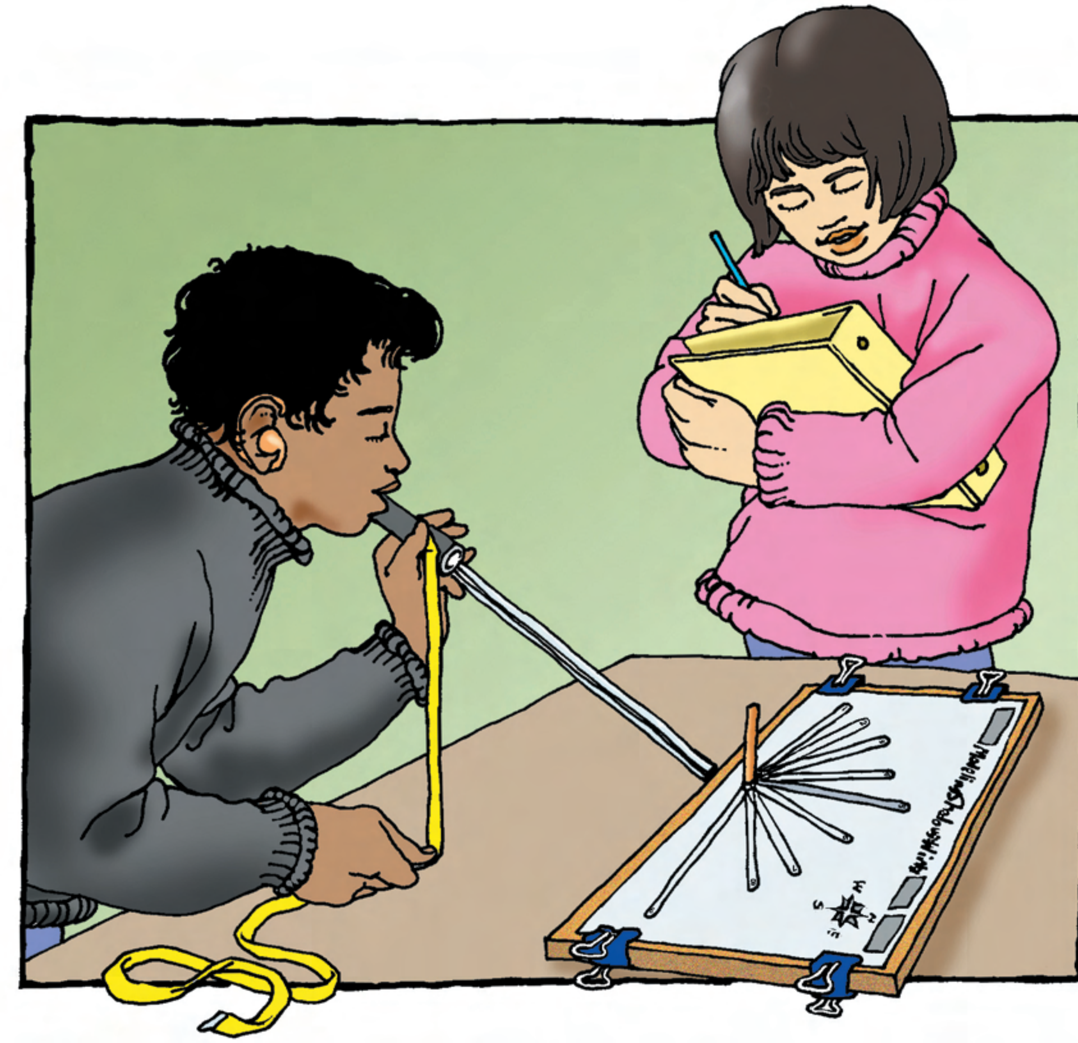

Figure 3.6 *Measure the height of the Mini Maglite® at each of the nine points.*

4. Move the Mini Maglite to recreate the Sun's motion in the winter sky in the Northern Hemisphere. Pull the string so that it is tight at all times. If you need help keeping the string straight, thread the string through the plastic straw.

5. For each shadow, record on Table 1 of Student Sheet 3.3 how high your Mini Maglite is from the table at each of the nine points for Winter (see Figure 3.6).

