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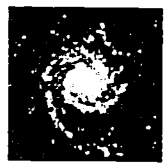
ABSTRACT

Presented is book two in a series of six books in the University of Illinois Astronomy Program which introduces astronomy to upper elementary and junior high school students. This guidebook is concerned with how celestial bodies move in space and how these motions are observed by astronomers. Topics discussed include: a study of the daily motion of the sun, the moon, and the stars; motions of the planets; moving models of the solar system; Kepler's law of planetary motion; and the motion of stars, starpairs, and galaxies. (DS)

THE UNIVERSITY OF ILLINOIS ASTRONOMY PROGRAM

THE UNIVERSE IN MOTION

CODIRECTORS: J. MYRON ATKIN STANLEY P. WYATT, JR.



BOOK 2

GUIDEBOOK

1817

Harper & Row, Publishers

New York Evanston London

THE UNIVERSITY OF ILLINOIS ASTRONOMY PROGRAM

1 *CHARTING THE UNIVERSE*

2 *THE UNIVERSE IN MOTION*

3 *GRAVITATION*

4 *THE MESSAGE OF STARLIGHT*

5 *THE LIFE STORY OF A STAR*

6 *GALAXIES AND THE UNIVERSE*

Cover: *The spiral galaxy NGC 628 in Pisces*, from Mount Wilson and Palomar Observatories.
Frontispiece: *The Copernican System*, from the Bettmann Archive.

Printed in the United States of America

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PROJECT STAFF

THE UNIVERSITY OF ILLINOIS ASTRONOMY PROGRAM is the product of eight years of research and development by the Elementary-School Science Project, a course content improvement project supported by the National Science Foundation. The program grew within a logical framework that incorporated writing conferences, classroom trials, evaluation reviews, and rewriting sessions. The staff of professional astronomers and science education specialists was under the direction of J. Myron Atkin, professor of science education, and Stanley P. Wyatt, Jr., professor of astronomy, both of the University of Illinois.

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INTRODUCTION

THE UNIVERSITY OF ILLINOIS ASTRONOMY PROGRAM is a series of six books that introduces astronomy to upper elementary and junior high-school students in a unique way. The program represents a complete restructuring of traditional descriptive school astronomy into a course of study based on selected major concepts that are pursued in depth. These basic themes of astronomy have been picked by professional astronomers to give children fundamental and accurate information about the solar system, the stars, and the galaxies.

Two subsidiary elements are reflected in this program's approach to the teaching of astronomy. First, there is a strong flavor of history throughout the books. Not only are fundamental concepts presented, but students also learn the way in which these concepts were uncovered by astronomers down through the centuries. Secondly, the interdisciplinary nature of astronomy is repeatedly emphasized. Your students will apply principles from several of the physical sciences as they study these books. They will also discover that mathematics is a tool of science.

Major concepts in each book are explored primarily through numerous student activities as well as through the development of models that explain astronomical phenomena. The physical and mathematical underpinnings of each book are developed in the early chapters. Later chapters are then devoted to the application of these principles to a variety of areas in astronomy. Within each book, the development is from simple, basic ideas to an understanding of the concepts and principles which the astronomer has established.

There has been a vast acquisition of new knowledge by astronomers in the past three decades, and the frontiers of astronomy are expanding at an increasing rate. Man is learning more and more about the nature of the universe. THE UNIVERSITY OF ILLINOIS ASTRONOMY PROGRAM is designed to guide your students to a fuller understanding of this universe.

An Outline of the Program

The following book-by-book summary of THE UNIVERSITY OF ILLINOIS ASTRONOMY PROGRAM will give you an overview of the scope of the series.

Book 1, CHARTING THE UNIVERSE, introduces the student to the measurement of sizes and distances of astronomical objects so that a static snapshot model of the universe can be developed. Book 1 includes:

- ★ The measurement of angles and the properties of triangles and scale drawings.
- ★ The use of triangulation to find distances on earth, to the moon, and to the stars.
- ★ Angular diameters as a means of determining the sizes of the sun, the moon, and the planets.
- ★ The inverse-square law of light as a tool for learning distances to stars and galaxies.

Book 2, THE UNIVERSE IN MOTION, is concerned with how celestial bodies move in space and how these motions are observed by astronomers. Book 2 includes:

- ★ A study of the daily motions of the sun, the moon, and the stars.
- ★ The motions of the planets.
- ★ Moving models of the solar system.
- ★ Kepler's laws of planetary motion.
- ★ The motions of stars, star-pairs, and galaxies.

Book 3, GRAVITATION, investigates the causes of celestial motion and examines in detail the laws that apply to all moving things in the universe. Book 3 includes:

* The basic concepts of speed, acceleration, force, and mass.
* Gravity at the earth's surface.
* Newton's universal law of gravitation.
* Orbital paths near the earth.
* The motions and masses of planets and stars.

Book 4, THE MESSAGE OF STARLIGHT, turns to the analysis of light as an essential clue to understanding astronomical phenomena. Book 4 includes:

* The behavior of light.
* The wave model and the particle model of light.
* The electromagnetic spectrum.
* The role of spectra in determining stellar temperature, size, and chemical composition.
* The origin of light and the Bohr model of the atom.
* The *Doppler effect* as an aid to understanding the motion of stars and galaxies.

Book 5, THE LIFE STORY OF A STAR, discusses the interior of stars, their source of energy, and their evolution. Book 5 includes:

* The physical properties of the sun.
* Models of the solar interior, using known physical laws as guides.
* The source of solar energy.
* Properties of other stars—their luminosities, temperatures, and masses.
* Stellar models and the evolution of stars.
* The birth and death of stars.

Book 6, GALAXIES AND THE UNIVERSE, takes up galaxies, the largest known units of matter that astronomers have discovered, and investigates the arrangement and motion of them in the universe. Book 6 includes:

* The home galaxy – its contents, its architecture, and the motion of stars within it.
* Other types of galaxies.
* The arrangement of galaxies in the universe.
* Motions of galaxies.
* Cosmology.

Suggestions for Using this Guidebook

You will find this guidebook allows you a great deal of flexibility in presenting the material to your class. You are urged to use it in a way that best suits your particular class, the time allotted for a particular unit, and your own methods of teaching. Since this astronomy material will be new to your students, you will want to study carefully both the student's edition and this guidebook before presenting a unit to your class.

A symbol consisting of a triangle, a circle, and a square identifies each student activity. The activities are performed with simple, readily obtainable materials. But they require careful performance. Try each activity before it is encountered by your pupils. Anticipate the questions and problems your pupils might have as they work through the activities.

Questions raised in the pupil's book that require specific answers are discussed and answered in the guidebook. You will note, however, that many questions are designed to stimulate interest and thought on the part of your students, often as a bridge to the next topic. You will, of course, find no specific answers to these questions.

Each chapter of your guidebook is laid out in a consistent arrangement that will lead you easily through the material in the student's !· '

The chapters in this guide are divided in this manner:

* An opening paragraph gives you a concise overview of the chapter.
* The main ideas of the chapter are listed to clarify for you the major concepts. It is not intended that this list be memorized by your pupils.
* A listing of suggested materials includes those items needed for the activities in the pupil's book.
* Suggestions for teaching are arranged to follow the sequence of sections within the chapter. In all cases in this guide, the page references are to pages in your students' book unless it is specified the reference refers to another page in this guide.
* At frequent intervals short sections of background information are introduced to provide additional material for extension of your knowledge.
* Guidelines to help you direct the student activities are identified by the activity symbol as well as by a page reference to the activity in the pupil's book. When required, these sections of the guide provide answers, completed tables, or finished diagrams.
* Most chapters conclude with a group of supplementary activities, each one keyed to a specific page in the pupil's book. Supplementary activities are helpful reinforcements or extensions of concepts already treated in the text. However, they are not essential; use them at your discretion.
* The book concludes with a guide to the pronunciation of the proper names found in the pupil's book and in the guidebook.

CHAPTER 1

TIME AND MOTION

pages 7-8

This introductory chapter is intended to make pupils aware that everything in the universe changes and moves and that describing the motion of celestial objects has occupied astronomers since ancient times.

Main Ideas

1. Everything in the universe moves.

2. The universe changes as time goes by.

Suggested Materials

No special materials needed for this chapter.

Suggestions for Teaching

This chapter should be read and discussed briefly. The questions are merely to stimulate thinking and discussion and are not designed to elicit specific answers. It would be wise to plan to move into the next chapter during the first class period.

CHAPTER 2

FROM DAY TO DAY

pages 9-26

The most readily apparent motions seen in the sky are the motions of the sun, the moon, and the stars. To learn more about these motions it is necessary to locate the bodies accurately in space. In this chapter students develop new skills in estimating and measuring the positions of celestial objects. They construct and use instruments to measure the bearing and elevation of the sun and moon. They discover similarities in the motions of the sun, the moon, and the stars as the earth rotates on its axis once every day.

Main Ideas

1. The sun's position and apparent motion can be estimated by observing its compass direction, or bearing, and its angular height, or elevation, above the horizon.

2. Changes in the bearing and elevation of celestial objects are important clues to their apparent motions.

3. The sun and the moon appear to move along similar paths across the sky.

Suggested Materials

magnetic compass   dowel stick or pencil   spool
flat, square piece of board or stiff cardboard
lengths of string   protractor   graph paper
glue   globe   weighted string   straws

Suggestions for Teaching

ESTIMATING THE DAILY MOTION OF THE SUN

pages 9-12

The central purpose of the questions on page 9 is to elicit student's observation or hunches.

Students are asked to recall what they know about the sun's apparent motions. Most students will know where the sun rises and sets, but there is a good chance that they have overgeneralized about the position of sunrise and sunset. There are, for example, seasonal variations. The sun rises somewhat in the northeast in summer and somewhat in the southeast in winter. It is essential that students be helped to realize that the motions with which they are familiar may appear different from other points on the earth.

When observing the sun's position, students should simply glance quickly in the direction of the sun and *not look directly at the disk.* Sunglasses, photographic negatives, and smoked glass *are not adequate protection* for direct viewing of the sun. The students should stand in the same place each time they make sketches of their observations during the day. They should include landmarks such as trees, houses, a flagpole, or other fixed objects.

Page 10 This first activity is intended to increase children's skill in finding directions of the compass. Let different children answer the questions and compare their "labels" (north, east, southwest, etc.) without any previous discussion of compass direction. Then let them check each other with compasses. Finally, have them use compasses to become more accurate in indicating directions to objects in the classroom or outdoors.

Pages 10-11 The purpose of this activity is to develop children's abilities to make estimates of the fractional distance of an object between the horizon and the zenith. Children should have practice outdoors with treetops, steeples, flagpoles, and other high objects. Encourage them to make comparisons of estimates. Discuss possible sources of error in their estimates. (Were the observers standing in the same place? Were they each observing the same thing? Was the object in motion relative to the observer? How well can we estimate fractions of a distance?)

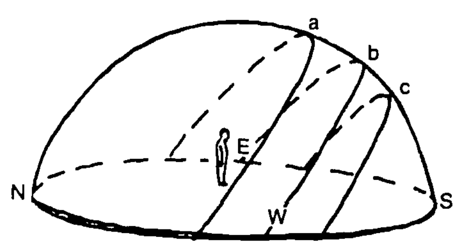
Page 11 To locate an object or a specific point on the earth or in space, *two* pieces of data are needed—compass direction and angular height. The direction of the top and bottom of the flagpole will be the same, but the angular height for each will be different with respect to the horizon. The bottom will even be slightly below the horizon line. Can the children think of any point that can be located by knowing just the direction or just the height? (The zenith and its opposite, the nadir. The center of the earth is 90° below the horizon, but has no specific bearing.)

Page 12 To obtain a more complete record of the sun's motion, estimates of position should be extended to include the hours before and after school. In this way early morning and late afternoon estimates will provide a good deal of information.

The sun rises in the east, but somewhat north of east in spring and summer and somewhat south of east in fall and winter. As seen from the United States, it is highest in the sky around noon (but not in general *at* noon). And it is due south when it is highest. After dark the sun moves down and to the right until about midnight, when it is due north and far below the horizon. Then it moves upward and right, still under the northeast horizon, until it rises the following morning.

Two months from now or at some other time of the year the sun's motion will be generally the same, but will differ in detail as can be seen in the diagram below. The diagram is valid for a person in the middle latitudes of the United States.

a June 21
b March 21 and September 23
c December 22



MEASURING THE POSITION OF THE SUN

pages 12-21

Page 12 The essential feature of a gnomon is that the stick must be vertical; it must point straight up and down. Gravity defines the direction *up* and *down*, and the weighted string helps determine if the stick is vertical.

The gnomon will be used for many activities in *The Universe in Motion*. It is desirable for each student to have his own.

Bearing is the angular distance in relation to true north, stated in degrees. For example (page 13), the compass direction when you face due east is 90°. Due south would be 180°. Technically, bearing is known as *azimuth*.

When the sun is southwest its bearing is 225°. The sun's approximate noontime bearing is 180°, or south. At midnight the sun's bearing is approximately 0°.

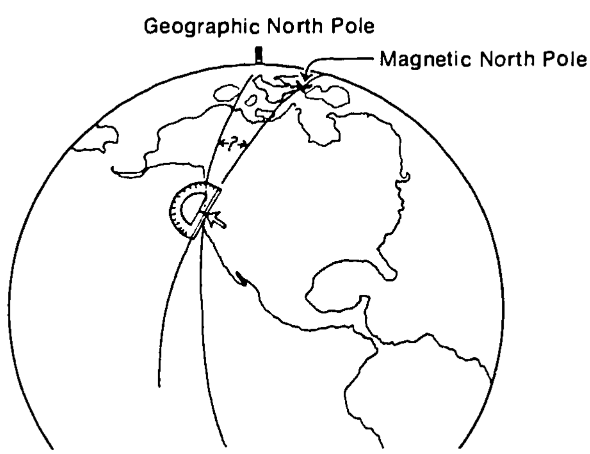
For additional practice in measuring bearing see Supplementary Activity 2-1.

At night Polaris (the North Star) is a reasonably accurate indication of true north. Although Polaris actually moves in a circle every 24 hours, the circle is very small—about one degree in radius. As a result, the bearing of Polaris is always very close to 0°.

Page 14 If the north magnetic pole is not printed on the classroom globe, it can be located at latitude 74° north, longitude 101° west. Further information about the location of the magnetic poles may be found in an almanac.

This activity provides students with the opportunity to estimate the angular distance between true north and magnetic north. This difference is known as magnetic declination.

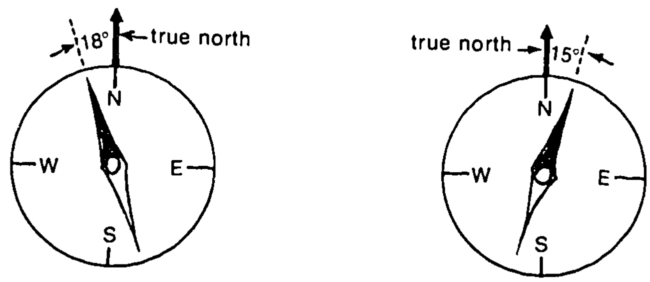
When stretching the strings through the home town and each of the north poles (true and magnetic) it will be helpful if the strings are held firmly in position. In order to protect the surface of the globe, use rubber cement only. Make sure that the protractor is placed carefully in position before the angle is measured.



Have several teams of students measure the angle. Compare measurements. Is a difference found? Ask students if they can explain why the measurements are not all alike.

As a test of accuracy of measurement, students can be referred to an almanac. Tables of magnetic declination give precise information for a number of cities.

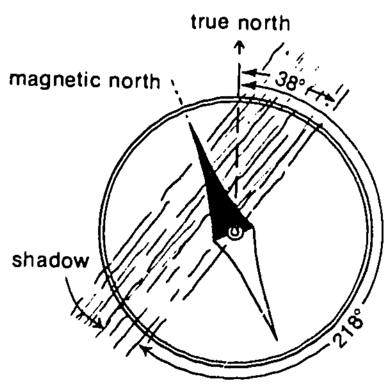
Your students will be using the declination angle to find true north. The compass can be set up as shown in the diagrams here.



If the north magnetic pole is 15° east of the north geographic pole, the situation resembles the picture on the right.

If the north magnetic pole is 18° west of the north geographic pole, the situation resembles the picture on the left.

Page 15 To find the bearing of the sun, slowly slide the compass into position so that one edge of the shadow passes through the pivot of the compass needle. Note in the diagram below that the edge of the shadow passes through the center of the needle. The bearing of the shadow is measured in degrees marked on the rosette of the compass.

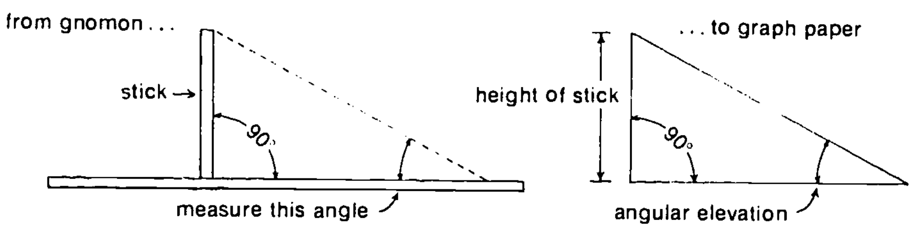


For practice in measuring the bearing of objects and their shadows see Supplementary Activity 2-2.

Using the gnomon and rosette provides another method of measuring the sun's bearing. See Supplementary Activity 2-3.

The questions in the paragraph above the illustration on page 15 are intended as lead-ins to the following activity.

Page 15 This activity measuring the height of the sun in the sky is a brief introduction to the concept of angular elevation. In the activity students construct similar triangles of the kind shown below. These constructions may be made with pencil, ruler, and protractor. Make sure the line representing the vertical stick is perpendicular to the base line of the triangle. Using graph paper for this activity and for those that follow will assure the construction of right angles.



Supplementary Activity 2-4 provides practice in measuring angles of elevation.

In the last paragraph on page 15, the students are asked to predict and test angles of elevation from evidence about shadows. Encourage them to estimate their answers and then to design a test to see if their estimates are accurate. With no shadow the sun will be at the zenith. Its elevation will be 90°. When the shadow is as long as the stick, the sun's elevation is 45°. When the shadow is infinitely long, the sun must be on the horizon. Its elevation is 0°.

The word *elevation* is used here in a new context. Students may be familiar with elevation as a linear measure of height in inches, feet, or miles. In the context of astronomy, *elevation* refers to the angular measure of distance in degrees above the celestial horizon. Astronomers also use the term *altitude* for the angular measure of distance in degrees above the celestial horizon.

Earlier in this chapter (page 10), your students learned that the point directly overhead is the *zenith*. Now on page 16 they have found that its elevation is 90°. At sunrise the elevation of the sun is 0°; it is on the horizon. If the sun is two-thirds of the way from the horizon to the zenith, its elevation would be two-thirds of 90°, or 60°.

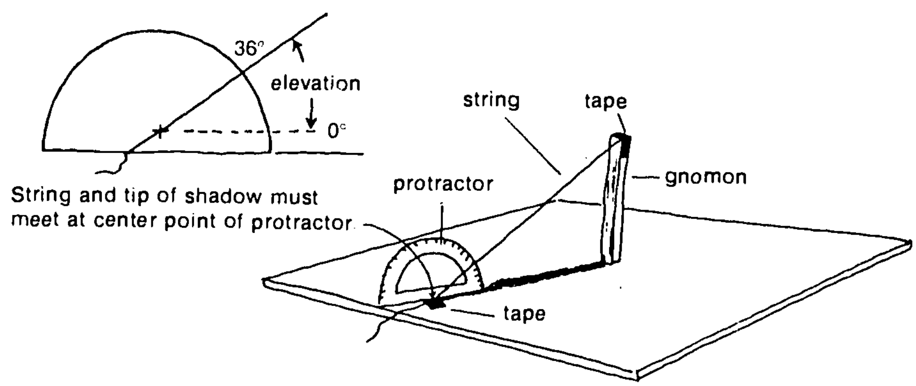
Students must think of the horizon as if there were no hills, trees, or buildings obstructing their view. Then they are using the celestial horizon as a point of reference, not the visible horizon.

You may use Supplementary Activities 2-5, 2-6, and 2-7 at this point.

Scale drawings of the Eiffel Tower's elevation as described on page 16 may be made here. See Supplementary Activity 2-8.

The important point that should be stressed in this section is that *both* bearing and elevation are necessary for the accurate location of an object in the sky.

