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ABSTRACT

This is the teacher's edition of one of the eight units of the Intermediate Science Curriculum Study (ISCS) for level III students (grade 9). This unit focuses on the properties of sunlight, the use of spectrums and spectroscopes, the heat and energy of the sun, the measurement of astronomical distances, and the size of the sun. Optimal excursions, in addition to the activities, are described for students who wish to study a topic in greater depth. An introduction describes light, inverse squares, orbits, and relativity in the sky. Illustrations accompany the text. (SA)

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Probing the Natural World/3

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INTERMEDIATE SCIENCE CURRICULUM STUDY TEACHER'S EDITION

In Orbit

Probing the Natural World / Level III

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ISCS PROGRAM

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An Introduction

Most people take the sun, the moon, and the stars for granted and leave them to those bearded old men who, they imagine, spend their nights gazing at the sky through telescopes. It will come as no surprise to you that there are very few bearded old men who spend whole nights at a telescope. Gazing through any telescope gives very little knowledge about the stars. Instead, astronomers, many of whom are very young, do much measuring of direction and angle, of light intensity and color, and of other qualities of celestial objects. You may have a student in your class who will think of you ten years from now while he stands beside the largest telescope in the world and photographs the spectrum of an object at the edge of the known universe.

In the meantime, all of us have been jolted out of our solid earth complacency by two very startling phenomena. In 1947, the first reports of "flying saucers" appeared. The believers and unbelievers are still trying to be as convincing and scientific as possible, but we all want to know if and where the saucers were seen and where they came from. In 1957, artificial satellites were first put in earth orbit. They stirred up the whole world to a conscious recognition that man is advancing beyond his own planet and that nations will compete for dominance in space. People who once confused astronomy with astrology now expressed interest in learning more about the sky and the objects in it. They wanted to know how large and how far away these bodies were and how fast they traveled. After all, perhaps everyone could have his own "saucer" for transportation, or could take a trip into space in a satellite. This desired knowledge of size, separation, and speed is really concerned with distance measurement in one form or another.

DISTANCES IN THE SKY

We have trained our eyes to estimate distances immediately around us. This is part of the skill needed in threading a needle. Furniture in a room helps with depth estimates because the sizes of chairs, tables, and pictures are familiar. In the open, we need familiar objects for reference. We know something about the height of a building by comparing it with automobiles on the street, or about distance when we see a house with a door or a window. But we can be fooled by a toy automobile or a dollhouse if there are no other objects for comparison T 3

For the sun and the moon, we have no familiar objects for comparison. We see them as bright disks in the sky, apparently of about the same size. They both subtend an angle of about ½° with the eye. If apparent size were an indicator of distance, we might argue that if it took three days to put a probe on the surface of the moon, we could put one on the sun in three days, too. But when either one approaches the horizon, where there are objects for comparison, we experience the common illusion of an enlarged appearance. Size, then, is a poor indicator of distance.

Part of our skill in estimating distances is due to having two eyes, set some distance apart. The angle that our eyes form with an object gives our brain a clue about the depth. As the distance from an object becomes greater, the angle formed by the lines of sight from our two eyes becomes smaller. At 1 meter, the lines of sight form an angle of about 4° with an object. At 10 meters, the angle has decreased to ½°; at 100 meters, it is only about 0.04° and has become too small to give reasonable clues to the brain. But even though our eyes cannot be depended on for the measurement of large distances, the principle can be used in astronomy. Astronomical measurements can begin, for example, with the length of the arc on the surface of the earth subtended by an angle of 1° at the center of the earth. This measurement makes it possible to calculate the earth's radius. The earth's radius subtends an angle at the moon. From that angle and the radius of the earth, we can find the dimensions, in miles, of our natural satellite.

The distance between your eyes could be called a "base line" for measuring distances. By making the base line longer, the principle can be applied to terrestrial and celestial measurements. Surveyors use base lines when they set up the boundaries for properties and for whole continents by triangulation. The Mason-Dixon line between the states of Maryland and Pennsylvania was the result of one of the earliest surveys, using a base line measured by Charles Mason and Jeremiah Dixon.

The base line can be increased from hundreds of miles on the earth's surface to the diameter of the earth. But distances are so great in astronomy that even this is too short for precise measurements of the distance to the sun. By using radar, however, an accurate distance to Venus can be determined, and now the base line can be extended to millions of miles. Neither the sun nor any other star can act as a reflector for the radar pulses, but an accurate sun distance can be determined by using the earth-Venus base line.

This distance from the earth to the sun—or, more specifically, the mean radius of the earth's orbit around the sun—is called the astronomical unit. In popular terms, it is known as the astronomer's yardstick. When observations of a star are made from opposite ends of the earth's orbit, the base line becomes two astronomical units. Distances to the nearer stars can be found by using this known base line (about 186 million miles) and the angle that it subtends to the star.