6. What do you notice about the Sun's path in relation to the horizon? Discuss your observations with your group.

7. Now attach the "Modeling Shadows: Summer" sheet face up on Side A of the SEM Board. Repeat Procedure Steps 4–6. Remember that the string must be pulled tight at all times. What do you notice about the Sun's path in the summer compared to winter? Discuss your observations as a group.

8. Graph the data that you recorded in Table 1 onto Graph 1 of Student Sheet 3.3. Connect each set of points on the graph with a curved line. Use the color key to label each set of points.

REFLECTING ON WHAT YOU'VE DONE

1. Share your data and graph with the class. Where would the winter shadow fall between points 6 and 7? Mark your prediction on your graph of Student Sheet 3.3.

2. With your teacher, use a planning sheet to summarize your investigation from Inquiry 3.3.

3. Answer the following questions in your notebook:

A. What shadow patterns did you observe for summer?

B. What shadow patterns did you observe for winter?

C. During which season and at what time of day might a post cast little or no shadow? Why?

D. At which locations did the longest shadows occur? Where is the "Sun" at these times of day?

E. Compare the path of the "Sun" in the winter sky to the path of the "Sun" in the summer sky. How are the paths alike or different?

MATERIALS FOR INQUIRY 3.4

For your group

1 globe of Earth, 12 cm
1 rod labeled "E"
1 toothpick, 1 cm of the tip
Modeling clay, bead-sized amount

Inquiry 3.4
Analyzing the Effects of Earth's Rotation

PROCEDURE

1. Help your teacher identify your local region on the class globe. How can you use the shadow stick to determine the effects of Earth's rotation on shadow data? Share your ideas with the class.

2. Make an axis for your group's small globe by placing the rod labeled "E" through the globe's holes.

3. Using modeling clay and the tip of a toothpick, mark your home location on the globe, as shown in Figure 3.7.

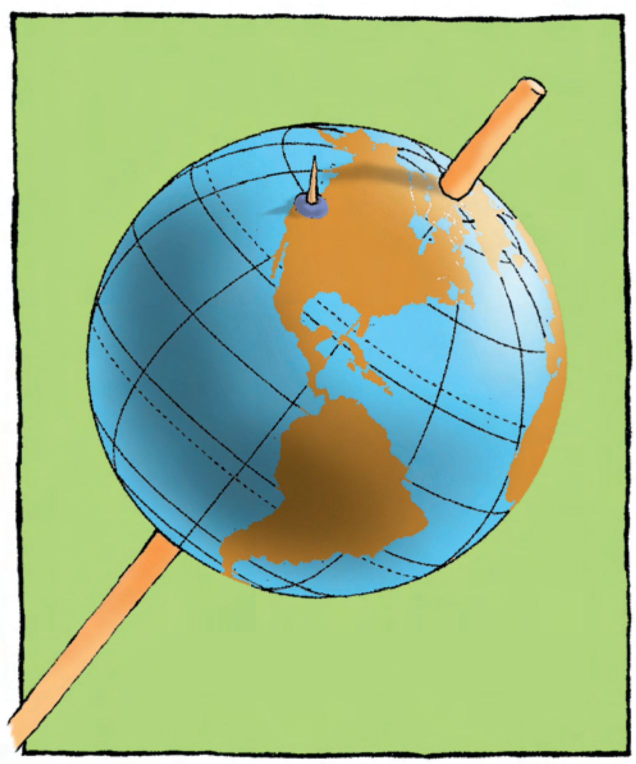

Figure 3.7 *Stick the toothpick on the globe at the location of your school. Hold the rod so the toothpick faces up.*

4. Work either outside with the Sun or inside with a clamp lamp. Find a shadow on your globe cast by the toothpick. What needs to happen to make the shadow change length and direction? Discuss your hypotheses with your group.

5. Test your predictions. Rotate your globe on the rod in all directions. How does the shadow of the toothpick change as the globe rotates? Record your observations in your notebook. Set the globe aside.

6. Now stand with the light (Sun or lamp) behind your left shoulder. Simulate the rotating Earth and apparent "rising Sun" by slowly rotating your body counter-clockwise. Watch how the Sun seems to move relative to your body. Discuss your observations with your group. Record them in your notebook.

REFLECTING ON WHAT YOU'VE DONE

1. Discuss your observations with the class. You may be asked to demonstrate your observations.

2. In collecting shadow data outside, you might describe the Sun's path as the "apparent path of the Sun across the sky." Why is the word "apparent" used in that description? Record your ideas in your science notebook.