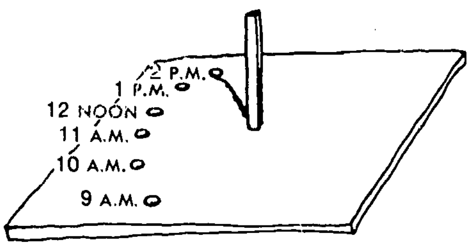
Page 17 To help measure the angle at the tip of the shadow, use a length of string. It is mounted as shown below.

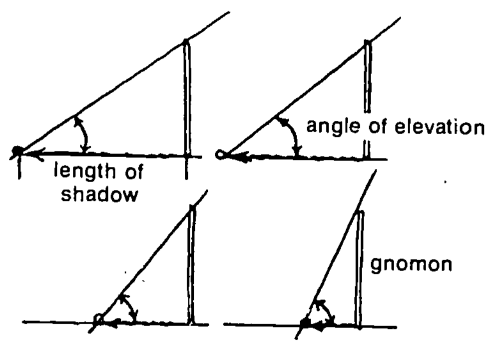


The string is held in position by tape. Note that one end of the string is taped exactly at the end of the shadow. The other is taped to the top of the stick. Place a protractor in position next to the string with its center point at the top of the shadow. The elevation can be read from the protractor.

Page 17 To find the bearing and elevation of the sun at different times during a day, students will have to find a level spot that is likely to be sunny all day. The spot should be one in which the gnomons will remain undisturbed. Observations should be made every hour.

After the gnomon is placed in position, the bearing of the shadow can be measured. At the same time the length of the shadow should be measured so that the angular elevation can be calculated later using similar triangles. To make a mark of the tip of the shadow, press a thumb tack into the wood base. After several observations the gnomon might look like the one in the illustration below.





Instead of tacks, small stones or clay balls can be used for the same purpose. A number of these observations should be made over a period of several days. Students will find that the bearing and elevation of the sun at a specific hour change little from day to day.

Using the bearing and elevation for each hour, students can try to make estimates of where the sun's shadow will be at other times. Comparison of hour-to-hour changes will show the amount of change in bearing and elevation for each observation period.

BACKGROUND INFORMATION *Although students may imagine the shadow will be shortest at noon, this may not be true. The length of the shadow at noon is influenced by several factors, such as location in the time zone and the time of the year. In contrast, the bearing of the shadow when it is shortest is always 180° as seen from any point in the middle northern latitudes.*

If viewing conditions are unfavorable for several days, students may use the data found in Supplementary Activity 2-9.

Page 18 At least six readings should be used in this activity to set up the sun plot on the graph. They should be recorded at even intervals from sunrise to sunset during one day. Have the students enter each reading by marking dots on the graph in consecutive order--the first dot on the left indicating the sun's position at the first observation in the morning. The observation time should be recorded next to each dot.

By referring to their graphs and charts your students should be able to answer the following questions:

1. How does the bearing of the sun change from hour to hour? (When the sun is lowest in the sky, its bearing changes least. When the sun is highest in the sky, its bearing changes most.)

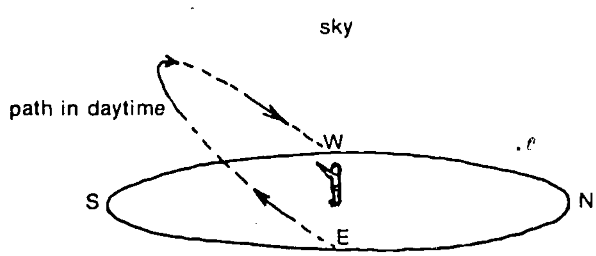
2. What is the sun's bearing at its greatest elevation? (180°.)

3. What is the shape of the sun's path? (A smooth curve.)

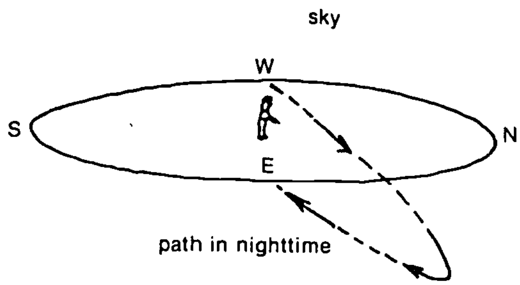
4. If direct observations have not been made each hour, can the sun's position be estimated? (Join the dots with a smooth curve. In this way the entire path of the sun throughout the day can be reconstructed.)

5. Did the sun rise due east (bearing 90°) and set due west (270°)? (Probably not. On March 21 and September 23 the sun will rise and set at these bearings. At other times it will be seen to rise and set somewhat north or south of these bearings.)

Page 19 Point to the eastern horizon (bearing of 90°). Turn to the right, raising the arm past southeast to south. At this bearing the hand should be highest. Slowly lowering the arm, continue turning past southwest until pointing directly at the western horizon (bearing 270°).



Past sundown we can only guess at the path of the sun. It would seem reasonable to suppose that the sun appears to move on the same kind of path as it did when observed during our daylight hours. Continue turning right as before, lowering the hand to point below the horizon. When pointing due north (bearing 0°), the hand should be at its lowest point below the horizon.



In this activity students will really be making inferences from their information about the bearing and elevation of the sun during the day. Only about half of the sun's path will actually have been plotted. When sweeping out the other half, students should be aware of the fact that they are taking something for granted. They take for granted that the sun's apparent motion in the sky is regular and predictable.

Page 19 The activity at the bottom of the page helps students see the different apparent tracks of the sun during a summer day and a winter day. The point of the pencil should be directed toward true north and elevated from the horizon at an angle equal to the number of degrees of latitude of your town (for example, bearing 0°, elevation 40° in Urbana, Illinois).

With the pencil in the proper position, the tip is actually pointing toward Polaris and the pencil parallels the earth's axis. The explanation as to why the straws are placed at 67° angles is found on page 47 of the student's book. When the straw is used for sighting points *above* the horizon, it is daytime. When it is *below* the horizon, it is night.

On the first day of summer the sun's bearing at sunrise is between 55° and 60° for most places in the United States. Its path is a long one and its average elevation is great. On the first day of winter the sun's bearing at sunrise is about 120° or 125°. Its path is shorter and its average elevation above the horizon is less.

To visualize the sun's apparent track on the first day of spring or autumn see Supplementary Activity 2-10.

Page 21 Standing on the North Pole, you are at latitude 90° north. The North Star (Polaris) is directly overhead at elevation 90°. Point the pencil tip at the zenith and rotate it. Notice the path traced by straw *A*. Does it ever trace a path below the horizon? Ask what effect this would have. (If the sun is never below the horizon during a 24-hour day, there is daylight around the clock.)

Rotate the pencil as before and observe what happens when straw *B* sweeps out a circle. How long a period of sunlight is observed? (In this event the sun never moves above the north polar horizon. It is always nighttime.) Can the students tell you what is happening at the south pole? (It is always daytime.)

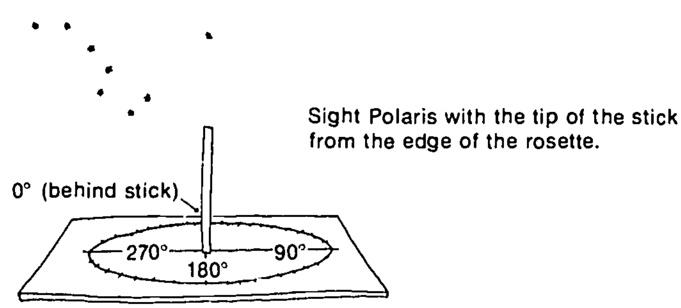
CHARTING THE MOON

pages 22-24

Page 22 For this activity your students will be working independently in the evening. They will have to locate Polaris. To help students, it may be advisable to use additional clues suggested on the star maps in Chapter 3 and in the accompanying text on pages 34 and 35.

Your students will have had a variety of experiences setting up a gnomon. They can use the rosette on page 27 of this *Guidebook* to help them find bearings of the moon.

To orient the rosette properly, place the gnomon on the ground. Find Polaris. Move your eye until Polaris is hidden behind the stick. Now you are looking due north (bearing 0°). Turn the rosette until its 0° marking is also behind the stick.



To give students needed practice at orienting the rosette, it is advisable to have practice sessions beforehand in the classroom. A small penlight can serve as Polaris. Have the students check one another for accuracy in orienting the rosette.

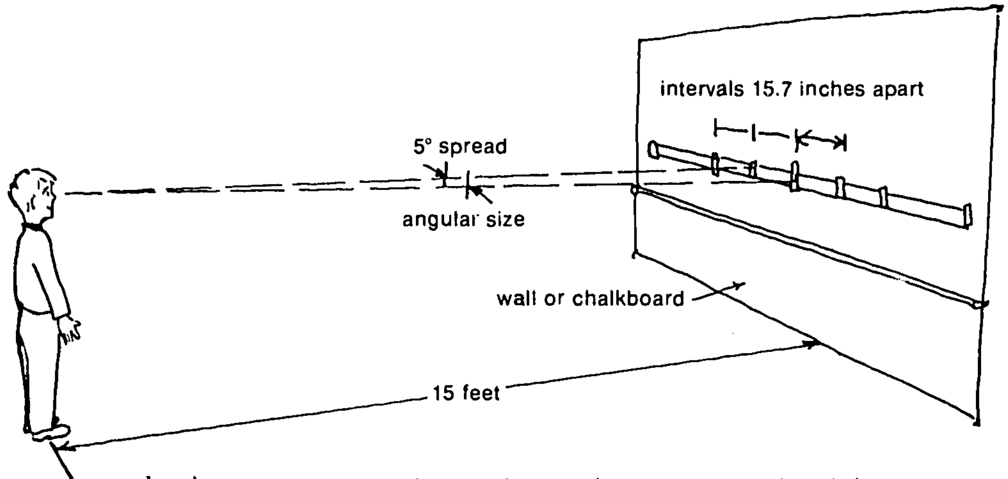
When your students are taking the bearing of the moon at a particular time, they should recall that the bearing of the moon is opposite the bearing of the shadow. To find the elevation of the nighttime moon, students can use one of the methods they used for finding the sun's elevation. They can make scale drawings of similar triangles on graph paper or they can measure directly with a protractor the angle formed by a string taped to a gnomon.

The daily motion of the moon is similar to that of the sun. It rises in the east and sets in the west. The major difference students may discover is that the moon rises about 50 minutes later each succeeding night. This change is caused by the monthly orbital motion of the moon around the earth. This pattern will be treated more fully in Chapter 4, "Wanderers Against the Stars."

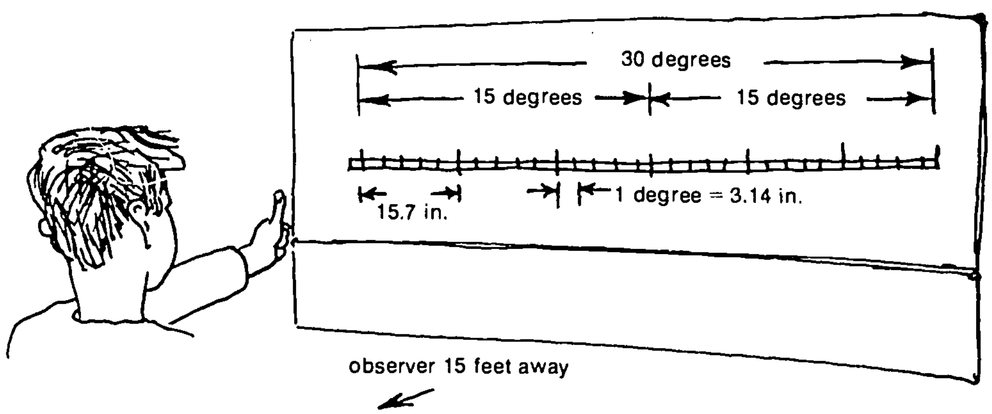
To find the daytime moon, refer to a calendar which includes the phases of the moon, their dates, and the time of moonrise and moonset. An almanac has similar information. The moon can be found in the east or southeast in the afternoon during the time of first quarter. Near the time of the last (or third) quarter it can be found in the west or southwest in the morning hours.

Page 23 This activity is intended to give students a convenient way of estimating angular distance. This method of determining the elevation of the moon is useful for other activities as well. For example, in Chapter 3, students will be able to use this method to measure the angular separation of stars.

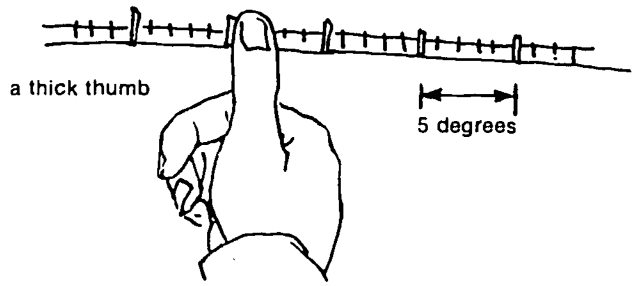
First, a scale must be constructed. Make a mark on the floor 15 feet from a wall. Place a strip of paper or tape horizontally on the wall as shown on the following page. The strip should be located at the eye level of the average student. Make a mark in the center. Measure 15.7 inches to one side of the mark. At a distance of 15 feet, 15.7 inches represents an angular distance of 5 degrees. Make two more marks, each one 15.7 inches away from the previous one so that each is separated by an angular distance of 5 degrees when observed from 15 feet away.



In the same way, make marks on the opposite side of the center point. When this is done there will be a range of 30° — 15° right and 15° left of the center mark. It will be necessary to finish the scale in one-degree intervals. This can be done by dividing 15.7 inches into five equal parts. One degree is 3.14 inches. Use this measurement to fill in the scale. When the scale is completed, students can use it to find the angular diameter of their fingers or hands as discussed in the pupil's book.



Students should stand 15 feet from the scale, with their toes touching the floor mark. Have them stretch their arm fully, with their thumb pointing straight up. Tell them to close one eye and line up one side of their thumb with one of the vertical marks. How many spaces does the thumb block from view? In the illustration on the next page, the thumb is blocking about two marks. This will be equal to about 2 degrees.



Your students will obtain different measurements. Compare the measurements. Discuss the reasons for these differences. (Some fingers are thicker than others; some arms are longer than others; errors may have occurred in the estimates.)

Using the method just outlined, take other mea rements as directed on page 23 of the pupil's book (three-fin and hand-spans).

Your pupils can now use this method of measuring angular distance to estimate the elevation of the moon in the daytime. Give the students an opportunity to practice using their hand measures. For example, have them measure the angular height of the door from various locations in the room. From top to bottom, how many thumb-widths is it? How many degrees? Others object can be measured in the same way. Use students' measurements to make comparisons of their estimates. Encourage them to make the estimates as accurately as possible.

Page 24 The activity on this page can be completed by using hand measurements of elevation and measurements of bearing as described earlier in the chapter.

The daily motion of the moon is roughly that of the sun. It rises generally in the east, but its bearing may vary. For example, it may rise at a bearing of 65° or 90° or 100°. It sets generally in the west, but its bearing varies as much as the bearing at moonrise. When its elevation is greatest, its bearing is 180°, due south. From moonrise to moonset is about 12 hours. Actually, the moon's own orbital motion results in a time somewhat longer than 12 hours. The average figure is 12 hours and 25 minutes.

For more accurate measuring of elevation with a simple sighting device see Supplementary Activity 2-11.

FOLLOWING THE STARS

page 25

Page 25 For the activity on following the stars, some students may want to refer to the star maps in Chapter 3. It is generally preferable for them to recognize a few on their own at first, without the help of the maps.

Viewed from the United States, the star in the east will move right and up. The one in the south will move right (increase its bearing) without changing its elevation much. The one in the west will move right and down. The Big Dipper will wheel counter-clockwise around Polaris, the whole circuit taking a day. Polaris will not appear to move if observed with the unaided eye.

To photograph the tracks of stars, see Supplementary Activity 2-12.

MORE ON DAY AND NIGHT

pages 25-26

The questions in this section are intended to remind students that the portion of the sky seen from the earth is often limited. At sea level with no obstructions, half of the sky will be seen. The celestial horizon divides the celestial sphere exactly into two parts. Note that the *visible* horizon of buildings, trees, towers, hills, and so on, is not exactly the same as the celestial horizon. Such objects limit the view. And in a valley, even less will be seen. From spacecraft, more than half of the celestial sphere can be seen. As a space vehicle moves away from the earth, more and more comes into view until at 20,000 miles from the center of the earth, all but one per cent of the celestial sphere is seen.

Before going on to Chapter 3, it is advisable to review the major ideas developed in this chapter. The review may be done in several ways. For example, teacher-directed discussion may be desirable for stimulating students to make general statements of what they have learned. Questions such as the following would be appropriate:

1. Can you describe the apparent motions of the moon and the sun?
2. What kind of motion do the stars seem to have?
3. What measurements are necessary to plot the position of an object in the sky?
4. In what ways can we plot the motions of the sun and moon?

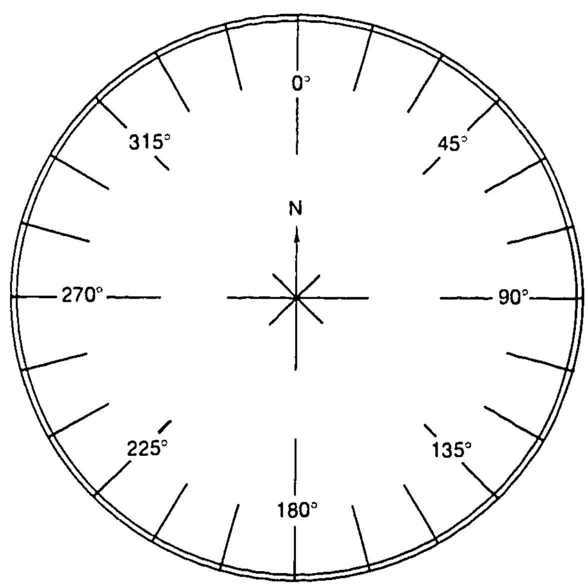
Another kind of review may be developed by the students themselves. For example, they can set up problems of measuring the bearing and elevation of objects outside the classroom. Each student submits a problem taken from a particular reference point. The class can then form in teams to work out as many of these problems as is practical. A "jury" can verify the measurements.

A third kind of review is an oral expression of the position of objects. For example, "How would I record the position of an object due east, halfway from the horizon to zenith? (Bearing 90°, elevation 45°.) "If a shadow has a bearing of 15°, what is the bearing of the sun?" (195°.)

By the end of this chapter students should have sufficient facility with measuring bearing and elevation to work independently in making these measurements.

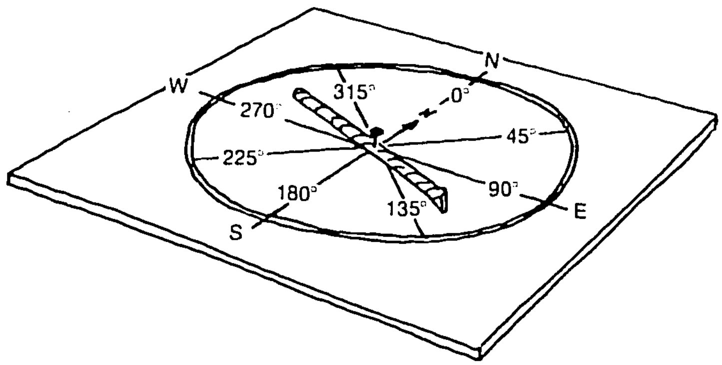
Supplementary Activities

SUPPLEMENTARY ACTIVITY 2-1 *page 13* Students may need help in relating bearing to the compass and to the degrees of a circle. The rosette illustrated here can be duplicated and used by each student for additional practice in measuring bearing. A thumbtack pushed up through the center of the circle serves as the pivot for the pointer—a drinking straw with one end flattened vertically.



28

When using the model make sure it is oriented properly with respect to compass directions. When estimating or measuring bearings, students should understand that they are standing in the center of the circle, where the tack is the pivot for the straw. In other words, bearing is taken from the center of an imaginary circle.