3. Write the following statements in your notebook. After each statement, indicate whether it is true or false and describe why.

   A. The Sun rises.

   B. The rotation of Earth makes it look as if the Sun is moving above the horizon.

4. In your own words, define the term "rotation." Record your working definition in your notebook. Compare this to the definition you wrote during Lesson 2.

5. With your class, return to the Lesson 1 folder for Question A. Is there anything you would now change or add? Discuss your ideas with the class.

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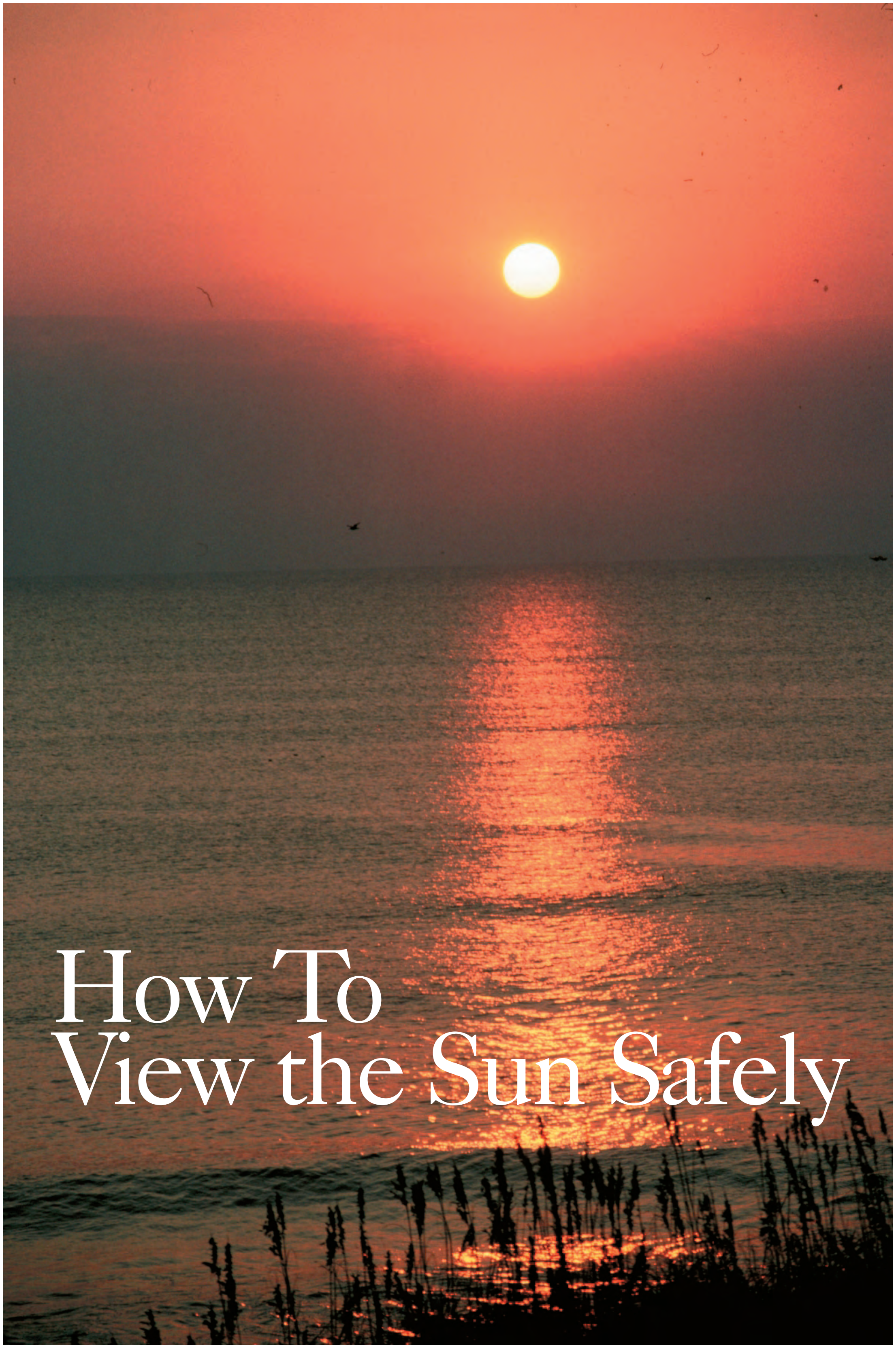
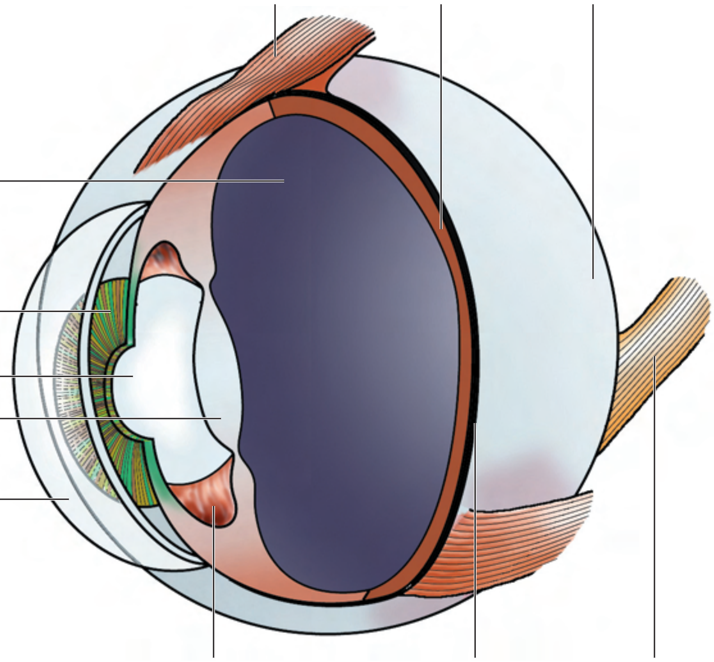


The Sun, our neighborhood star



Cross-section of the eye

Much of our progress in understanding stars comes from studying our "neighborhood star," the Sun. Although we usually associate the study of astronomy with the night, studying the Sun during the day can help us learn more about Earth as a planet.

You will study the Sun in this module. Before you begin, keep an important warning in mind: *Never look directly at the Sun*. Never use binoculars or a telescope to view the Sun directly, even when you have on safe solar viewing glasses. Looking directly at the Sun will cause *permanent eye damage* in seconds. Because you cannot feel the injury, you will not know that your eyes have been damaged until it is too late! This damage is permanent and it can even cause blindness.

How the Eye Is Damaged

Immediate eye damage occurs if you directly observe the Sun without adequate eye protection. The retina of the eye burns from the solar exposure. Over time, exposure to high levels of ultraviolet radiation from the Sun can cause rapid aging of the outer layers of the eye, as well as the skin. Solar ultraviolet radiation eventually can lead to the development of cataracts, which cloud the lens of the eye.

How does exposure to the Sun damage the eye? The dark pigment behind the retina absorbs visible light and near-infrared radiation. The light energy is converted into heat that can literally cook the exposed tissue. This destroys the nerve endings and light-sensitive cells of the eye, leaving a permanently blind area in the retina.

Safe Viewing

The best way to view the Sun and avoid eye damage is with projection—that is, by looking at a projected image of the Sun rather than at the Sun itself. You can project an image of the Sun onto the ground or a screen using a pinhole projection. You can make a pinhole projection by poking a very small hole into a piece of cardboard or other material so that the Sun's light travels through the pinhole onto the screen. You can even project the image of the Sun onto the ground using a small telescope or a pair of binoculars with low magnification. (You will do this in Lesson 8.)

If your telescope is equipped with a special filter, you can also view the Sun through the telescope. The only reliable filters are those that fit over the front of the telescope and reflect away most of the light. Unless you are working with an adult and are *absolutely sure* of what you are doing, do not use a sun filter or telescope to view the Sun.

You also can view the Sun directly using solar viewing glasses, which are designed specifically for viewing the Sun. Keep in mind that regular sunglasses or 3-D tinted glasses

A pinhole projects the image of the Sun onto the screen.