Using this model, or estimating from known compass directions, students can have additional practice as follows:

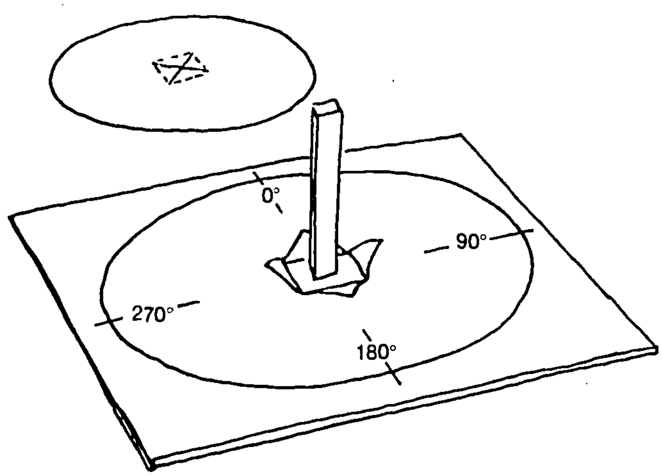
1. What is the bearing of a house southeast of you? (135°.)
2. What is the bearing of a tree northeast of you? (45°.)
3. What is the bearing of a telephone pole northwest of you? (315°.)
4. What is the bearing of the classroom door?
5. What is my bearing from where you are standing?
6. What is your bearing from where I am standing?
7. What is the bearing of the principal's office?
8. What is the bearing of the nearest supermarket?
9. What is the bearing of the sun at this moment?
10. What is the bearing of the flagpole from you?

Problems such as these will be likely to result in some interesting observations. For example, will the bearing of the classroom door be the same for all students? Bearing is taken from the observer's position. It would be impractical for all students to observe from one point. And so the bearing of the door will generally differ from one student to the next. Another interesting observation will be that if an object is fairly close, differences in bearing from two close observers may be appreciable. On the other hand, if an object is far away, small differences in the position of the observers will not affect the observed bearing.

SUPPLEMENTARY ACTIVITY 2-2 *page 15* Students may need practice finding bearings of shadows, and bearings of the objects that give off light causing shadows. Using a flashlight and the gnomon in the classroom provides many opportunities for developing skill in using a shadow and a compass to find the bearing of a "sun."

SUPPLEMENTARY ACTIVITY 2-3 *page 15* Once children become familiar with the fact that the sun's bearing is directly opposite the bearing of a shadow, the rosette on page 27 of this *Guidebook* may be used to read the sun's bearing.

Cut an X in the center of the rosette and slip it over the gnomon until it rests on the base. When a magnetic compass is used as it is in the pupil's book, it is possible to measure the bearing of the sun directly because the point of observation is away from the vertical stick. With the gnomon placed at the center of the rosette, however, you can measure the sun's bearing only by measuring the bearing of the shadow and finding its opposite value.



To read the sun's bearing directly, rotate the rosette by 180°, setting the 180° mark at true north. Now the bearing of the shadow may be read as the bearing of the sun. In this case, measure the bearing where the middle of the shadow crosses the rim of the rosette.

SUPPLEMENTARY ACTIVITY 2-4 *page 15* For additional practice in measuring angles of elevation, use a flashlight and gnomon in the same manner as they are used in Supplementary Activity 2-2.

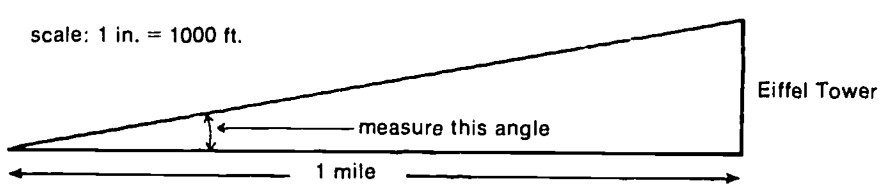
SUPPLEMENTARY ACTIVITY 2-5 *page 16* To help students understand more about the number of degrees between the horizon and the zenith, have them point one arm toward the horizon and the other directly overhead. By observing other students' arms they can see that the arms describe an angle of 90°. What will happen if they turn around? Is the angle different? Students will easily see that the angle between the horizon and the zenith is always 90°, no matter which way they are facing.

SUPPLEMENTARY ACTIVITY 2-6 *page 16* For further practice and discussion, students may work on these problems:

1. What is the angular elevation of a cloud halfway between the horizon and the zenith? (45°.)
2. What is the angular elevation of an airplane one-third of the way from the horizon to the zenith? (30°.)
3. What is the elevation of the top of a flagpole when it seems to be three-fourths of the way from horizon to zenith? (67½°.)

SUPPLEMENTARY ACTIVITY 2-7 *page 16* Objects in the classroom can be used to make estimates of angles of elevation. For example, from where a student sits, the elevation of the chalk tray will probably be close to 0°. It is on the "horizon." If the clock on the wall seems to be about halfway between the horizon and the zenith, its elevation will be about 45°.

SUPPLEMENTARY ACTIVITY 2-8 *page 16* An appropriate scale for a drawing of the Eiffel Tower's elevation would be 1 inch equals 1000 feet. The height of the Eiffel Tower may be rounded to 1000 feet and represented by a vertical line 1 inch in height. A horizontal line 5¼ inches long represents the distance of approximately 1 mile. The angle will measure about 11°.



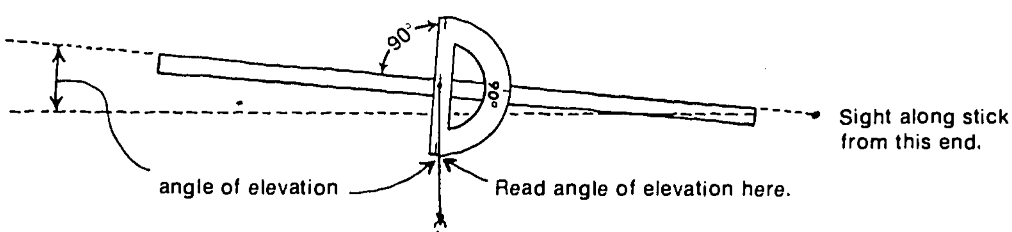
SUPPLEMENTARY ACTIVITY 2-9 *page 18* The following data were recorded at latitude 40° north in mid-July. Daylight-saving time was used. They should be used to plot the track of the sun on a graph if viewing conditions do not permit direct observation by your students.

Time	*Bearing*	*Elevation*
8:00 A.M.	84°	28°
9:00	94°	40°
10:00	106°	52°
11:00	122°	64°
12:00 NOON	150°	74°
1:00 P.M.	192°	76°
2:00	227°	69°
3:00	248°	58°
4:00	261°	46°
5:00	271°	34°
6:00	280°	22°

These data will differ from students' observations because of differences in latitude, differences in time of year, and differences in longitude within a time zone.

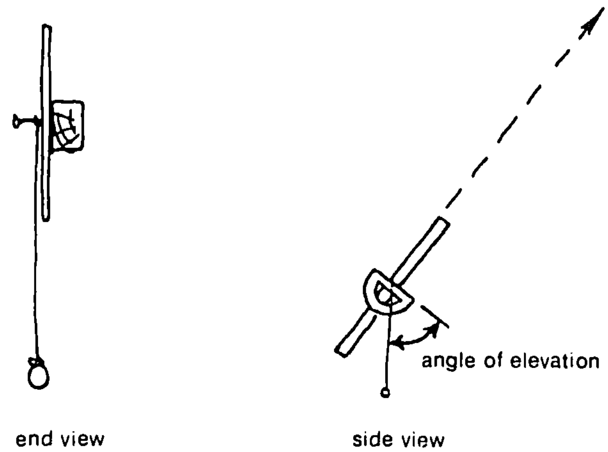
SUPPLEMENTARY ACTIVITY 2-10 *page 21* The path of the sun on the first day of spring and autumn can be shown by fixing just one straw at an angle of 90° to the pencil. Repeat the activity as before. On both of these days the bearing of the sun at sunrise is 90° (due east) and at sunset, 270° (due west).

SUPPLEMENTARY ACTIVITY 2-11 *page 24* A simple instrument for measuring the elevation of the daytime moon is shown below.

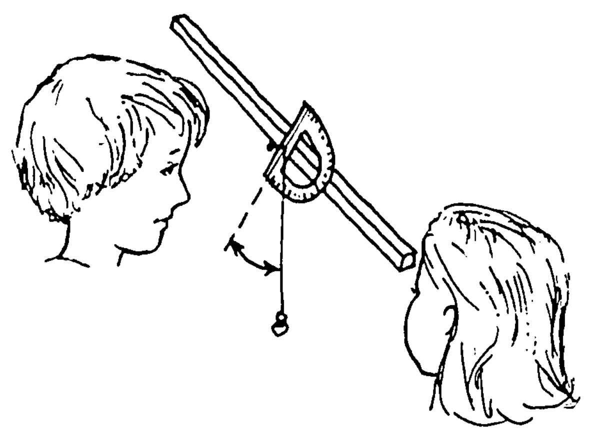


To build the instrument the following materials will be needed: a straight stick about 18 inches long, a protractor, a pin, some sewing thread about 12 inches long, and a small weight.

Mount the protractor in the center of the stick. Use clear tape to hold it in place. Make sure the 90°-line is parallel to the top of the stick. Work a pin through the reference point of the protractor until it is held fast in the wood. Make a loop in the thread and slip it over the pin. It should not fit tightly. Tie a small weight, such as a rubber eraser, to the other end of the thread. When the instrument is ready for use, the stick should be held so that the thread can swing freely along the face of the protractor.



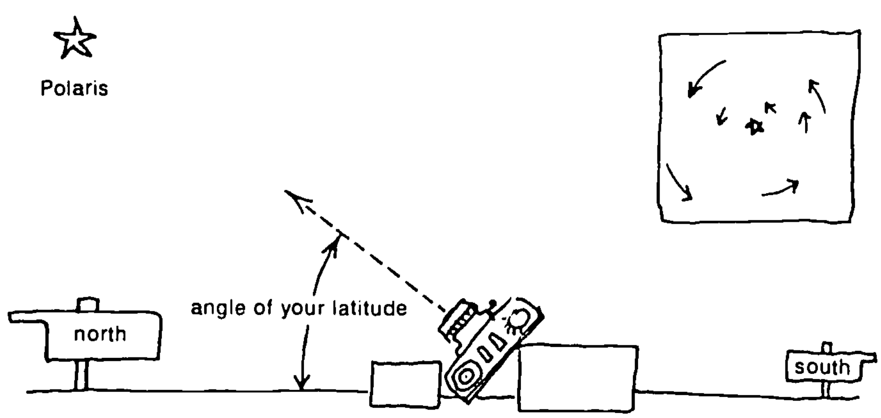
The instrument is best used by a team of two students. One student sights an object along the top of the stick. The other student reads off the degrees by observing the size of the angle formed by the protractor base line and the sewing thread.



With this instrument, the angular elevation of objects in the sky can be measured directly. The instrument may also be used to measure the angular size of objects standing on the ground. Using this instrument, students can measure the angular size of a flagpole or a steeple. How do the hand measurements compare with those made by instrument?

SUPPLEMENTARY ACTIVITY 2-12 *page 25* Students can get a good idea of the motions of stars if they are able to make photographs at night. To do this, it is necessary to use a camera that can be set for a time exposure. If a Polaroid camera is used, the photographs will be available for study the next day in class. Best results are obtained on clear, moonless nights.

Set up the camera with the lens bearing 'N' (facing due north). Polaris can be used as a reference point or a compass can be used. Remember that the magnetic declination must be taken into account when finding true north with a compass. Prop up the front of the camera until Polaris appears in the center of the viewer. If this is difficult, tilt the camera at an angle approximately the same as the latitude of your town. You may also mount the camera on a tripod with an adjustable head, if one is available.



When the camera is in position, carefully open the shutter. Leave it open for at least an hour. The longer the shutter is open the better will be the results. The camera should not be moved during this time. When the exposure is completed, the shutter should be closed. Develop the film. What is seen on the print? Ask students to explain the shape of the tracks made on the print.

CHAPTER 3

STAR PATTERNS IN THE SKY

pages 27-37

In Chapter 3 students begin to develop some familiarity with the major constellations seen in the sky. Using star maps in the book, students learn to find the major constellations throughout the year. Looking northward, students observe prominent polar constellations and find clues to the location of selected stars in the northern skies. Southern constellations are also considered as a part of the celestial sphere, but some of them are never visible from the United States.

It is not essential that work in this chapter immediately follow Chapter 2. Star patterns in the sky may be explored at any time that seems convenient for the class.

The activities in this chapter are best carried out over an extended period of time. It is recommended that your students move through the chapter very quickly and then go out on their own to stargaze once or twice a week during the course of the school year. You may plan a schedule of regular reporting by students on their observations so that stargazing activities can be continuous during the year.

The primary intent of this chapter is to expose the students to the excitement of exploring the constellations. With continued practice, they can become quite proficient in identifying the major constellations. They will be able to invent new ways of locating stars and constellations and will develop an interest in stargazing that should remain with them for many years. It is also hoped that teachers will share the excitement of students and will find time to join the students for stargazing parties—or go out stargazing on their own.

Main Ideas

1. The size and shape of constellations have not changed for many thousands of years. They will remain unchanged for thousands of years to come.

2. With respect to other constellations, the position of a constellation does not change during one's lifetime.

3. The positions of the constellations above the horizon vary with the seasons as well as during the hours of any one night.

4. The stars in the sky form a useful fixed background against which objects in the solar system can be observed

Suggested Materials

Star maps such as those on pages 28-33 of the text.

Suggestions for Teaching

At the end of this chapter (page 38 in this *Guidebook)* are notes on a number of important constellations that your students will be viewing in the nighttime sky. These notes are keyed to the sky maps (pages 28-33) on which the constellations appear.

Stargazing is most rewarding on a moonless night. Check a calendar to find the time of moonrise. It is best to wait until one hour after sunset before studying the skies.

Students should go out on their own, or in small groups, to try finding their way around the stars. Since it will be dark, a flashlight is necessary to refer to the maps. It is advisable to cover the lens of the flashlight with wax paper or tissue paper. Hold the paper in place with a rubber band. The dim light will be quite satisfactory for seeing the maps. Often an adult will be available to help — father, mother, scout leader, or other person who may be somewhat familiar with the constellations. If a planetarium is nearby, you should plan a class trip to see the sky show.

Supplementary Activities 3-1 and 3-2 introduced at this point will give class members practice in recognizing the major constellations they will be identifying during their stargazing sessions.

While the maps are drawn for 8 P.M. (standard time), discrepancies between sky and maps may occur, depending on your location in your time zone. However, these discrepancies will never be large. If you are on daylight-saving time on the date or your observations, subtract one hour to get standard time.

AROUND THE NORTH STAR

pages 34-36

Since the major part of students' stargazing will not be under the direct supervision of the teacher, it is advisable to help students develop a procedure for observing. A suggested procedure is outlined for the two activities which follow.

Page 34 Lead your class through the following steps with the map of the north polar constellations (page 28).

1. Find Polaris (bearing 0°).
2. Check with handspan to see if it is about 29° from nearest "pointer" star of the Big Dipper.
3. Measure its elevation with the handspan. Then measure elevation directly with an elevation instrument. (It should be nearly the same.)
4. What is your latitude? (It should be the same as the elevation of Polaris.)
5. Find Cassiopeia. (It forms a misshapen W.)
6. Rotate the map until it is lined up with the constellations you see in the sky.

If you are observing at an hour earlier than 8 P.M., the map should be turned clockwise 15° for each hour.

LOOKING SOUTHWARD

pages 36-37

Page 36 These activities provide opportunities to use the seasonal maps. If the autumn map is used, students should follow these steps:

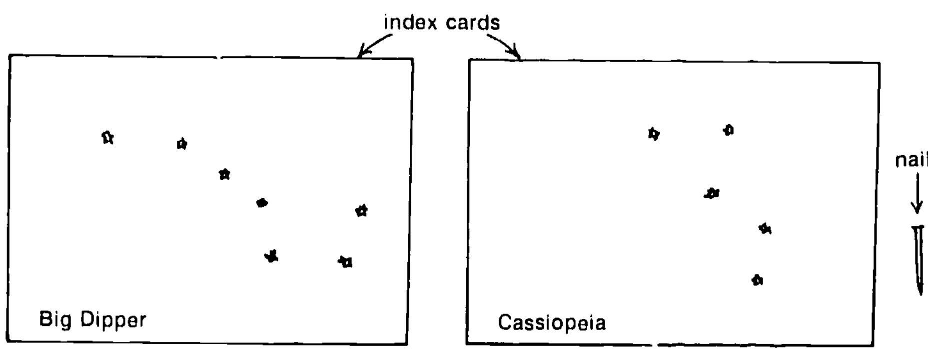
1. Face south (bearing 180°).
2. Hold the map in front of you with north at the top.
3. Find Cassiopeia.
4. Find Pegasus (somewhat southwest of Cassiopeia).
5. Find Pisces (somewhat southeast of Pegasus).
6. Find Aries (due east of Pegasus).

Students can use these landmarks to find additional constellations such as Cygnus, Capricornus, and others. Ask them to write out directions that other students can use. The remaining seasonal maps may be used in a similar way.

Note on the seasonal maps that *east* is to the *left* and *west* to the *right*, the opposite of geographical maps. The reason for the reversal is that we are looking from inside the celestial sphere outward, whereas on a geographical map we are looking downward at a portion of the earth's surface from outside.

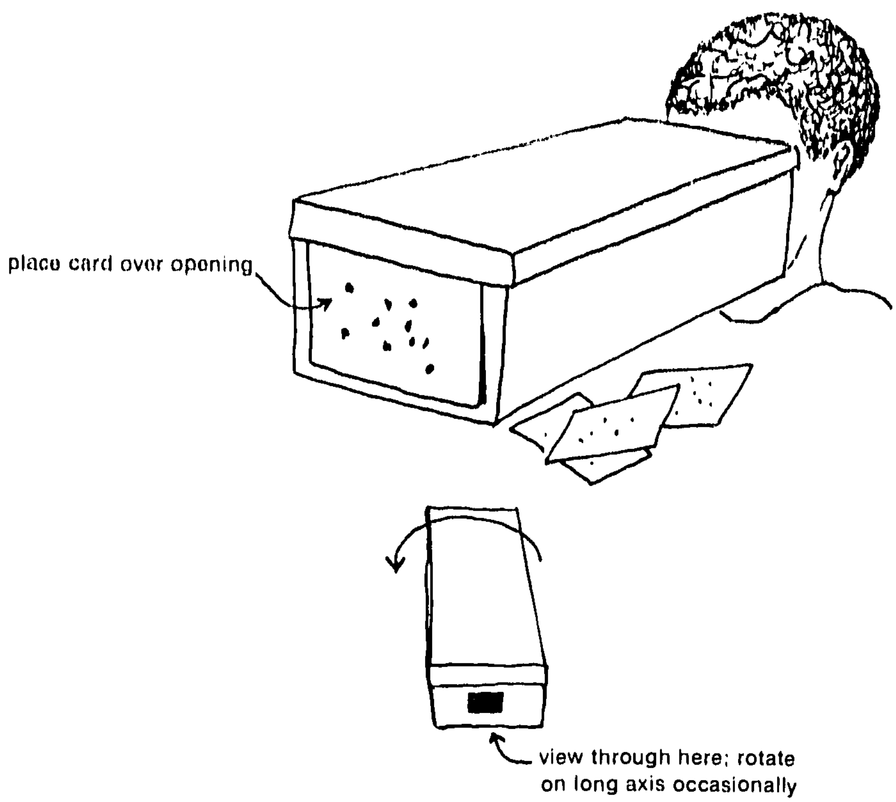
Supplementary Activities

SUPPLEMENTARY ACTIVITY 3-1 *page 34* Before students go out to stargaze at night it will be very helpful for them to practice recognizing the configurations of major constellations. For this purpose a number of different techniques can be devised. For example, use a nail to punch the shapes of constellations on index cards or 3″ × 5″ pieces of dark paper. Make sure the shape of the constellations is accurate. Refer to the star maps for accurate position and spacing of the stars.



Tape the cards of the constellations against the classroom window. Practice identifying the constellations. From time to time place the cards in a different order. With north polar constellations, mount the cards upside down, or on one side. The primary purpose of this is to accustom students to the shapes of the polar constellations regardless of their orientation in the sky. This skill is particularly important in identifying these constellations.

SUPPLEMENTARY ACTIVITY 3-2 *page 34* Other devices can be constructed by the students. Most "star boxes" are built in a similar way. A box or small carton is opened so that there is a window at one end. A peephole is punched in the other end. To view a constellation card, the card is placed over the window and the box is held up to the light. The group of "stars" is seen as it appears in the sky. If a star box is used, the polar constellation cards should be rotated as suggested above. Another way to effect rotation is to turn the box around its longest axis.



Star Maps

Following is a list of constellations that appear on one or more of the star maps. Included with each name is the English equivalent and a phrase describing the constellation. Constellations in boldface type are prominent in the sky because of their distinctive shapes or because of the brightness of some of their member stars. Only fifty-one constellations appear in the list and on these maps. There are actually eighty-eight altogether in the sky, but many are inconspicuous. The entire list can be found in encyclopedias.