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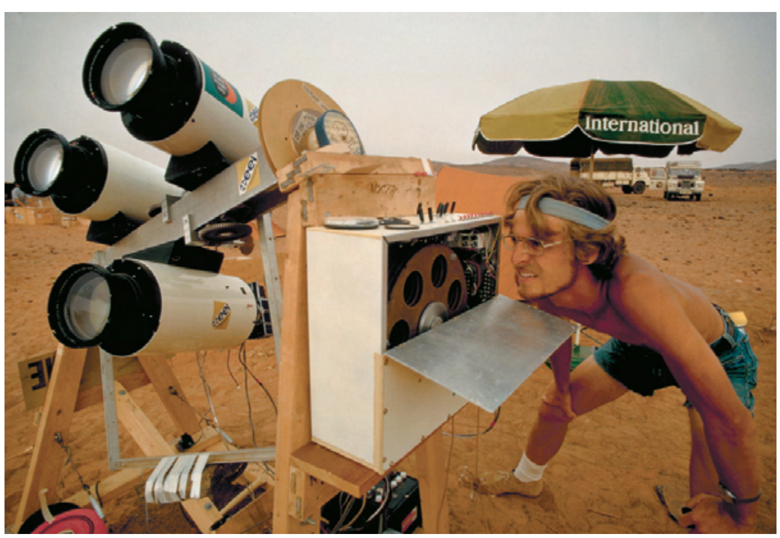


U.S. scientists from Hopkins Observatory check a telescope in Ramnicu Valcea. The August 1999 eclipse lasted for 2 hours and 23 minutes, casting a 113-kilometer strip of darkness across Romania.

Watching total solar eclipse in southern Belgium, August 1999. The people shown here are wearing special safe solar viewing glasses.

cannot protect your eyes from solar radiation while you are observing the Sun!

In this module, you will use projection and safe solar viewing glasses to view the Sun. Do not use any other methods unless you have adult supervision.

Remember, even though there are safe ways to view the Sun, there is always a chance that someone may not take the necessary precautions, or may disobey instructions, and an accident may result. So stay safe. *Never* look directly at the Sun! ☐

THE ANASAZI: Ancient Skywatchers

You only have to look at a calendar to know what month it is. The Anasazi, who lived in the Southwest about a thousand years ago, had no calendars. Their lives depended on knowing precisely the time of year.

These ancient people made their home in a desert valley in Arizona called Chaco Canyon. Temperatures there can sink as low as –39 °Celsius (C) in the winter and soar to 38 °C in the summer. Because the Anasazi had a short growing season, they needed to plant crops at just the right time. If they planted too early, the plants would freeze; too late, and the plants wouldn't have time to mature or bear fruit.

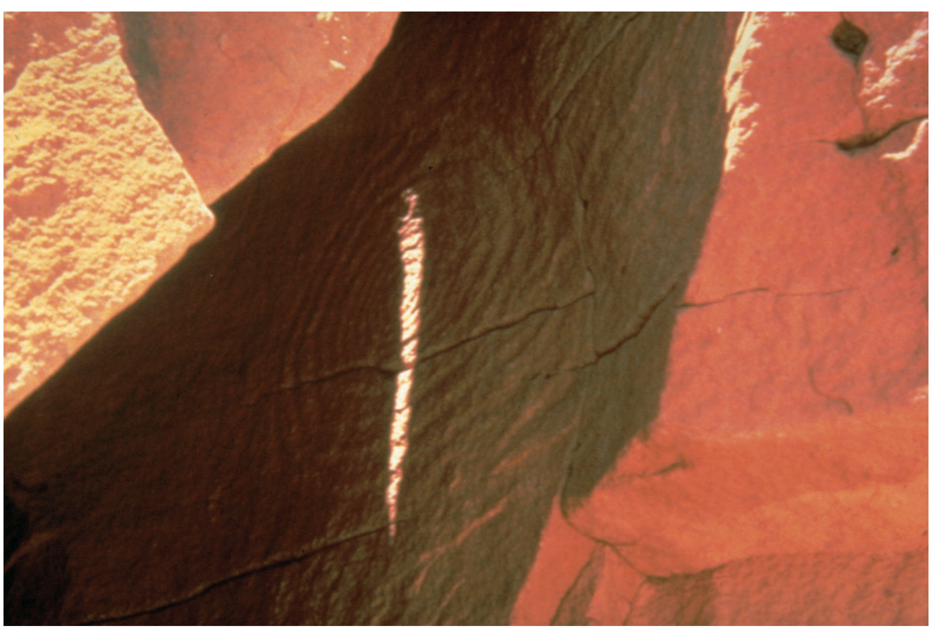
How could the Anasazi determine the best time to plant their crops? They created their own calendar—based on the movements of the Sun.