THE NORTH POLAR CONSTELLATIONS *page 28*

Cassiopeia, the Queen (KASS-ee-oh-PEA-uh). Forms a slightly mis-shapen W.

Cepheus, the King (SEE-fee-us). Looks like a church and steeple.

Draco, the Dragon (DRAY-ko). Appears coily and serpentine with its head near Vega.

Ursa Major, the Greater Bear (ER-sa MAY-jer). The most prominent feature is the Big Dipper.

Ursa Minor, the Smaller Bear (ER-sa MY-ner). Shaped like a dipper, but only Polaris at one end and the two "Guardians of the Pole" at the other end are at all bright.

WINTER *page 29*

Argo, the Ship. Contains the second brightest star in the sky, Canopus, clearly visible in the United States only in the far south.

Auriga, the Charioteer (aw-RYE-guh). A prominent muffin shape with very bright Capella at one corner and the little trio known as the Kids as a subfeature.

Canis Major, The Greater Dog (KAY-nis MAY-jer). Is highlighted by Sirius, the brightest star in the sky.

Canis Minor, the Lesser Dog (KAY-nis MY-ner). Contains two stars, one of which is the bright star Procyon.

Columba, the Dove (kuh-LUM-buh). Located well to the south from most places in the United States.

Eridanus, the River (ih-RID-eh-nus). A long and tortuous stream beginning near Rigel and ending at the bright star Achernar, the latter visible in the United States only from the extreme south.

Gemini, the Twins (GEM-eh-nigh). Marked by two bright stars, Castor and Pollux, and more or less rectangular in shape

Lepus, the Hare (LEE-puss). A reasonably notable sextet south of Orion.

Orion, the Hunter (oh-RYE-un). The brightest constellation of all, with Betelgeuse and Rigel; a rectangle with a central belt of bright stars and a dangling sword of three fainter ones.

Perseus, the Hero (PER-see-us). Rather difficult to see, it somewhat resembles an evergreen tree; home of Algol, a star that varies in intensity about every three days.

Taurus, the Bull (TORE-us). Shows two major subparts — the Pleiades, a star cluster shaped like a tiny dipper, and the Hyades, a V-shaped assembly containing the bright star Aldebaran.

AUTUMN *page 30*

Andromeda, the Chained Maiden (an-DROM-uh-duh). The major feature is a prominent line of stars extending out from the Square of Pegasus; the location of the Great Spiral Galaxy of Andromeda is shown.

Aquarius, the Water-Bearer (eh-KWARE-ee-us). Rather faint and difficult to see.

Aquila, the Eagle (AK-weh-luh). A prominent diamond, distinctive because bright Altair is flanked by moderately noticeable stars.

Aries, the Ram (AIR-eez). Three stars look like a clock reading 4:45.

Capricornus, the Goat (cap-ra-CORE-nuss). A big, ragged triangle but there are no very bright stars.

Cetus, the Whale (SEE-tus). Overlaps the autumn and winter maps.

Cygnus, the Swan (SIG-nus). Is also called the Northern Cross, with bright Deneb at its top.

Delphinus, the Dolphin (del-FINE-us). A pretty little diamond.

Grus, the Crane (GRUHS). Is prominent only from the southern United States.

Pegasus, the Winged Horse (PEG-uh-sus). The most prominent feature is the Great Square of Pegasus.

Phoenix, the Bird of Fire (FEE-nix). Is notable only from the southern United States.

Pisces. the Fishes (PIE-seez). A faint constellation south of Pegasus.

Piscis Austrinus. the Southern Fish (PIE-sis aw-STRY-nuss). The solitary bright star Fomalhaut and a few fainter ones make an arrow.

Sagitta, the Arrow (sa-JIT-eh). A lovely little arrow not far from Altair.

Triangulum (try-ANGH-you-lum). A nice little elongated triangle.

SUMMER *page 31*

Boötes, the Herdsman (boh-OH-teez). A fine kite with bright, orange Arcturus at its base.

Corona, the Crown. A lovely six-star crown near Boötes.

Hercules, the Strong Man. A large constellation with six central stars resembling a butterfly flying westward.

Libra, the Scales (LIE-bruh). Rather faint.

Lupus, the Wolf (LOO-puss). Far to the south.

Lyra, the Lyre (LIE-ruh). Very bright Vega makes a small equilateral triangle with two other stars, and a parallelogram is appended.

Ophiuchus, the Serpent-Holder (oh-fee-YOU-cuss). Big, but its shape is not very distinctive.

Sagittarius, the Archer (saj-ih-TARE-ee-us). A splendid teapot with a handle to the east.

Scorpio, the Scorpion (SCORE-pee-oh). Beautiful and bright, with reddish Antares flanked by two nearby stars.

Serpens, the Serpent (SIR-penz). Its head south of Corona, winding down and around Ophiuchus and then up toward Aquila.

SPRING *page 32*

Cancer, the Crab. Relatively inconspicuous, but it contains Praesepe, the Beehive Cluster, a good test for the unaided eye.

Corvus, the Crow (CORE-vus). Looking like the mainsail of a sailing vessel, it is not bright but does have a very memorable shape.

Crater, the Cup. A faint group sitting on top of Hydra.

Hydra, the Water-Snake (HIGH-druh). Has a conspicuous head east of Procyon, then winds rather faintly across a large segment of the sky.

Leo, the Lion. Shows a fine sickle in the western part, with the bright star Regulus at the end of its handle and a nice triangle farther to the east.

Virgo, the Maiden (VUR-go). Looks something like a chair with the bright star Spica marking the base of the rear leg.

Ursa Major, the Greater Bear (ER-sa MAY-jer). Its most prominent feature is the Big Dipper.

Ursa Minor, the Smaller Bear (ER-sa MY-ner). Shaped like a dipper, but only Polaris at one end and the two "Guardians of the Pole" at the other end are at all bright.

THE SOUTH POLAR CONSTELLATIONS *page 33*

Ara, the Altar (AY-ruh). Makes a nice group of four.

Centaurus, the Centaur (sen-TORE-us). A big constellation highlighted by two very bright stars not far from each other—Alpha Centauri and Beta Centauri.

Crux, the Cross (KRUKS). The extremely well-known Southern Cross.

Triangulum Australe, the Southern Triangle (try-ANGH-you-lum aw-STRY-lee). A reasonably prominent trio.

Also included in the south polar map are the locations of our two satellite galaxies. The Small Cloud of Magellan is due south at 8 P.M. in early December and the brighter Large Cloud of Magellan is due south at 8 P.M. in early February. Neither can be seen from any place in the continental United States.

Objects within 25° of the center of the south polar map cannot be seen from any place in the United States. The map is included mainly to familiarize students with the major constellations seen from the Southern Hemisphere. Some students will have read about a few of the southern constellations such as the Southern Cross, or about the Clouds of Magellan seen near the south celestial pole.

CHAPTER 4

WANDERERS AGAINST THE STARS

pages 38-52

In this chapter the pupils' attention is focused on the apparent motions of objects in the solar system. These motions are observed against the fixed background of stars. Students plot the track of the moon as it moves eastward among the stars each day. They also plot the eastward motion of the sun through the constellations during the year. The looping motions of the planets are introduced as a basis for considering models of the solar system.

Main Ideas

1. The sun, moon, and planets are seen to move in relation to the fixed background of stars.

2. The moon orbits the earth once a month, moving eastward through the constellations.

3. The sun appears to move eastward through the constellations, following the same path from year to year.

4. Most of the time the planets move eastward against the stellar background. Periodically the eastward motions of planets seem to reverse. They go westward for a time, then resume their eastward motion, following a looped path against the stars.

5. The interval of time from one backward loop to the next backward loop is called the loop-to-loop period. Each planet has its own loop-to-loop period. Astronomers call the loop-to-loop period of a planet its synodic period.

6. The sun, moon, and planets move along the same narrow highway in the sky.

Suggested Materials

protractor ruler

Suggestions for Teaching

Your pupils may recall that the earth is not an exact sphere. Actually its polar diameter is about 27 miles shorter than its average equatorial diameter. As a result, the earth is slightly flattened at the poles.

Page 38 In this activity, pupils are challenged to describe the paths of objects that have more than one motion. Some motions are more difficult to describe than others. Pupils should try sketching the motions of other objects, such as a propeller tip, a horse on a moving merry-go-round, or a point on the rim of a wheel as the wheel rolls along the ground. How many different kinds of paths can your class think up?

MOON AGAINST THE STARS

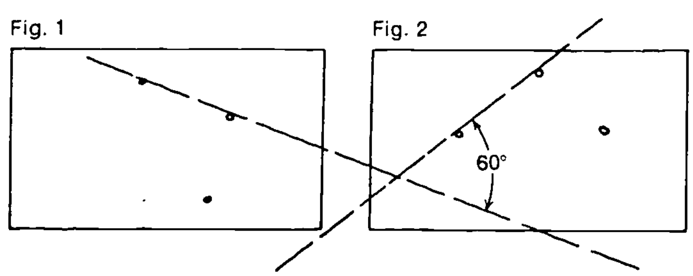
pages 38-42

Page 39 Students have the task of measuring or describing the ways in which the positions or apparent sizes of star groups have been modified. The activity is intended to help reduce the difficulty of using the star maps in Chapter 3, and to prepare for locating the moon. A protractor and ruler will be needed for the purpose of making accurate measurements.

In each of the examples in the first activity on this page, the "constellations" have been rotated, changed in size, or both. The first constellation has been rotated counterclockwise 40°. The second has been reduced to half its original size. The third has been rotated 180°. The last group of stars has been doubled in size and rotated counterclockwise 60°.

The rotation of some of the figures is easily estimated by inspection. For greater accuracy students can use the method illustrated below.

Fig. 1 Fig. 2

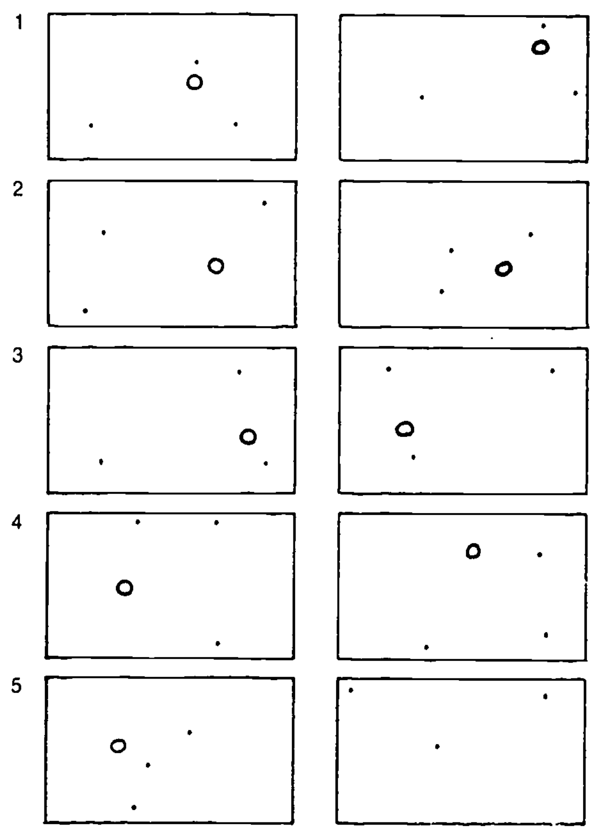


Draw a line segment through two stars in the first figure. Draw a line segment through the same two stars in the second figure. Measure the angle formed by the two intersecting lines. In this case the angle is 60°. This constellation has been rotated counterclockwise 60°.

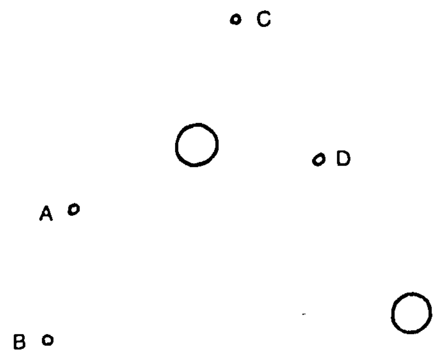
Supplementary Activity 4-1 provides additional practice in recognizing changes in the positions of constellations.

Page 39 The second activity on this page is similar to the previous one. A new element has been added, however—the moon.

In the first figure, the triangle has been moved upward and to the right. In the second it has shrunk to half its size. The third triangle has been rotated 180°. The fourth has been rotated clockwise 90° (or counterclockwise 270°). In the fifth figure, the constellation is twice its previous size and rotated counterclockwise about 120° (or clockwise 240°); the moon will be outside the frame.



Page 40 In this activity, pupils should merely estimate the moon's position from the data given. Notice that there are two possible answers, as indicated by the large circles.



Page 41 Before starting the moon-plot activity, check a calendar or almanac to find the date of the new moon. When the moon is full it is somewhat difficult to plot its position among the constellations. A full moon is too bright and star groups near it are not easily seen. A few days after the moon is new it will be found in the western sky shortly after sunset.

In planning for the first observation, your students should consider questions such as these:

1. At what time should the first sighting be made each night?
2. What kind of notation of position should be used?
3. What kinds of clues can be used to estimate position? (The same as was used in the preceding activities.)

Following the initial observations, the methods used to describe the positions of celestial objects should be reviewed. Comparisons of the first few observations will facilitate a check of your pupils' work, and may possibly uncover common measurement errors.

Have the students enter the estimated positions of the moon on star maps. The maps in Chapter 3 may be duplicated. Note that a scale indicating 10° of angular distance is found on the seasonal maps.

In one hour the moon moves its own diameter against the background of stars. Pupils may not be able to notice this small motion, of about one-half degree. In two or more hours, the change in position of the moon will be more noticeable.

Each day the moon will move about 13° against the stellar background. Plots made from night to night should show considerable motion eastward across the map.

Observations should be carried out over a period of at least a month. Pupils should make their initial observations at approximately the same time each night that they are observing. On cloudy nights no observations can be made, but students can estimate the positions from data collected on other nights.

To find the position of the moon on Wednesday night, place the moon halfway between the points plotted for Tuesday and Thursday. On Friday night, the moon will be on the same path as Tuesday, Wednesday, and Thursday but it will appear about 13° east of the Thursday position.

If conditions are not favorable for observation, the pupils should plot the moon's path from the data on page 42 of their book. Later, when conditions are more acceptable, they can go outdoors in the evening to collect their own data.

Page 42 If an overhead projector is available, it may be used to show students how the moon is plotted. Prepare transparencies of the star maps and use them for locating the moon's positions. An opaque projector may be used in a similar way.

To make a plot of the first position given for the moon (January 18), pupils should look through their star maps to locate the first reference point — Pleiades. This group of stars will be found on the map of the winter constellations (page 29). Note the scale of angular distance on the star map. Mark the moon's position 6° southeast of Pleiades. Mark the date at this position.

Continue to mark the positions of the moon on the star maps until all the positions are plotted. You will use all four maps on pages 29-32. When plotting the moon's position, disregard the names of the months at the bottom of the maps. The designation of the months is useful only as a guide for stargazing.

The path of the moon is a curved line through the constellations. Your pupils can estimate the positions of the moon for the nights of February 4 through 8. This can be done by using the known daily eastward motion of the moon as a clue and extending the curve. For example, on February 6 the moon would be halfway between the positions of February 3 and February 9 — somewhere near the southern region of Capricornus. Work out the positions for the other days.

After the moon plot is completed, notice how long it has taken the moon to make a complete trip against the stars. Your pupils will be able to see that one complete circuit takes a little less than a month. Remind the class that these observations were made at the same hour each evening.

The path of the moon through the constellations will be similar from month to month. Due to certain characteristics of the moon's orbit, it will return next month to the same region of the sky, but not the very same position as this month.

BACKGROUND INFORMATION *If moon plots are continued for more than a month, your class will make several discoveries. The moon takes about four weeks (27.3 days) to move around once against the stellar background. This is known as the* sidereal month. *In addition, the students may notice the phases of the moon. It takes about 29.5 days to go completely through its periodic phases (from new moon to new moon). This is known as the* synodic month. *The phases depend on the angular distance of the moon from the sun. For example, an observer on earth measures the angular separation of the moon and sun as 180°. In this position there is a full moon. When the angular separation is at its smallest, the moon is new.*

If students have carefully observed the face of the moon, they will have noticed that the same side of the moon is always seen from earth. This is because the moon's period of rotation is the same as its orbital period (one sidereal month).

SUN AGAINST THE STARS

pages 43-47

Students may experience difficulty understanding how the sun can be located between constellations. A very good device to help students visualize how the sun may be located in this manner is described in Supplementary Activity 4-2.

Page 46 The table on page 46 provides the boys and girls with fairly accurate measurements of the sun's position over a period of several years. The positions are to be entered on star maps and the path of the sun plotted by connecting the positions. Plots of the sun's positions should be made in a manner similar to that used for plots of the positions of the moon. Note the 10° scale of angular distance on the star maps. As you did with the moon, when plotting the sun's positions disregard the months printed on the bottom of the maps.

To make the first plot, pupils should look through their star maps to locate the first reference point—Spica. Plot a point 3° north of Spica to indicate the sun's position. Above the upper margin of the map write the month "October."

In this manner continue plotting the positions of the sun as given on page 46. Each time a plot is made, write the correct month in the upper margin above the sun's position. When all plots have been made, connect the points.

When the maps are completed, have your students study the positions and path of the sun. Questions such as these will help them arrive at some reasonable conclusions about the path of the sun:

1. Look at the compass points on the maps. In what direction does the sun move through the stars? (It moves eastward.)
2. Look at your maps and the dates in the table. How long does it take for the sun to come back to the same place against the stellar background? (One year.)
3. Find October 12th in the sun plot data. What do you notice about the position of the sun? (Every year it's in the same place at the same date.) What about December? (Again, it is in the same place on the same date.)
4. With your finger, trace the path of the sun through the year. What is the shape of this path? (The path is in the form of a gentle wave.)
5. Does the location of the path change? (The path stays the same from year to year. The sun's path through the stars is called the *ecliptic.)*

6. How many degrees around the celestial sphere does the sun travel in one year (360°.) How many degrees in one day? (About 1°.)
7. If the sun is 7° east of Spica on October 22, where will it be on October 23? (8° east of Spica.)

Refer to the months you have marked at the tops of the star maps. The sun is closest to Polaris on or about June 21, the beginning of summer. Looking at the track of the sun that was plotted on the star maps, the students can see that the sun is closest to Polaris when it is near Taurus, a daytime constellation in the summertime. The angular distance between the sun and Polaris is greatest on or about December 21, the beginning of winter. From the path of the ecliptic it can be seen that the sun is farthest from Polaris when it is near Sagittarius, a daytime constellation in the wintertime.

To understand what causes the difference between the summer and the winter tracks of the sun, use Supplementary [illegible] 4-3.

PLANETS AGAINST THE STARS

pages 47-52

Page 48 Planets usually may be distinguished from stars by the lack of twinkle; fluctuations in brightness and color are less apparent in planets. From the United States, planets are never seen in the northern skies. They are found in a narrow belt close to the path of the sun and moon.

BACKGROUND INFORMATION *Planets may be distinguished from one another by their color, brightness, and position with respect to the sun. For example, Mercury is quite bright, but it is so near the sun that it is difficult to locate. It may be seen shortly before sunrise or shortly after sunset. Venus is the brightest object seen in the sky (excluding the sun and the moon). It is white. Like Mercury, it is seen only before sunrise or after sunset. Neither Mercury nor Venus, of course, are ever on the opposite side of the earth from the sun so they are never seen in the midnight sky.*

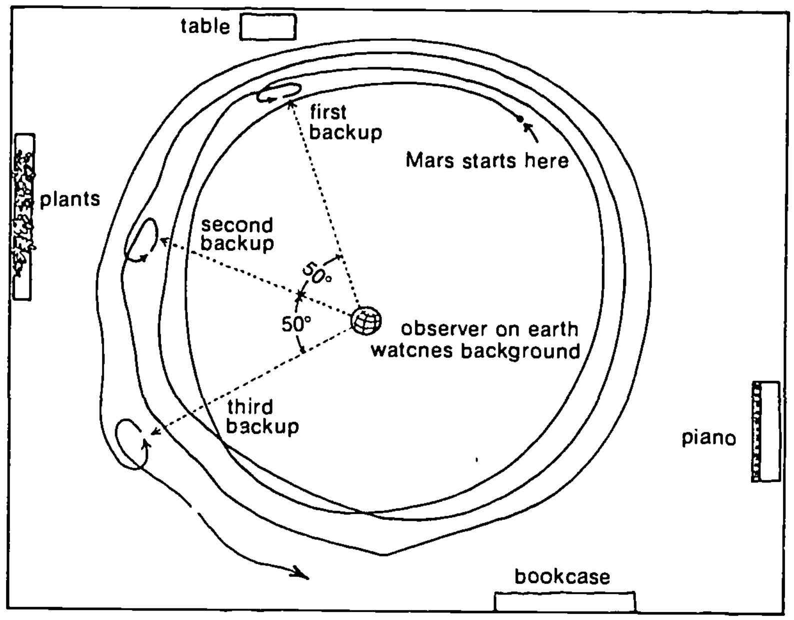
Mars is the "red" planet. It may be brighter than the stars, but this is not always a dependable clue. Jupiter is golden-white, and a bit brighter than the brightest stars. Saturn is white-to-golden in color. It is not as bright as the brightest stars.

For accurate information on where and when the planets appear in the sky, students may refer to a current almanac.

Supplementary Activity 4-4 uses a telescope to view the planets.

Students may be confused by the observed looping motion of Mars. Most of them are aware that planets move in nearly circular orbits around the sun and that these motions are in only one direction. For the present it will be sufficient for students to understand that planets only appear to loop periodically against the stellar background. In the chapters that follow, your pupils will have ample opportunity to discover why these apparent motions are seen.

Page 50 Students can observe the apparent backward motion of Mars by acting it out in the classroom. The illustration below is an example of the way in which this may be done.



To the observer in the center of the room, the pupil's path will appear as Mars' path appears from the earth. The walking student makes a complete circle of 360° and continues onward for 50° more. The walker (Mars) stops, backs up for a little while, and then resumes his forward motion. What background "constellation" was seen by the observer when Mars stopped the forward motion? In the illustration, the table was in the background.

From the point where his forward motion first stopped, Mars continues to move another 360° and again continues onward for 50° more. Once again the same stop, the back-up, and the renewed forward motion are seen. What "constellation" is in the background this time? In the illustration, the plant on the window sill was the background constellation. The same pattern is repeated over and over again. Each time the forward motion stops and a back-up begins, a different constellation appears in the background. After many re-enactments, students may be able to predict the next looping point and consequently the background constellation.

Page 50 Do not wait for the second activity on this page to be completed before continuing on in the book. The activity may also be done with Jupiter or Saturn which are fairly easy to identify among the stars. If enough observations are made, it will be discovered that these planets occasionally make a back-up loop.

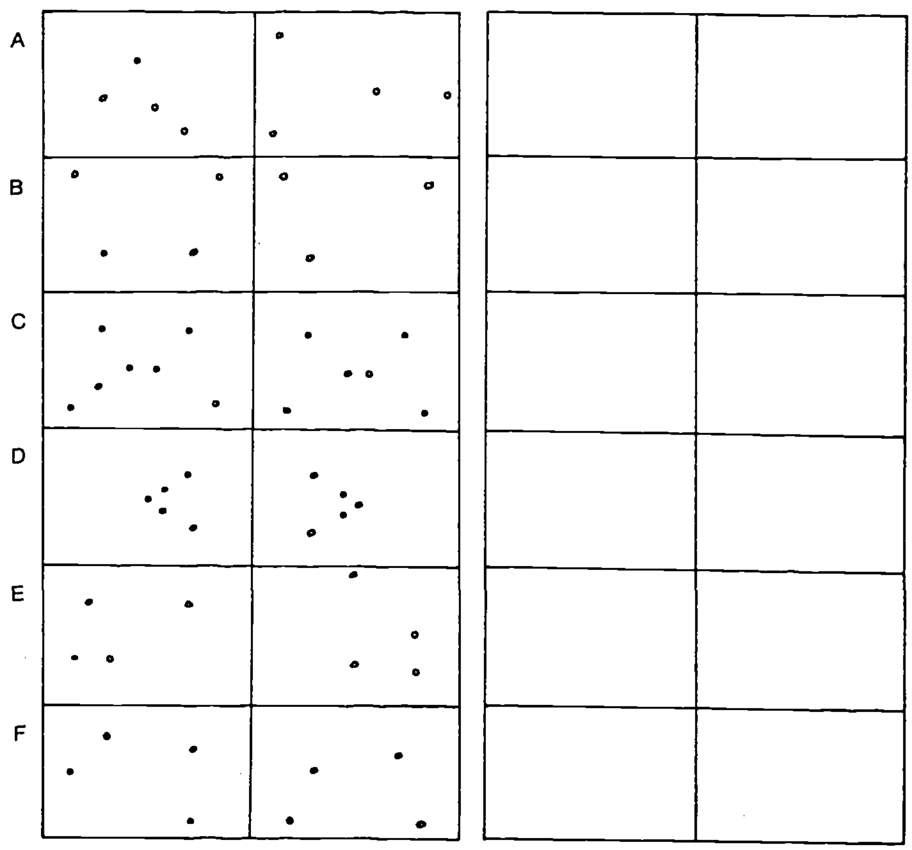
In addition to the apparent backward motion of Mars, the facts listed on pages 51 and 52 are a result of many years of observations, independently recorded and systematized by a number of people. Point out to your students that all of these events could be observed by them if there were sufficient time. The purpose of this section is to present to them some observations of planetary motions without attempting to make an adequate explanation. Students are likely to be puzzled and curious about the reasons why planets appear to move as they do. In the next chapter, Chapter 5, "Models of the Solar System," this problem will be explored in detail, and your pupils will soon begin to unravel these strange observations.

In concluding this chapter, it would be well to review with your class the major themes developed. The sun moves eastward through the constellations throughout the year. In one year it is back in the same constellation where it was observed the year before. Its path through the constellations is always the same, along the ecliptic. The moon, too, moves eastward through the constellations, but its motion is not exactly like that of the sun. The angular distance between Polaris and the sun varies with the seasons, influencing the duration of daylight with respect to latitude on the earth. The motions of the planets are along the ecliptic, but their motions eastward through the stars are not regular as is the motion of the sun. Each planet has its own loop-to-loop time. Planets are brightest when they are in the middle of their loops.

Supplementary Activities

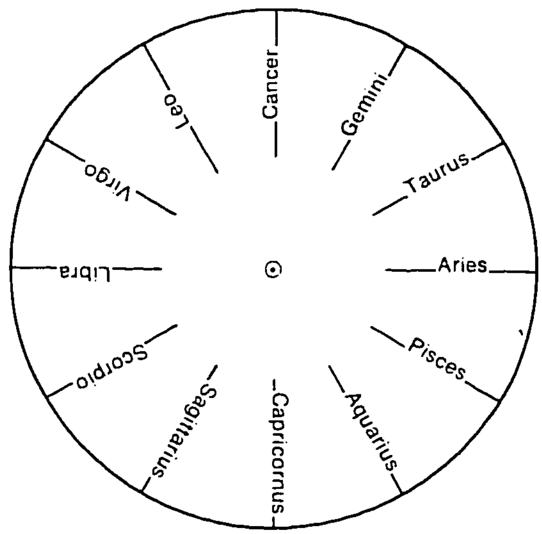
SUPPLEMENTARY ACTIVITY 4-1 *page 39* Prepare a stencil similar to the illustration you see here. In the left-hand section sketch in problems like those shown. Students can use the blank section to prepare problems of their own to test one another. Encourage them to work with as much precision as possible.

WHAT IS THE DIFFERENCE IN THE TWO CONSTELLATIONS?

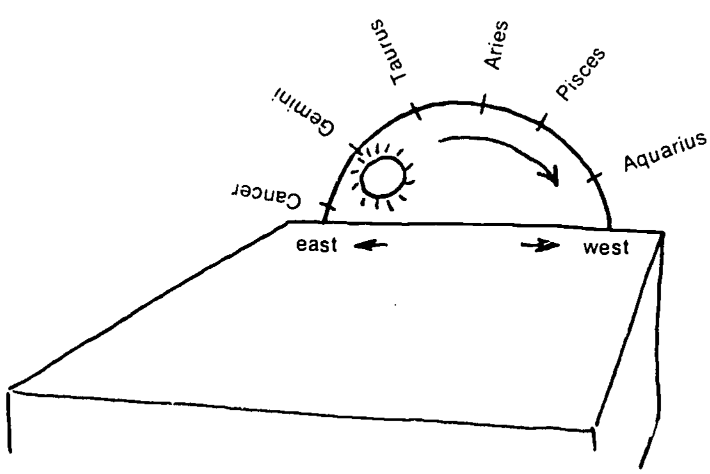


In the examples here, *A* is doubled in size and rotated counterclockwise 45°. *B* and *C* have a star left out. *D* is rotated 180°. *E* is rotated counterclockwise 90° (or clockwise 270°). *F* is rotated counterclockwise 20° (or clockwise 340°).

SUPPLEMENTARY ACTIVITY 4-2 *page 43* Cut out a disk of stiff paper or cardboard with a radius of about 6 inches. Make a small hole at the center of the disk. Letter the constellations of the zodiac around the disk as shown in the illustration. The constellations should run counterclockwise.



Mount the disk on the side of a box as shown in the second illustration. The center of the disk should be below the edge of the box. And it should turn freely. The edge of the box serves as the horizon. Any constellation above the edge will be above the horizon.



Now cut out a 1-inch disk to represent the sun. Place a little bit of rubber cement on the back of the disk and let it dry. Then fix the sun in position over one of the constellations. When the sun is "up," constellations above the horizon of the box will not be visible in the sky. They will be "blocked out" by the sun's light.

Facing the disk, rotate the constellations from east to west to stimulate the apparent daily motion of the celestial sphere. In the Northern Hemisphere, the sun is south, so east will be on the left. When the sun disappears below the western horizon, what constellation is seen in the western sky? Students will know that the sun is slightly west of this constellation.

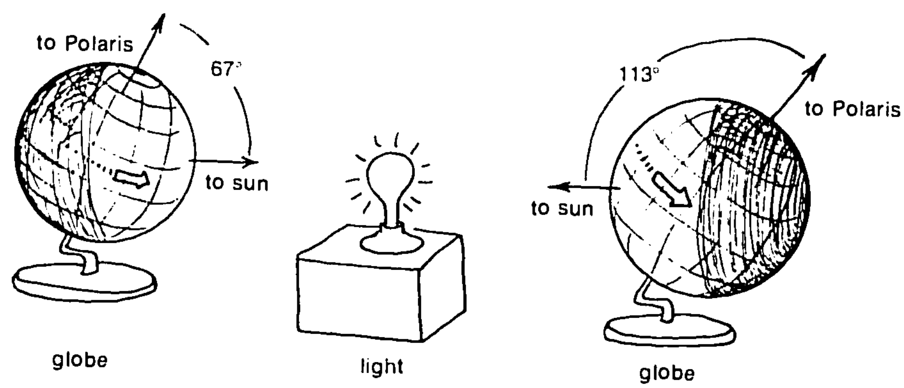
Continue rotating the "celestial sphere" until the sun reappears above the eastern horizon. What constellation was seen just before sunrise? The sun is slightly east of this constellation. When we can identify the constellations that precede and follow the sun, we know the sun must be between these two constellations.

For example, suppose Cancer is seen in the western sky shortly after sunset. Before sunrise Taurus is seen in the eastern sky. From the constellation disk, students can see that the sun must be between these constellations—in Gemini. Looking at the sky in July, that is what an observer would see.

Place the sun in other constellations to give your class an opportunity to find out what constellations the sun is between. This table shows the month during which the sun will be found near a particular constellation.

Month	*Constellation*	*Month*	*Constellation*
September	Leo	March	Aquarius
October	Virgo	April	Pisces
November	Libra	May	Aries
December	Scorpio	June	Taurus
January	Sagittarius	July	Gemini
February	Capricornus	August	Cancer

SUPPLEMENTARY ACTIVITY 4-3 *page 47* Set up a light to represent the sun. Place a globe about 3 feet from the light. Make sure the earth's axis is oriented as shown in the illustration. Place another globe opposite the first, the same distance away from the light. The axis should be oriented in the same direction as the axis of the first globe. When the light is turned on, observe that about half of each globe is illuminated.



Notice the globe at the left. The angular distance between the sun and Polaris is 67°. When the earth is in this part of its orbit, the Northern Hemisphere is exposed to more direct rays of the sun than the Southern Hemisphere and consequently receives more heat and light. Six months later the earth has moved halfway around its orbit. Notice the globe at the right. The angular distance between the sun and Polaris is now 113°. The Southern Hemisphere now receives more heat and light.

Call your students' attention to the north polar area of the globe on the right. Rotate the globe on its axis. How much light does this region receive? Pupils will see that it is dark for a complete rotation. When the angular separation of the sun and Polaris is 113°, it is wintertime in the Northern Hemisphere and continuous nighttime in the north polar area. Encourage your pupils to continue working with this model to find out more about seasons and polar days when the sun is 67° from Polaris.

SUPPLEMENTARY ACTIVITY 4-4 *page 48* Although a telescope is not necessary for students' tracking of planets, the use of a small but good telescope for observing Jupiter and Saturn will be a worthwhile experience. Through a telescope Saturn's rings can be seen nicely. Four of Jupiter's moons may also be visible.

CHAPTER 5

MODELS OF THE SOLAR SYSTEM

pages 53-65

The central theme of this chapter is the search for models to account for the observed motions of celestial objects. To explain the daily cycle of day and night, models of the relative motions of the earth and sun are considered. On a larger scale successive models of planetary systems are examined. Each model is seen as an attempt to represent reasonably the observed motions of objects in the solar system.

Main Ideas

1. Scale models help increase understanding of objects and events from very small to very large.

2. When only the earth and sun are considered, the occurrence of day and night can be explained in several ways.

3. Various models have been devised to account for the motions of the sun, moon, and planets.

4. Models are considered reasonable as long as the observed facts fit the models. The simplest model may be preferred.

5. When new facts of observation are discovered that do not fit an existing model or theory, the model or theory needs to be changed to account for these facts.

Suggested Materials

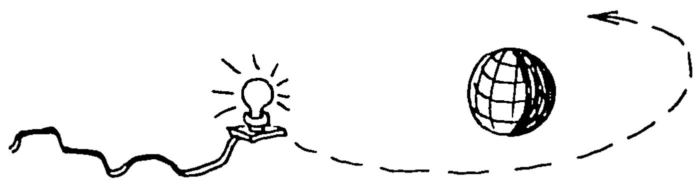
ball   lamp without a shade   flashlight   wire   clay

Suggestions for Teaching

MODELS OF DAY AND NIGHT

pages 54-56

Page 54 In the first model, the lamp must be carried around the earth in a circle. The time for one complete circuit is equivalent to a day. Seated on the floor in a large circle around the ball, the students will see the changes occurring on the face of the ball. Half the time the part of the ball they see will be light (daytime); the remainder of the time that same part of the ball is dark (nighttime). Students should notice the rhythm of day and night that recurs with the regular circling of the sun in the model.



Page 55 In the second activity, pupils are directed to formulate other sun-earth models that would account for day and night. With the sun stationary, two models will satisfactorily explain the occurrence of day and night. In one (Fig. 1), the earth spins on its axis but does not move around the room. In the second (Fig. 2), the earth does not spin on its axis but moves in an orbit around the sun once a "day." Both models are valid if the background of stars is not considered.

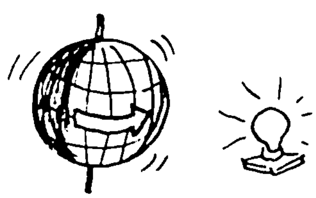


Fig. 1

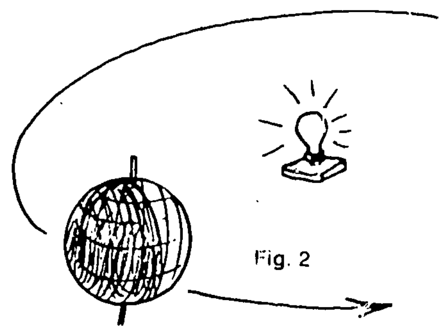


Fig. 2

Now, recall the annual motion of the sun against the stars as observed in Chapter 4, "Wanderers Against the Stars." With this information the model in Fig. 2 is still valid.

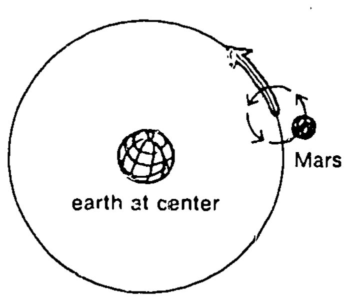
When reading about the Greek model (page 50), your pupils will find that the sun was known to be in different constellations throughout the year. Have them compare the facts observed by the Greeks with their plot of the sun's position among the stars. They will find that the sun has returned to the same position in the sky for thousands and thousands of years.

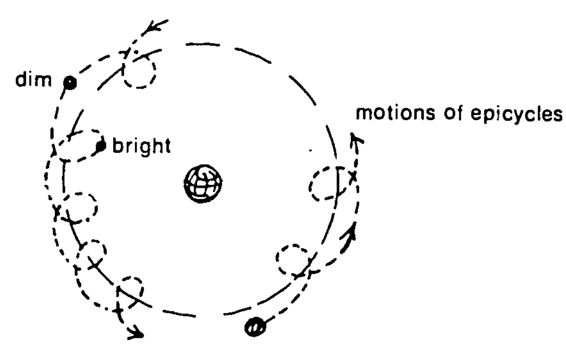
BACKGROUND INFORMATION *Claudius Ptolemy (TAHL-eh-mee) (about 150 A.D.) was an astronomer who lived in the Egyptian city of Alexandria. His work is known through an Arabic translation of his famous treatise, the* Almagest. *His geocentric model of the world used epicycles—circles on circles—to help explain the observed motions of the planets.*

Page 57 This activity provides opportunites for your boys and girls to develop a theory of planetary motion with the earth at the center of the universe. Your pupils should try to make pencil and paper diagrams before they make models or enact the schemes. Each new model should be tested against two observed facts: (1) Periodically, Mars appears to move backward, and (2) Mars appears brightest in the middle of its backward motion.

In the Ptolemaic system, the earth was considered motionless. It was at the center of the universe. It was neither spinning nor moving in any kind of orbital motion. A major premise of Greek astronomers was that celestial motion was "perfect." This perfect motion was circular motion at a constant speed. Encourage the members of your class to sketch their ideas and test them, using a system of circles.

In Ptolemy's solution, observed facts require that Mars move in a little circle which in turn moves in a bigger circle. The speed of Mars on the little circle must be greater than the speed of the little circle along the big circle if the effect of backward motion as seen from the earth is to be obtained.





Such a model also accounts for an additional fact—that Mars is brightest at the center of the backward loop. In this position it is closest to the earth and would appear brighter.

COPERNICUS

pages 58-62

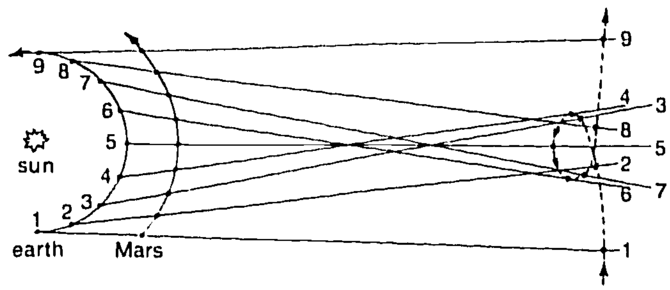
BACKGROUND INFORMATION Nicholas Copernicus (cuh-PER-nick-us) was a native of Poland. In his early years he studied law and medicine. Later he became interested in astronomy. His great contribution to this field was his heliocentric or sun-centered theory of the solar system which opposed Ptolemy's earlier geocentric or earth-centered system.

Copernicus did not strive to have his theory published. Eventually, however, it was printed through the efforts of a Protestant scholar and a Lutheran priest who knew Copernicus well. The completed publication is said to have been given to Copernicus just hours before his death in 1543 at the age of 70.

His system was considered by many people to be simpler. It finally found acceptance, although there were objections both on religious and astronomical grounds.

Page 59 The activity on this page is an enactment of the Copernican model of the solar system. This activity may also be duplicated indoors with some stationary object taking the place of the flagpole. The essential feature of this model is the way the central object (the sun) seems to move against the fixed background. As pupils dramatize this model, ask them to find out how much of a circle must be traveled before the flagpole appears against the same background again. They will find that they must travel through 360° before the flagpole is seen against the same "stars."

Emphasize the major premises of Copernicus as contrasted with those of Ptolemy. In the Copernican system (pages 59-60), the sun is motionless at the center of the universe. The earth spins from west to east on its axis once a day, accounting for the observed daily motions of celestial objects from east to west (except meteors and, at the present time, nearby earth satellites). The spinning earth moves in an orbit around the sun once a year. Other planets do the same, but they orbit the sun at different distances. Some move more quickly than others. All orbits are thought to be combinations of circular motion.