Tracking the Sun

The Anasazi tracked the Sun and other celestial bodies in several ways. They etched spirals on rocks throughout Chaco Canyon. Sunlight would strike certain points of these spirals and act like a seasonal clock to tell the Anasazi what they needed to know about the season, time of year, or time of day.

One of the most famous Anasazi spirals, the "Sun dagger," was carefully placed behind three upright slabs of rock on a butte. A dagger of light sliced through the spiral during the change of each season—at the winter solstice (around December 21), the spring equinox (around March 21), the summer solstice (around June 21), and at the fall equinox (around September 21).

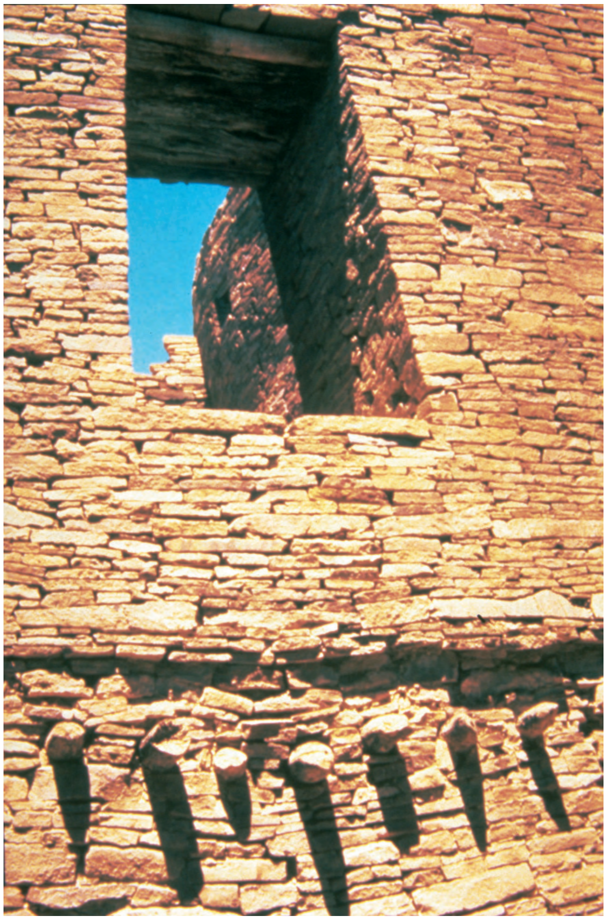
The Anasazi also used natural markers to track the Sun. When sunrise and sunset occurred at certain places against the peaks and valleys of a distant mountain range, skilled observers would know that it was time to plant crops or to expect the arrival of the rainy season.



CHACO ARCHIVE/NATIONAL PARK SERVICE

The "Sun dagger" marks various solar events.

CHACO ARCHIVE/NATIONAL PARK SERVICE, PHOTOGRAPHER: FRED MANG



The time of year and the time of day make all the difference in what you see. These are support beams whose shadows indicate the Sun's position in the sky.

CHACO CULTURE NATIONAL HISTORICAL PARK/NATIONAL PARK SERVICE

Petrograph of supernova 1054. Notice the large star blazing next to the hand and crescent moon.

Recording the Great Events

The Anasazi civilization was at its peak in 1054. That same year, light from an exploding star, or supernova, reached Earth. The gas, dust, and other matter that blew out of the exploding star burned six times brighter than Venus! Visible even in the middle of the day, the supernova could be seen for 23 days before it disappeared.

Before the supernova left their sight, the Anasazi did something that may never have been done before. They recorded the first image of a supernova—a large star blazing next to a hand and crescent moon. This record is called a petrograph.

Just a few years after the supernova, Halley's comet streaked across the southwest sky. Below the petrograph of the supernova, the Anasazi added three circles with flames trailing from them. Scientists believe that these ancient drawings represent Halley's comet.

The Skywatchers Burn Out

Just two hundred years after their desert civilization began, the Anasazi abandoned Chaco Canyon. Many scientists believe they left after years of drought. Others aren't so sure. Perhaps the sky signs became unreliable, and the Anasazi lost faith in their calendar system. Whatever the reasons, these ancient astronomers left their homeland, leaving behind only their stories in stone. □

QUESTIONS

1. Why did the Anasazi need a calendar?
2. What did the Anasazi use to create their own calendars?
3. What is one astronomical event, besides the apparent motion of the Sun and Moon, which the Anasazi recorded in stone?