How does this model account for the apparent back-up motion of Mars? Mars' backward motion can easily be explained if the earth is moving at a greater velocity. Pupils can test this model on the playground.

Supplementary Activities 5-1 and 5-2 help reinforce the Copernican explanation of the loop-to-loop motion of Mars.

Page 61 This activity reinforces a youngster's understanding of the reason for Mars' increase in brightness. Your class knows that brightness is related to distance.

For best results, cover the lens of the flashlight with a piece of waxed paper or tissue paper. "Mars" should point the flashlight directly at the observer's eyes. To "earth," the light will become brighter as he catches up to "Mars." When "earth" is closest to "Mars," the light is brightest. As "earth" pulls ahead (and away from) "Mars," the light becomes less bright.

Most pupils know that Copernicus' scheme was the more accurate of the two contrasting models. At the time, however, there was no conclusive evidence that one model was superior to the other.

You will want to review with your pupils how it was possible to have two opposed, yet equally satisfactory theories. Each theory was supported by the available observations. Based on these observati ns, each theory attempted to explain the pattern of planetary arrangement. Furthermore, each theory attempted to explain the observations in the simplest possible terms. The following section will describe further gathering of evidence that began to tip the scales in favor of the Copernican model.

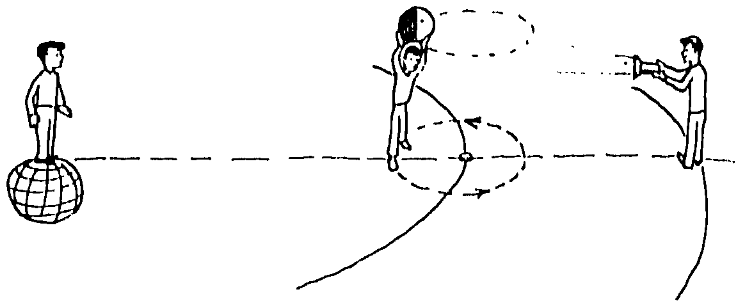
BACKGROUND INFORMATION *Galileo Galilei (gal-eh-LAY-oh) was born in Pisa in 1564. He received his early training in a Jesuit monastery. Then there were two years of concentrated study in mathematics followed by a series of teaching assignments in Pisa, Padua, and Florence.*

Galileo is well known as the first person to use an astronomical telescope. The observations he made of Jupiter and its moons and of the phases of Venus proved that the Copernican theory, not the Ptolemaic, was the correct description of the solar system. Galileo had favored Copernicus' heliocentric hypothesis all along but had not committed himself publicly for fear of being burned at the stake as others who were considered heretics had been. As it was, the Inquisition put him under "house arrest" because of his opinions. He lived in Florence until his death in 1642.

Page 63 Working with the wire and foil balls, students can make a fairly good model of the motions observed by Galileo. As the wire is slowly rotated, they will see the small ball move in one direction across the face of Jupiter. It continues, stops, reverses its direction, and then passes beyond the other side of the planet. It disappears behind the planet for a short time then reappears, still moving in the same direction. Soon it slows down, stops, and reverses again.

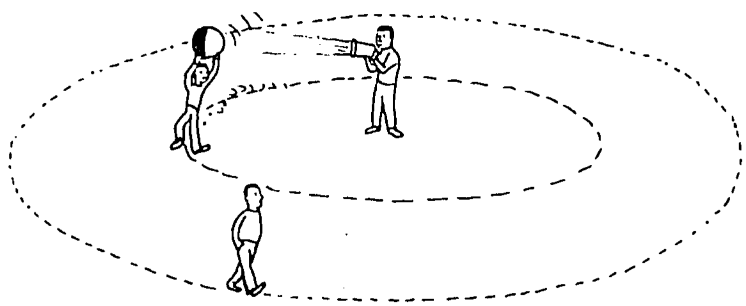
Up to this point the Ptolemaic and Copernican models seem equally valid. The invention of the telescope opened up new possibilities for observing the planets and for gathering additional data. Galileo's observations of Venus and its phases set the stage for re-examination of the two theories in light of the new evidence.

Page 64 Ptolemy's model, at the top of the next page, indicates placement of the sun and Venus with respect to the earth. A pupil should hold the ball representing Venus on his head and follow the Ptolemaic motions—a little circle on a larger circle. Work the activity in a darkened room. As "Venus" moves along its orbit around "earth," it also makes small circles. This double motion may be difficult for "Venus" to accomplish. The same effect may be observed if the motion of "Venus" and the motion of the "sun" are stopped from time to time to permit observation and discussion.



The "sun" will move along a path around "earth," always shining on "Venus." The "sun" must always be on a line connecting "Venus" and "earth." Now, direct the observer's ("earth") attention to the phases of "Venus." What phases are seen? Ask if "Venus" is ever seen as a complete circle? (From the observer's position on earth, Venus is seen to go through some phases but is never seen as a complete circle of light.)

Copernicus' scheme is sketched below. Enact the model according to the Copernican system. The "sun" is in the center, always shining on "Venus." "Venus" moves in orbit at a steady speed. Farther from the "sun," "earth" orbits somewhat more slowly than "Venus." "Earth" watches "Venus" to observe the phases.



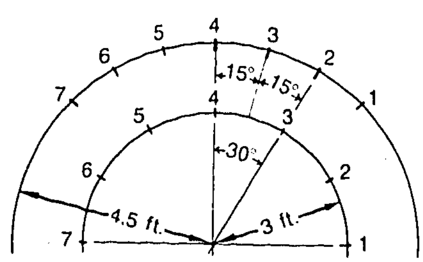
As motion starts, the observed phases of "Venus" will change. When "earth" sees "Venus" in full phase, both should stop their motions. Ask your students to notice their positions. What are the positions of Venus and the earth when Venus is "full"? (The two planets are on opposite sides of the sun.) Start the motions again. Stop them when "earth" sees "Venus" in the new phase. What are their positions this time? (Both planets are on the same side of the sun and about in a straight line with the sun.) In the Copernican system Venus can go through all phases.

By testing the models themselves, the students have learned that the Ptolemaic model could not account for all the observed phases of Venus. In the following chapter, your class will learn how additional evidence ultimately led to the abandonment of the model of Ptolemy and the refinement of the Copernican view of the solar system.

When reviewing the major ideas of this chapter, encourage your students to search for additional biographical material on Ptolemy, Galileo, and Copernicus. The lives of these men are relevant to the material in this chapter. In addition, their theories about the organization of the solar system represent an excellent example of the evolution of an idea. In this case each idea had merit until facts were observed which cast doubt on one of the hypotheses. Students may be surprised to learn that Ptolemy's theory was not easily abandoned. Only in the face of overwhelming evidence gathered later by Tycho Brahe and others did the Ptolemaic theory quietly die.

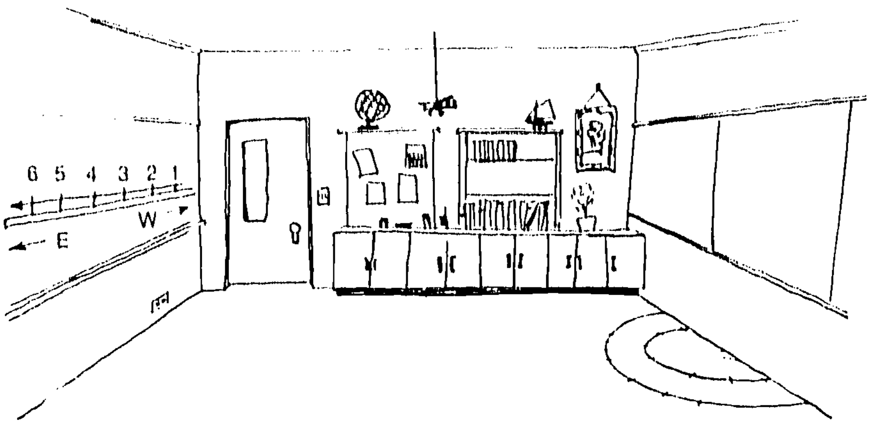
Supplementary Activities

SUPPLEMENTARY ACTIVITY 5-1 *page 60* Apparent back-up motion may be demonstrated in the classroom. At a point in the room opposite the blackboard, make two concentric semicircles with radii of 3 feet and 4.5 feet respectively. On the center of each arc mark a reference point. On the inner arc, mark three points on each side of the center point. The points should be 30° apart. On the outer arc, mark three points on each side of the center point. These points should be 15° apart. Number these points as indicated in the diagram below.



Draw a chalk line on the blackboard from one side to the other. Starting at the right side, place marks one foot apart all the way across the board. Number the marks in ascending order. This line will represent the stellar background.

One pupil stands on position 1 on the outer circle and represents Mars. "Earth" takes position 1 on the inner circle. "Earth" sees "Mars" against the background. Against what stars does "earth" see "Mars?" "Earth" calls out the number and it is recorded (or checked on the blackboard). When the observation is completed, the planets move to position 2 of their orbits. Where is "Mars" seen against the background? Continue this procedure until both planets have moved through all seven positions.



"Earth" should be able to observe the apparent back-up motion of "Mars." This should also be apparent to the class. "Mars" appears to move about the same distance eastward in the first two positions. Then it should slow up against the background, reverse its direction and move westward. Finally, from the last two positions it is seen moving eastward once again.

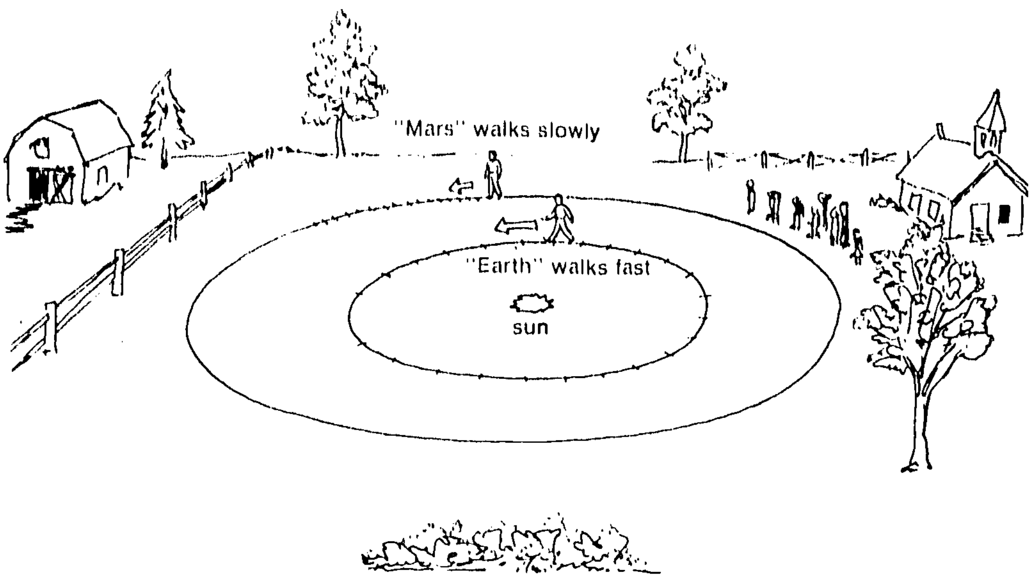
If the activity is repeated, other observations may be made. For example, in position 4 "Mars" is in the middle of its back-up motion. At this time "Mars" and "earth" are lined up with the "sun" (the center of the circles).

Now lead your class in a discussion of these questions:

1. When does Mars' angular motion seem greatest? (During its back-up motion.)
2. When is Mars seen to move very slowly? (At the times when it reverses its direction.)
3. How does Copernicus' model account for the increase in brightness? (Ask the children to notice where Mars is when it is exactly opposite the sun from the earth. Then it is in full phase. They will see that we are also closest to Mars at this time. As a result, this is when it appears the brightest.)

SUPPLEMENTARY ACTIVITY 5-2 *page 60* This activity is very much the same as that on page 59 in the pupil's edition. Simply place an extra pupil in an "orbit" which is at a greater distance from the "sun" than "earth" is. Start them around in their circles. "Earth" is moving somewhat faster than "Mars." As "earth" watches "Mars," and the background behind "Mars," they are both moving. As "earth" approaches "Mars," he should watch "Mars'" motion against this background. "Mars" will slow down against the background, seem to stop and move backward against the background, and then move forward again as before.

Your pupils may have to go through these models of motion several times before they can readily notice the backward motion of "Mars."



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CHAPTER 6

TYCHO AND KEPLER

pages 66-91

In this chapter, students find out how Kepler used loop-to-loop times to calculate the orbital periods of the known planets. They see how Kepler searched for and found laws to describe the observed motions of planets. Students develop an understanding of how Kepler's laws provided sufficient support for acceptance of the Copernican theory of the solar system. As students share Kepler's quest, they experience some of the ways in which scientists search for proof.

Main Ideas

1. Tycho's accurate and systematic measurements of the positions of planets and stars provided Kepler with reliable evidence to test the Copernican theory.

2. Kepler discovered three laws of planetary motion which describe the orbits of planets.

3. Kepler's laws were consistent with the general Copernican scheme of the solar system, but modified the Copernican model.

Suggested Materials

drawing board or stiff cardboard string 2 thumbtacks
protractor ball ruler

Suggestions for Teaching

TYCHO

pages 67-68

BACKGROUND INFORMATION The Danish astronomer Tycho Brahe (TIE-*koe* BRAH) *is one of the most fascinating figures in the history of science. Born of noble family in 1546, he became interested in astronomy when there was an eclipse of the sun in 1560. While at Leipzig studying law in 1563, he observed a close approach of Jupiter and*

Saturn. According to computations of that time, the event should not have occurred in the way he observed it. It was clear to Tycho that astronomy was not yet as exact a subject as it might be.

Tycho was a rather tempestuous character and often had difficulties getting along with others. During his student days he and another young man argued so violently about the solution to a geometry problem that they settled the argument in a duel in which Tycho lost the end of his nose. He had a false nose-tip made of gold, silver, and wax.

Tycho's reform of astronomy consisted primarily of a careful and exact mapping of the heavens, especially the planets. In order to obtain more exact observations than his predecessors, Tycho constructed instruments of a size not previously attempted. One of the novel features of his establishment was a printing press which enabled him to publish and distribute his tables and treatises at once for the use of other astronomers. He worked near Jutland on the island of Hven until after the death of his patron. He spent the last years of his life in Prague as astronomer to King Rudolph of Bohemia. He died in 1601.

To help students visualize the tiny fraction of a degree Tycho was able to measure, see Supplementary Activity 6-1.

The time line on page 68 is included to help children develop some notion of the life spans of selected astronomers of the period.

KEPLER

pages 68-70

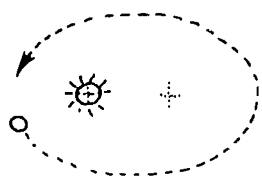
BACKGROUND INFORMATION *Johannes Kepler (yoe-HAHN-ess KEP-ler) was born in December, 1571, in the Duchy of Wurttemberg. His early schooling was irregular, but he finally obtained a bachelor's degree and a master's degree by 1591. He was originally intended to become a Lutheran minister, but he turned to mathematics and astronomy, accepting the post of provincial mathematician of Styria in 1594. His job consisted in part of preparing a yearly almanac that contained astronomical and astrological information as well as long-range weather predictions. Successful weather predictions made his reputation.*

In 1600 Kepler joined Tycho in Prague. After Tycho's death Kepler was made his successor. He held various other jobs and seems to have *been in constant difficulties with his noble patrons. He died in 1630 at 59 years of age. He was a fine interpretive scientist. He was a man of wild and fanciful ideas, but also abundantly endowed with caution. If the consequences of his ideas didn't fit the facts, he rejected his ideas — not the facts.*

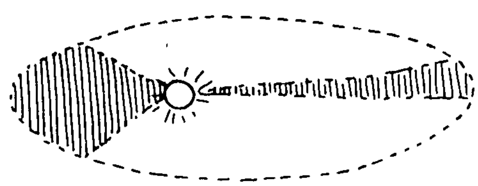
Kepler's three laws of planetary motion should not be quickly or superficially introduced to the class. Through the activities of this chapter, it is intended that students will first develop an intuitive understanding of the laws before the laws are actually stated.

Here are Kepler's laws of planetary motion stated in concise form:

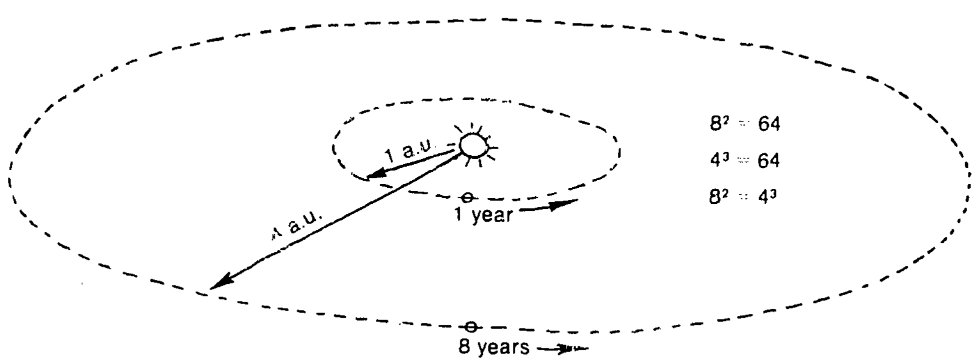
1. The orbit of a planet is an ellipse, and the sun is located at one focus of this ellipse.



2. A planet moves along its orbit so that an imaginary line joining the planet and the sun sweeps out equal areas in equal times.



3. For any planet, the square of the orbital period in years is equal to the cube of its average distance from the sun in astronomical units.



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Contrast the roles of Tycho and Kepler. Tycho was the great observer, the collector of facts about the motions of objects in the skies. Kepler used these facts of observation and interpreted them to form a general description of motions. He assumed that measurements taken with Tycho's instruments were consistent and precise. He also assumed that the measurements were made from a moving platform—the earth. Through class discussions your students should be led to realize that Kepler's work was based on these assumptions. Fortunately he was justified in assuming them, but during his time there was little positive proof to support them conclusively.

LOOP-TO-LOOP TIMES AND ORBITAL PERIODS

pages 70-73

Page 70 After sufficient experience with this activity, students should be given the opportunity to discuss what they have observed. The following questions will help students focus their attention on the relevant features of the motions.

What is observed from the earth? Mars appears to move against the background. However, when earth is overtaking Mars, Mars appears to be moving backward. When Mars is closest, it is in the middle of its backward motion. Earth, Mars, and sun are then aligned. Mars is opposite the sun. It takes one loop-to-loop period for the earth to overtake Mars again—when Mars is again opposite the sun.

What is observed from the sun? Earth and Mars move steadily around the sun against the background, but Mars moves at a slower angular rate. From time to time earth and Mars are lined up, and then earth moves ahead of Mars. The time interval between these alignments is the loop-to-loop period of Mars. Your students should understand that earth has gained one more lap on Mars each time the planets are aligned.

Page 71 The sample problem on this page is intended to develop your students' understanding of Kepler's method for calculating the orbital periods of various planets. The problem data are imaginary so that the computation is simple.

For further work with your class with planets Inner and Outer, see Supplementary Activity 6-2.

Certain regularities can be noticed in the table on page 73. Loop-to-loop times increase from the sun outward to the earth. Beyond the earth these periods decrease, but they never are less than one year. Another regularity is that the orbital periods increase steadily with the distance from the sun.

A more complete explanation of the relationship between distance and orbital period will follow later in this chapter when Kepler's third law is explored.

Supplementary Activity 6-3 will introduce the mathematically inclined members of your class to the computation involved in determining orbital periods.

THE ORBIT OF MARS AND KEPLER'S FIRST LAW

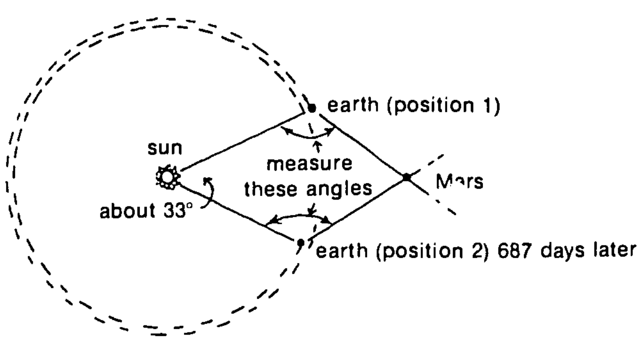
pages 73-79

BACKGROUND INFORMATION How Kepler was able to locate the position of Mars from pairs of observations is fully developed in the first book of this series, Charting the Universe *(see Chapter 6, "Charting the Solar System"). The following is a simplified explanation. It is not necessary to work it out with your pupils unless they are concerned about the procedure of plotting the Martian orbit.*

1. Every 687 days, Mars returns to the same place in its orbit.

2. In 687 days, however, the earth is not in the same place; it has moved to a different position in its orbit. In fact, these two positions make about a 33° angle at the sun.

3. From an observation point on the earth, the angle between Mars and the sun can be measured on two occasions, 687 days apart. Then one position for Mars can be plotted. See the diagram below.



Earth has not quite made two revolutions in 687 days.

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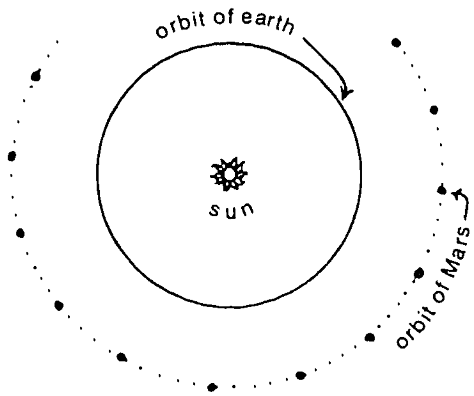
4. By using many such pairs of measurements, the Martian orbit may be drawn.



Page 76 In the activity on drawing ellipses, the students will probably start with stiff paper or cardboard. If possible, the paper should be at least 8½ by 11 inches. Larger paper, if available, will provide space for more experimentation. The string should be about 15 inches long for working on the small sheet of paper. Larger string lengths can be used for ellipses on larger sheets. The string should always be kept taut when the ellipses are being drawn.

Theoretically when the tacks are as far apart as possible but still inside the loop, a straight line would be formed. As the tacks are brought closer and closer together, the ellipses become more and more circular. When the tacks are together at the same spot, a circle is formed. Note that the plural of focus is foci (FOE-sigh).

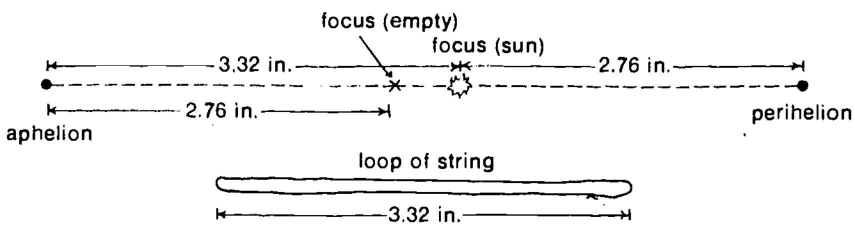
Use Supplementary Activity 6-4 at this point.

An astronomical unit (page 77) is defined as the average distance from the earth to the sun and is about 93 million miles. The average distance of a planet from the sun is defined as the distance from either perihelion or aphelion to the center of the ellipse.

The perihelion distance of Mars is 1.38 a.u. from the sun. The aphelion distance is 1.66 a.u. When these distances are added together and then divided by two, the average distance is found. In the case of Mars, the average distance from the sun is 1.52 a.u. Point out that aphelion, perihelion, the two foci, and the center of the ellipse all lie in a straight line.

Page 78 In this activity, students are directed to try to draw a scale model of the orbit of Mars. Stress the fact that perihelion is 1.38 units of measure, whether it is in terms of a.u., inches, miles, or any other unit. In the same way, aphelion is 1.66 units. Students may invent their own scales for the model. One satisfactory scale is 1 astronomical unit equals 2 inches. On this scale the orbit can be drawn on a sheet of 8½ by 11-inch paper. Larger scales will require larger paper.

Make a ruled line about 8 inches long. Near the middle of the line, mark an X as the location of one focus (the sun). Put perihelion 2.76 inches on one side of the mark and aphelion 3.32 inches on the opposite side. The "empty" focus will be 2.76 inches from the perihelion point.



Make a loop of string with the dimensions as shown. These dimensions fit the scale selected. Press a tack into each focus and loop the string over the tacks. As before, the ellipse is made with the pencil inside the taut loop, orbiting the foci. If the measurements are accurate, the orbit should pass through the perihelion and aphelion points. The chances are that small errors in measurement resulted in an orbit that didn't pass exactly through these points, but were close enough for the class to see how the scale model represents Mars' orbit.

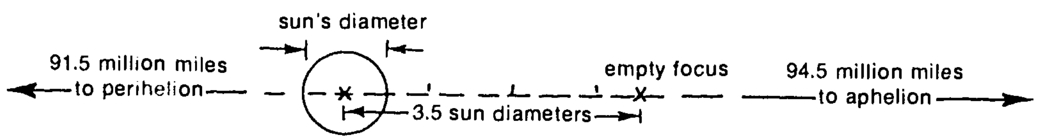
Place the point of a pencil compass at the center of the ellipse. Set the compass at the aphelion distance. Use the compass to draw a circle. Compare the two figures. By looking closely at their ellipses students can see that they are nearly circular but that they are not perfect circles.

Recall that both Ptolemy and Copernicus considered that the planets moved in perfect circles. What does the students' evidence show? Do planets indeed move in circles?

Here are the answers to the questions on page 79:

1. The average distance is 93,000,000 miles.

2. From the sun to the empty focus is 94,500,000 miles minus 91,500,000 miles, or 3,000,000 miles. Since the sun's diameter is approximately 860,000 miles, how many diameters are found in 3,000,000? When 3,000,000 is divided by 860,000 it equals approximately 3.5 sun diameters. Therefore, the two foci of the earth's orbit are relatively close together.



3. Mercury's average distance from the sun is 36,000,000 miles.

4. The empty focus of Mercury's orbit is 14,900,000 miles from the center of the sun, or about 17 sun diameters.

KEPLER'S SECOND LAW

pages 79-82

This section introduces the evidence that led Kepler to find the second law of planetary motion.

Page 82 The path taken by the students need only be roughly elliptical. Perihelion, or what you might call "peri-ball," is, of course, the closest point in the orbit to the ball at one focus.

NUMBER THREE OF JOHANNES KEPLER

pages 82-87

Distances and orbital periods of other planets are expressed in units of the distance of the earth from the sun (one astronomical unit) and the time it takes for the earth to make one complete orbit around the sun (one year) (*see* table, page 83).

Page 83 The graph used in conjunction with this activity includes only the first five planets. There is no known planet at a distance of 4 a.u. from the sun. This figure was chosen because it will be convenient for the students to use in the sample calculations. From the graph, the best estimate of the planet's orbital period is 8 years.

The quotation from Kepler (pages 84-85) serves to emphasize for the children that it took Kepler as long as seventeen years to develop his three laws of planetary motion.

In the first of the two puzzles on page 86, your pupils can think of a variety of ways to fill in the numerals of the set. All that is required is some consistent relationship among the numerals. Some possible sets are listed here. The students can discover others.

1, 2, 3, 4, 5, 6, 7, 8, 9.
1, 2, 3, 2, 1, 2, 3, 2, 1.
1, 2, 3, 3, 2, 1, 1, 2, 3.
2, 2, 3, 3, 4. 4, 5, 5, 6.
0, 2, 3, 5, 6, 8, 9, 11, 12.
1.5, 2, 3, 5, 9, 17, 33, 65.

As the students invent sets, ask them to submit them to the class in the form of their own puzzles. This will test the class and the puzzle maker. The intent of this activity is to help students realize that when data are limited, many conclusions may be based on the limited data. In this case the conclusions will certainly not be in agreement.

In the second puzzle it would be very difficult to think of any numeral but 6 to insert in the space. The rest of the data in the set are quite extensive and leave no room for anything else but the conclusion that 6 is the numeral that belongs there. Clearly, any rule made about the first puzzle would be based on rather sketchy evidence. But one can put the 6 in the second puzzle with a feeling of considerable confidence.

Page 86 Here are the points to discuss in the four examples:

1. For an average distance of 3 a.u., the graph gives the orbital period of just over 5 years (5.2 years). The cube of 3 is 27. The square of 5 is 25, and the square of 5.2 is 27.04. Rounded off, it is 27. So the cube of the distance (3) is equal to the square of the period (5.2): $3 \times 3 \times 3 = 5.2 \times 5.2$.

2. The average distance can be found on the graph. It is 2.1 a.u. The distance can also be found using Kepler's formula. If the period is three years, its square is 9. To find the distance one needs to find a number that, when cubed, gives 9. The number 2 is too small ($2^3 = 8$). The number 3 is much too large ($3^3 = 27$). The number must be very close to 2. If 2.1 is cubed the result is 9.261. This rounds off to 9. At a distance of 2.1 a.u., a spacecraft would orbit the sun beyond Mars' path.
3. The table on page 87 should be completed like this:

Imaginary Planet	*Orbital Period (years)*	*Average Distance from Sun (a.u.)*
V	2.8	2.0
W	4.0	2.5
X	5.2	3.0
Y	10.0	4.6
Z	11.2	5.0

4. The average distance of the object from the sun is 100 a.u. Cube the distance and the result is 1,000,000. What number squared is 1,000,000? This number is 1000. The orbital period of the far-out object is therefore 1000 years.

THE SPEEDS OF THE PLANETS

pages 87-91

This section, concerned with orbital speeds, is directly related to Kepler's third law. Be sure your students develop the understanding that inner planets move at greater orbital speed than outer planets.

Page 88 If you change the distances into feet in this activity, then the division is simple. Sam runs at 20 ft/sec and Chuck at 10 ft/sec. Therefore, Sam runs twice as fast as Chuck on the average.

Students need to know how to find the circumference of a circle when the radius is known (page 89). Circumference equals two times the radius times pi. In the case of the earth, the average distance from the sun is the radius of the orbit. Students may use the value of pi expressed as a mixed number (3 1/7), an improper fraction (22/7), or a decimal fraction (3.14). Multiplying the radius by pi and by 2, their calculations should result in a number approximating 580 to 590 million miles—a good estimate of the circumference of the earth's orbit.

To calculate the number of seconds in a year, the interested student should work out this problem: $60 \times 60 \times 24 \times 365 = 31.5$ million seconds per year. Finally, dividing 580 million miles by 31.5 million seconds results in a figure of about $18\frac{1}{2}$ miles a second. This is the earth's average orbital speed.

Page 90 Here are the main points of discussion for the problems on pages 90 and 91:

1. The first problem follows directly from the discussion on page 89. Notice the relationship between average distance from the sun and orbital speed. The first planet is *four times* the earth's distance from the sun. It travels at *half* the earth's speed. The second planet is *nine times* the earth's distance. It travels at *one-third* the speed of the earth. At a distance of 16 a.u. a planet would travel about one-fourth the earth's speed—about 4.5 mi/sec.
2. If the average speed of a planet is twice that of the earth, the planet is $\frac{1}{4}$ a.u. from the sun. The completed table found on page 90 will look like this:

Planet	*Distance from Sun (a.u.)*	*Fraction of Earth's Orbital Speed*	*Average Orbital Speed (mi/sec)*
Gamma	$\frac{1}{4}$	2	37
Earth	1	1	$18\frac{1}{2}$
Alpha	4	$\frac{1}{2}$	$9\frac{1}{4}$
Beta	9	$\frac{1}{3}$	$6\frac{1}{6}$
Delta	16	$\frac{1}{4}$	$4\frac{5}{8}$

From the table, your pupils may notice something else about distances and speeds of planets. The orbital speed of planets, compared to that of the earth, is the inverse square root of the distance in astronomical units. Few students are likely to state the relationship in this way. But many may see the numerical relationship between speed and distance in the table.

Below is a list of the planets, their average distances from the sun, and their average orbital speeds. The table may be duplicated and handed out to each pupil for the purposes of checking his table and for further discussion.

Planet	*Average Distance from Sun (a.u.)*	*Average Orbital Speed (mi/sec)*
Mercury	0.38	30
Venus	0.72	22
Earth	1.00	18.5
Mars	1.52	15
Jupiter	5.20	8.1
Saturn	9.55	6.0
Uranus	19.20	4.2
Neptune	30.09	3.4
Pluto	39.50	2.9

3. According to the text, an asteroid whose speed is half that of the earth must be 4 a.u. from the sun. To find the orbital period, use the formula $D^3 = P^2$. So $4 \times 4 \times 4 = 64$ and the square root of 64 is 8. Therefore the orbital period is 8 years.
4. The orbital speed would be zero. The farther out an object orbits, the lower its speed. An object infinitely far would have no orbital speed.
5. The closer to the sun, the greater the average speed. The orbit should be circular so the object will not strike the sun at perihelion. Orbiting at the surface of the sun, an object would have a velocity of about 270 mi/sec. At that distance, however, all known objects would be vaporized by the sun's heat. In actual practice, an object would have to orbit somewhat farther away from the sun. As a result, it would also move more slowly.

In reviewing this chapter with your class, it is advisable to recapitulate the central themes carefully. For your reference, these themes are summarized here:

1. Theory cannot advance beyond a certain point, or degree of refinement, until fresh and more accurate data are obtained. In most sciences, the data are obtained by doing experiments. In astronomy the

data are observational rather than experimental. The advances made by Kepler depended on the data collected by Tycho.

2. Kepler is an excellent example of the interpretive scientist at work. He was a man of wild and fanciful ideas, but he always drew the line; if the consequences of his ideas didn't fit the facts, he rejected his ideas — not the facts.

3. Kepler's three laws of planetary motion describe the orbits of the planets successfully, and we still use them today.

a. The orbit of a planet around the sun is an ellipse with the sun at one focus.

b. A planet moves along its orbit so that the line joining the planet to the sun sweeps out equal areas in equal times.

c. The square of the orbital period of a planet is proportional to the cube of its average distance from the sun.

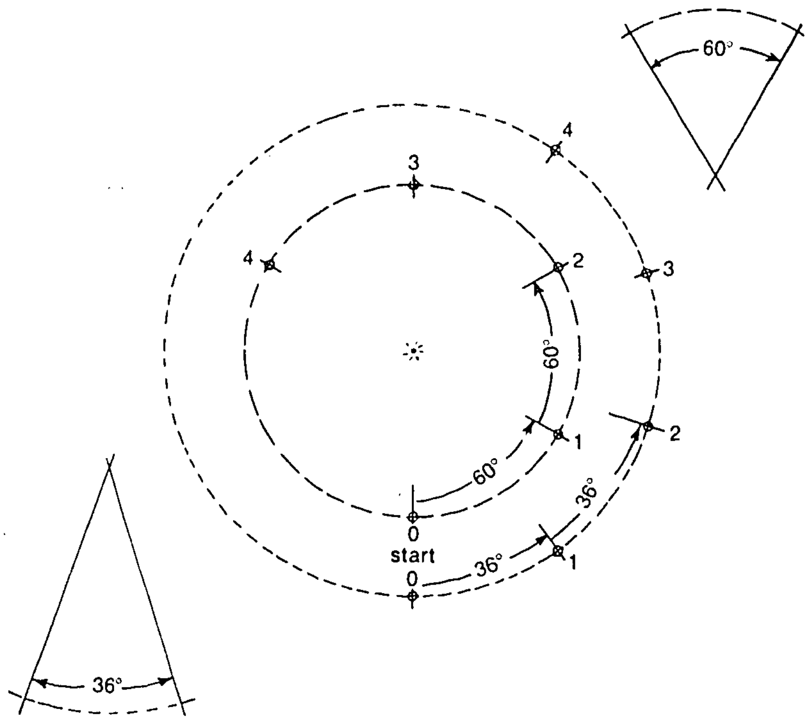
4. Kepler's third law requires a planet closer to the sun to move faster than one farther out. This consequence of the third law fits nicely with the general Copernican scheme of a sun-centered universe that is able to explain the retrograde motions of the planets.

Supplementary Activities

SUPPLEMENTARY ACTIVITY 6-1 *page 68* Draw a straight line 12 inches long. With a protractor, measure off 1 degree. Draw a second 12-inch line to form an angle of 1 degree. Draw a line connecting both sides of the angle, 12 inches from the vertex. Ask the students to use their tenths rulers to measure the length of the vertical line. It should be 0.2 inches long. Remind your students that this is a 1° angular separation at one foot.

How long would the vertical line be if the angle were 1/100th of a degree? The line would be one-hundredth the size of the present line, or about 2/1000ths (.002) of an inch. If a strand of hair is held one foot away from the eye, its angular width is about 1/100th of a degree.

SUPPLEMENTARY ACTIVITY 6-2 *page 72* The problem of Inner and Outer can be demonstrated with a chalkboard workup at the same time the pupils are making replicas of the orbital sweeps at their desks. Working on 8½ by 11-inch paper, pupils can make two concentric circles of about 2-inch and 3-inch radii, respectively. On the chalkboard, somewhat larger circles should be made with distances in the same proportion. If an overhead projector is available, this device is particularly well suited for a demonstration of this activity.



Cut out angles of 60° and 36° to fit on the circles to represent the angular distance Inner and Outer travel in 60 days. Choose two points even with each other on the circumferences as starting points. Mark their positions with zeros. Next, use the cut-out angles to mark the positions of Inner and Outer after 60 days. Inner will be 60° from its starting position, and Outer will be 36° from its starting position. Mark each next 60-day period in the same manner as the first. Remember to start from the position most recently marked. Find out how many days will pass before Outer returns to its starting point. (Outer will need 600 days.)

The illustration above simply indicates the patterns of motions of Inner and Outer. Plots have been made for only a 240-day span. Encourage your students to finish the plots of positions for a complete orbital period.

Below is a completed table of plots for the two planets. The table is intended for your reference only; it will help guide your students as they complete their plots of the planets' positions. Have the boys and girls complete their own charts from the diagrams and facts presented in the activity in the pupil's edition (pages 71-72).

Position	*Days*	*Degrees from Start*	
		of Inner	*of Outer*
0	0	0	0
1	60	60	36
2	120	120	72
3	180	180	108
4	240	240	144
5	300	300	180
6	360	360*	216
7	420	60	252
8	480	120	288
9	540	180	324
10	600	240	360*

*orbital period

SUPPLEMENTARY ACTIVITY 6-3 *page 73* If your students have sufficiently developed skills of computation, they will be able to calculate orbital periods. The calculation for Mars is given as an example here. Computations may be made for the other known planets.

For Mars the loop-to-loop time is 780 days. From the sun, earth is seen to forge slowly ahead of Mars each day, until it finally overtakes Mars once again 780 days later. Earth has gained a full lap on Mars; it has traveled one lap farther. So earth has gained a full 360° on Mars.

Earth took 780 days to gain the 360°. How much did earth gain each day? Earth gains 1/780th of 360° (0.46°) each day. Or we also say that Mars falls behind 0.46° each day.

From the sun the earth would be seen moving against the stellar background 1/365th of 360° each day (0.99°). While earth moves 0.99°, Mars seems to fall behind by 0.46°. So Mars' rate of speed must be 0.53° against the stellar background each day. In 100 days Mars will move 53° against the stars. In 200 days it will move 106°.

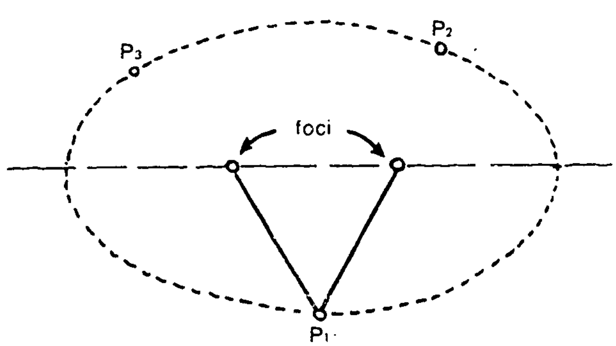
Now the problem is to find how many hundreds of days Mars will take to move 360°. This is easily found using decimal fractions.

$$360 \div .53 = 679 \text{ days}$$

This calculation indicates that Mars takes 679 days to complete its orbital period around the sun. The figure as calculated does not completely agree with that in the book (687 days). Ask students why there seems to be a difference. Actually, there has been some approximation of numbers in the angular rate of Mars. For the purposes of the problem, the calculated answer (679 days) is within reasonable limits of accuracy.

SUPPLEMENTARY ACTIVITY 6-4 *page 77* Here is an interesting characteristic of ellipses to investigate. Pick a point on an ellipse (P_1). Measure the distance from P_1 to each focus. Add the two distances and record the figure. Now do the same for two other points, P_2 and P_3. What do you notice about the sums of the distances? (If your students have measured accurately, they should find that the sums of the distances are always the same for one ellipse.) Will the sums be the same in other ellipses? Encourage your students to measure and find out.

Emphasize that each planet has one focus of its orbit at the center of the sun, but that each of the planets has its own second focus. The empty focus of a planet is at a different point in space than the empty focus of any other planet.



CHAPTER 7

MORE ON MOTIONS

pages 92-112

This final chapter of *The Universe in Motion* is concerned mainly with the observed motions of stars and galaxies. Students learn that most stars move in random directions in a nearly straight line. They will find that the sun is moving like a typical star. The billions of stars in the Milky Way galaxy are revolving in huge orbits about the galactic center. Students find that all known galaxies of the universe are in motion, rushing apart at enormous velocities. On the grandest scale, students begin to conceptualize motions in the entire known universe.

Main Ideas

1. With the aid of telescopes, scientists have systematically observed celestial objects beyond the solar system.

2. Observations made over a period of many years have provided information about the motions of stars and galaxies.

3. Kepler's laws of planetary motion are applicable in binary star systems.

4. On the average, stars in our galaxy are separated by a distance of about four light-years.

5. With respect to each other, most stars in our galaxy are moving in a straight line in random directions.

6. As part of a galactic system, stars orbit around the center of the galaxy.

7. Astronomers see a star or galaxy, not as it is today, but as it was when its light was emitted. This may have been billions of years ago for a distant galaxy.

8. Galaxies are moving away from one another at different velocities. The combined effect of these motions supports the hypothesis that the universe is expanding.

Suggested Materials

graph paper   cotton-tipped sticks   balloon   clay   string
paper tube

Suggestions for Teaching

FAR BEYOND THE PLANETS
pages 93-94

The questions found at the top of page 93 are not meant to be answered, but serve merely to help students develop a perspective for the evolution of ideas about the universe as accepted in the times of Ptolemy, Copernicus, and Kepler. Since Kepler's time, man has drastically modified his view of the universe.

BACKGROUND INFORMATION *The new conceptual ideas of the late 1500's seem to have begun with the speculation of Thomas Digges of England that the stars might be suns occupying three-dimensional space. Giordano Bruno of Italy liked this idea, too, and speculated that there might be men living on these stars or on other far-away bodies. Bruno was declared a heretic and was burned at the stake in 1600.*

Reference is made on page 93 to several ways in which data about stars are obtained. One method is measuring a star's parallax. This method of measuring distance was developed at length in Book 1 of this series, *Charting the Universe*. In Book 4, *The Message of Starlight*, students will learn more about how starlight provides clues to the composition and temperature of stars. For the present, you may wish to point out to your class the relationship between stellar temperature and color. In general, blue-white stars are hottest. Red stars are cooler. The colors of stars give scientists clues to their surface temperatures.

Page 93 This activity is intended to develop the concept of random distribution. This concept is useful for visualizing stellar distribution in a representative region of space.

Two ways of obtaining a random distribution of numbers are described for the pupil. The telephone-directory method works particularly well. Using this method, students will obtain completely different number pairs. As they plot the points, their graphs can be compared to see how a random distribution found by one pupil compares with the random distributions found by other pupils. Emphasis should be placed on the fact that if a pupil selects a particular method, he should use the same method consistently in choosing all his number-pairs from the telephone book.

When comparing plots of numbers picked at random, students will see that no two graphs look exactly alike. Points may be close together occasionally, but on the average they are separated from one another by similar distances.

A light-year is the distance light travels in a year. It is about 6 trillion miles or about 63,000 a.u. At an average separation of about 4 light-years, stars are approximately 250,000 a.u. apart.

THE MOVING STARS

pages 95-99

The essential reason that the map of stars changes so slowly is that the moving stars (except for the sun) are extremely far away. In the example given on page 96, a jet plane flying at high altitude would seem to move across the sky at a very slow speed. Near the ground, however, the same plane would appear to move against the background with tremendous speed. In a similar manner, a distant star may be moving many miles per second, but its angular rate across the sky would be so small it would take years to detect the changed position. In addition, part of the motion of any star may be toward or away from the observer. This motion may not be seen as motion across the face of the sky.

Brighter stars, on the average, are closer to the observer than stars that appear faint. As a result, the brighter stars appear to move at a greater rate of angular motion than fainter stars. The explanation for these observed differences in motion is developed later in this section.

Page 97 The activity at the top of the page is intended to help students visualize the relative motions of a nearby and a more distant object. It is easier to distinguish between the pencils if they are different colors. In addition, the pencils will be held steady if they are taped to the ends of a 12-inch ruler. The observer should stand a little distance to the side of the walker's path.

The observer will notice that the nearer pencil seems to be catching up with and passing the farther pencil. In other words, the nearer pencil has a greater angular rate of movement. Point out that the nearer pencil has the same velocity as the other pencil. It simply appears to move faster because it is closer to the observer.

In the second part of the activity, each observer will see the pencil closer to him move at a faster angular rate.

Page 97 This activity is designed to help students visualize the essentially random motions of stars. It will also reinforce and clarify the relationship between the distance to a star and its apparent rate of angular motion.

Students should prepare slips of paper with all combinations of three speeds and directions that include the cardinal compass points and the four points between the cardinal points. For example:

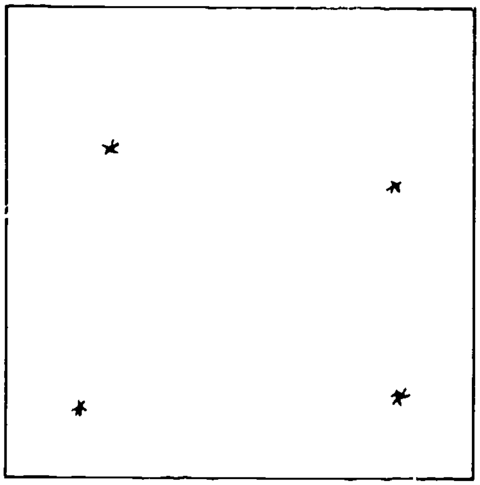
NW slow	N slow	NE slow
NW medium	N medium	NE medium
NW fast	N fast	NE fast

In all, there should be eight directions with three different speeds for each direction, making a total of 24 slips. Make two complete sets, a total of 48 slips.

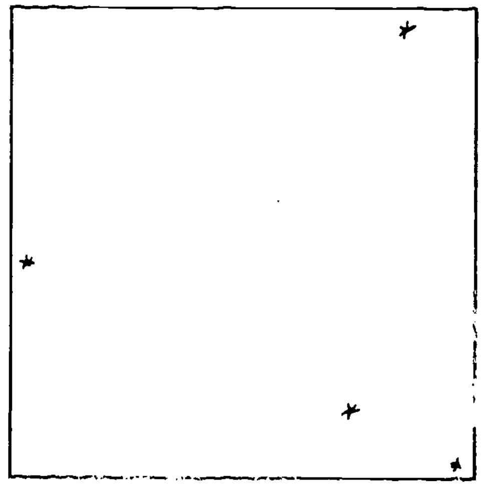
Before choosing the first group of "stars" (half the class), make certain that all your students know the directions and that they are agreed on the meaning of "fast," "medium," and "slow." Prepare the other pupils for more accurate observations by asking them to notice particularly the motions of near and distant "stars" against the background. Proceed with the activity as described on pages 97 and 98. Then have the "stars" and the observers change places. After everyone has had a chance to be an observer and a "star," give your students ample opportunity to report and discuss their observations.

The following observations are likely to be made in this activity. Other things being equal, the slower the speed, the slower the angular motion against the background. And other things being equal, the farther away the star, the slower the rate of angular motion. Also, stars moving toward or away from the observer have slower rates of angular motion.

To see what the Great Square of Pegasus will look like 200,000 years in the future, students can place a small square of tracing paper over the illustration on page 99. Tell them to make a mark at the tip of each arrow. Then have them compare the shape of the future constellation with the shape that is seen at present in the sky. The two constellations bear little resemblance to each other.



Pegasus today



Pegasus in [illegible],000 years

Working on this problem provides another opportunity to reinforce your pupils' understanding of the relationship between apparent angular motion and distance from the earth. Looking at their tracing paper, can pupils tell which star is probably closest to the earth? Ask them to explain why. (The star with the greatest angular motion is probably the closest.) Which star is farthest away? (Most pupils will pick the star with the smallest angular motion.) In nearly all cases they would be correct. But without additional information they cannot tell whether a slow star is moving chiefly toward or away from the earth. In these latter instances its actual velocity may not result in a fast angular rate across the sky.

If pupils assume that the direction and rate of motion of the stars of Pegasus remain unchanged, in a million years the four stars will not be recognized as members of the same constellation.

DOES THE SUN STAND STILL?

pages 99-102

The effect noted by Herschel (pages 99-100) may be difficult for some students to visualize. The analogy of a bus or automobile ride will give them a rough example of these motions. The analogy is not perfect, however, for the stars themselves are in motion, whereas the features on the landscape outside the bus are for the most part stationary.

Page 101 The observer's eye in this activity should be at desk-top level. As the observer moves "toward" the stars, they seem to be scattering apart. Stars on the sides scatter the greatest distance. As the observer moves "away" from the stars, the stars seem to move together. Stars on the sides move together most rapidly. It is important that each student have an opportunity to observe this effect.

Page 102 When your pupils go back to the schoolyard, they all draw slips and station themselves a good distance from one another. On signal they will walk according to the directions on the slips. They will be watching all the other "stars." They should notice that on the average the other "stars" seem to be moving backward against the background of trees and buildings. The greatest effect is noticed directly to the right and left of the observer, 90° on either side of the direction in which he is walking.

STAR-PAIRS IN MOTION

pages 102-103

BACKGROUND INFORMATION *Of the 60 nearest known stars, 9 are in three trios, 24 are in twelve pairs, and 27 are isolated. Thus these 60 stars may be considered as 42 systems. These systems are distributed at random, with typical separations between nearest neighbors amounting to four light-years.*

These points should be covered as your class discusses the two questions at the bottom of page 103:

1. There is little likelihood that the sun is a member of a star-pair. Another star like the sun, 1000 a.u. distant, would be about as bright as the full moon. Of course, no such star has been seen. The only condition under which we would fail to detect such a star would be if it were very distant and subluminous. So to the

best of present knowledge the sun is an isolated star, moving in its own direction at a constant velocity. However, the sun is, of course, attended by a family of planets.

2. There is no known danger of collision in the next hundred years. The sun moves at a velocity of about 12 mi/sec, which is roughly equivalent to 4 a.u. a year. In 100 years it would move 400 a.u. from its present position. Any star at that distance would certainly be noticed even if it were an extremely small and subluminous star.

The main point to be made is that space is extremely empty. The stars occupy about 1 part in 1,000,000,000,000,000,000,000 of the volume of space. The odds are something like one billion to one against the sun's colliding with another star in the next few billion years. This model may be contrasted with the fact that a single molecule in the air of the classroom has several billion collisions with other molecules every second.

THE WHEELING GALAXY

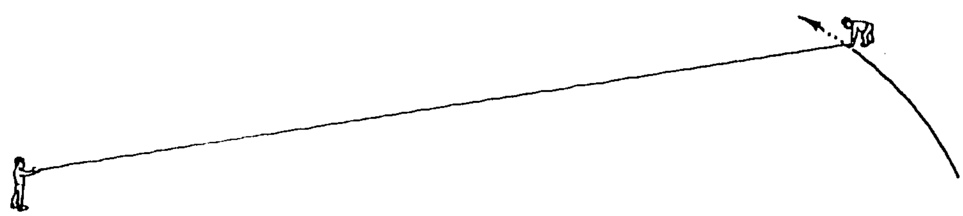
pages 104-107

A conceptual difficulty may arise when students find out about the relative motions of stars as members of the galactic system. Students learned that isolated stars are in straight-line motion. Now they find that stars are in a giant orbit around the center of the galaxy. How can this be explained? Teachers will recognize that the frame of reference in each situation is different. Previously pupils viewed stars in relation to a few stars around them. Now they are visualizing stars in relation to the entire galaxy.

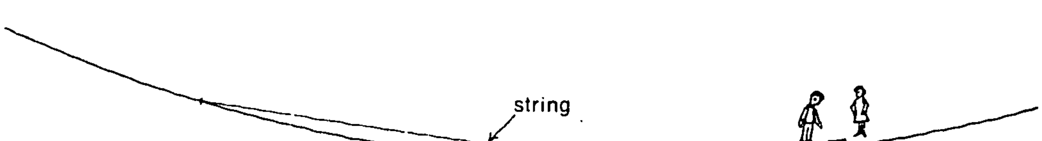
A useful analogy for students might be to pretend that they are on a very large, fast merry-go-round. If students are moving at random all over the merry-go-round, their individual positions relative to one another will change. With respect to one another they will move in all directions. But the overall effect would be that all pupils are moving in very large circles, in the same general direction, relative to the center of the merry-go-round.

An explanation is offered on page 105 for the fact that our apparent motion is in a straight line, but that our actual motion is in a large curved path. It is suggested that this concept be examined more carefully. Help your pupils to understand the contrast between straight-line motion on a time scale of centuries and curved motion on a scale of millions of years. The following activity is intended to clarify any misunderstandings.

Page 106 In this activity, pupils can draw a part of a very large circle. This is best done on the playground or in the gymnasium. Cut a piece of string 100 feet long. It may be shorter if space is limited. Tie one end of the string around a piece of chalk. The other end will be held by a child about 100 feet away. The string should be pulled tight and an arc of the circle drawn. The arc should be at least 8 to 10 feet in length.



Use a yardstick to measure off segments on the circle. Start with 6 inches as the smallest segment. The next segment should be 12 inches, the next 18 inches, and so on. Ask students to describe the shape of the 6-inch segment. Does it appear to be straight or curved? What will they observe about the shape of other segments? A fairly large segment of the circle must be seen to notice its curvature. The yardstick will not be long enough. Instead, use another piece of string stretched tightly between the ends of the segment.



FAR OUT AMONG THE GALAXIES

pages 108-109

For the remainder of the book, your pupils will be reading and thinking about the largest known units in the universe. The motions of galaxies are to some extent analogous to the motions of stars, except that distances and velocities are much greater. In general, galaxies do not collide. When collisions of galaxies do occur, the stars of one galaxy pass by the stars of the other galaxy without actual collision of the individual stars.

BACKGROUND INFORMATION *Astronomers study galactic collisions with the aid of radio telescopes. When galaxies are in collision, special radio waves are produced. Scientists on earth have learned to analyze the radio signals as a clue to what has happened between the galaxies billions of light-years away.*

THE EXPANDING UNIVERSE

pages 109-110

The story of the expanding universe is presented here in a descriptive way. Astronomers are able to estimate run-away speeds of galaxies by analyzing their spectra. Students learn how this is done when they study the Doppler effect in Book 4 of this series, *The Message of Starlight.*

It should be made clear that the expansion is a statistical, or average, effect. Any one galaxy will find a few of its nearest neighbors (four out of 600 for our own galaxy) approaching. But on the average, the recessional velocities are proportional to distances. Each galaxy moves in a straight line in a random direction at a typical speed of 50 to 100 mi/sec relative to its surroundings. Superimposed on these small random motions are the much bigger systematic expansions of great parts of the universe away from one another.

Supplementary Activity 7-1 may be used here.

Light from the galaxies may take millions or billions of years to reach the earth. To the astronomer this poses challenging problems. He is seeing the galaxies *as they were* when the light was emitted. So the information is ancient history when it gets here. We may be studying the light of some galaxies that have long since changed.

Here is a brief summary of the development of ideas about the motions of astronomical objects beyond the solar system:

1. After Kepler achieved his remarkably successful description of motions in the solar system, the next breakthrough on motions concerned the stars themselves.

2. Halley discovered in 1718 that stars themselves move; no longer could the map of the sky be regarded as completely fixed and unchanging.

3. Later in the eighteenth century, in 1783, Herschel found that the sun, like other stars, is also moving. Gradually the picture of stellar motions emerged: The nearby stars move among one another in random directions at various speeds, with a typical speed of 10 or 15 mi/sec.

4. In 1803 Herschel also discovered that Kepler's laws are applicable far beyond the solar system. Here and there in our galaxy are double stars, and they move around one another according to Kepler's laws.

5. The home galaxy is an enormous collection of about 100 billion stars; each star moves in a gigantic orbit around the center of the galaxy, taking hundreds of millions of years for each revolution.

6. The system of galaxies extends as far as we can probe. The system is expanding; the farther away a galaxy is, the greater is its outward speed.

7. As far as astronomers can tell, the universe of galaxies looks much the same whether you study it from here or from other galaxies. It is a good working hypothesis that no matter where you are in the universe you see galaxies all around you out to great distances, and that this universe of galaxies is expanding.

BACKGROUND INFORMATION *The largest optical telescope in the world is the Hale reflector at Mount Palomar, California; the diameter of its mirror is 200 inches. It can photograph galaxies several billion light-years away. The largest refracting telescope is at Yerkes Observatory, Williams Bay, Wisconsin. Another means of gathering evidence from great reaches in space is the radio telescope. Radio telescopes have also probed billions of light-years into space and are now gathering evidence to solve fundamental problems. Men are also building platforms for observing the universe from space. Now that the first daring* *steps in space exploration have been taken, we are beginning to learn more and more about planets, stars, and galaxies from instruments aboard man-made satellites orbiting the earth and the sun.*

Supplementary Activity

(A) SUPPLEMENTARY ACTIVITY 7-1 *page 110* As a rough analogy, blow up a balloon covered with dots. Assume that each dot has a slow random motion. Despite this random motion, the overall effect will be the same. As the balloon is blown up, each dot will be moving away from each other dot. Adjacent dots will move away from each other somewhat slowly. Dots separated by a greater distance will move apart much more quickly.

PRONUNCIATION GUIDE

Achernar	AY-ker-nahr
Alcor	al-CORE
Aldebaran	al-DEB-er-un
Algol	AL-gol
Alpha Centauri	AL-fa sen-TORE-eye
Altair	al-TAH-ear
Andromeda	an-DROM-uh-duh
Antares	an-TARE-eez
Aquarius	eh-KWARE-ee-us
Aquila	AK-weh-luh
Ara	AY-ruh
Arcturus	arc-TOUR-us
Aries	AIR-eez
Auriga	aw-RYE-guh
Betelgeuse	BET-'l-jooz
Boötes	boh-OH-teez
Brahe	(*see* Tycho Brahe)
Canis Major	KAY-nis MAY-jer
Canis Minor	KAY-nis MY-ner
Canopus	kuh-NO-puss
Capricornus	cap-ra-CORE-nuss
Cassiopeia	KASS-ee-oh-PEA-uh
Castor	KASS-ter
Centauri	sen-TORE-eye
Centaurus	sen-TORE-us
Cepheus	SEE-fee-us
Cetus	SEE-tuss
Columba	koh-LUM-buh
Copernicus	cuh-PER-nick-us
Corvus	CORE-vuss

Crux	KRUKS
Cygnus	SIG-nuss
Delphinus	del-FINE-us
Deneb	DEN-ub
Draco	DRAY-ko
Eridanus	ih-RID-eh-nuss
Fomalhaut	FO-mul-hoat
Galileo	gal-eh-LAY-oh
Gemini	GEM-eh-nigh
Grus	GRUHS
Halley	HAL-ee
Herschel	HER-shull
Hipparchus	hi-PAR-cuss
Hyades	HIGH-uh-deez
Hydra	HIGH-druh
Kepler, Johannes	yoe-HAHN-ess KEP-ler
Lepus	LEE-puss
Libra	LIE-bruh
Lupus	LOO-puss
Lyra	LIE-ruh
Mizar	MY-zar
Ophiuchus	oh-fee-YOU-cuss
Orion	oh-RYE-un
Pegasus	PEG-uh-sus
Perseus	PER-see-us
Phoenix	FEE-nix
Pisces	PIE-seez
Piscis Austrinus	PIE-sis aw-STRY-nuss
Pleiades	PLEA-uh-deez
Polaris	poh-LARE-iss
Pollux	PAHL-uks
Praesepe	preh-SEE-pee

Procyon	PRO-see-on
Ptolemy	TAHL-eh-mee
Regulus	REG-you-lus
Rigel	RYE-jull
Sagitta	sa-JIT-eh
Sagittarius	saj-ih-TARE-ee-us
Scorpio	SCORE-pee-oh
Serpens	SIR-penz
Shapley	SHAP-lee
Sirius	SEER-ee-us
Spica	SPY-kuh
Taurus	TORE-us
Triangulum Australe	try-ANGH-you-lum aw-STRY-lee
Tycho Brahe	TIE-koe BRAH
Ursa Major	ER-sa MAY-jer
Ursa Minor	ER-sa MY-ner
Vega	VEE-guh
Virgo	VUR-go