Hold a pencil at arm's length from your eyes, and sight at a distant object. Close first one eye and then the other. The pencil seems to shift position in relation to the distant object. This effect is called parallax and can be used to find the angle that the base line subtends to the star. Half of this angle

T 4

and an astronomical unit from the sun to the earth form the necessary parts to a right triangle, the solution of which gives the distance to the star.

The path of the solar system as it swings in a huge orbit of its own can provide a still longer base line. However, for any but the nearer stars in our galaxy, the parallax method soon loses all accuracy. Yet we talk about galaxies, nebulae, and quasars millions of times farther away. To see how we can do this, we need to look at another tool of the astronomer.

LIGHT FROM THE SKY

Of man's five senses, sight is by far the most important for the astronomer. All the distance measurements that have been discussed so far are dependent directly or indirectly on the perception of radiant energy. And all radiant energy, of which visible light is a small part, travels from its source in a way that can give the astronomer further information about the distance and other characteristics of the body.

Light from a tiny candle or a star is sent out in all directions in an expanding sphere. The only way in which this energy of a star becomes weaker is by the increasing size of the sphere, or in other words, by being spread over a greater area. The apparent brightness of a star is dependent on the radius of the sphere of its energy at the point at which it is observed.

From the earth we observe the sun at a point on a sphere whose radius is one astronomical unit. All radiant energy travels at 186,000 miles per second, so the light from the sun reaches us in about 500 seconds, or a little more than 8 minutes. The sphere of the nearest star has a radius of 270,000 astronomical units, or 4.3 light-years. One light-year is the distance light travels in one year—about 6 million million miles—another way of measuring distance. The sphere of energy surrounding a galaxy with a radius of billions of light-years is almost beyond comprehension, but if the galaxy is visible, the shell of energy has reached the earth.

The energy or light measured on the earth will depend on the area of the energy shell intercepted for observation. The eye intercepts a circular area about 5 mm in diameter. This is a very tiny part of a sphere whose radius is one astronomical unit. It is a still smaller portion of a sphere from the nearest star. At a certain level of energy, the eye fails to see any light, so we gather more energy from the stars by using larger areas, such as telescopes. The 200-inch Hale telescope can intercept more than a million times the energy picked up by the human eye. For that reason, it allows us to see stars that are a million times fainter.

The little pyrheliometer, or sun-energy measurer, used by the student is a typical device for measuring the unit power from the sun or a star. The area of the copper strip represents a portion of the energy sphere. The thermometer indicates the rate, in degrees per minute, at which energy is absorbed by the copper strip. From these data, the energy unit for the sun, called the solar constant, can be found. Using the area of the sphere and this solar constant, the total energy per second, or the wattage, of the sun can be calculated.

Light from the sun or a star can carry other messages besides energy. When the spectrum is examined with a spectroscope, the resulting colors can give important clues about temperature. The brighter the red end of the spectrum, the cooler the photosphere, or light-producing surface, of the star. The brighter the blue end, the higher the temperature of the star.

Stars can be classified by size and temperature in comparison with the sun. Once this comparison is made, the total power is known. By using this power and the energy-sphere concept, the problem can be worked in reverse and the distance to the star found. Thus, distances far beyond the parallax limit, and not dependent on base lines, can be determined photometrically.

Careful examination of the continuous spectrum of the sun with a good spectroscope reveals hundreds of dark lines interspersed with the colors. When the spectroscope is pointed at glowing hot gases or vapors of the separate elements, bright colored lines appear that can be matched with the dark lines in the solar spectrum. Thus, the spectrum of a star can tell us something about its composition by the "fingerprints" of the elements that appear. The dark lines are caused by the subtraction of discrete lines of color from the continuous spectrum by the gases through which the light passes; hence these spectra are called absorption spectra, and show the presence of specific elements in the "atmosphere" in the path of the light. One element, helium, was discovered in this way on the sun before it was found on the earth.

The spectroscope can convey much more information, including the relative motion in the line of sight, the rotation of the body, the magnetic fields, and many other features of stars. The spectroscope is a very important tool in astronomy and, coupled with the known laws of the behavior of light, can supply information about size and relative age of a star that to the present time cannot be found in any other way.

INVERSE SQUARES IN THE SKY

The expanding-sphere concept of light propagation can help illustrate one of the basic laws underlying science. The area of a sphere equals $4\pi r^2$. If r, the radius of the sphere, is one unit (one meter, one astronomical unit, or whatever), then the light falls on a sphere whose total area is 4π square units. If the radius of the sphere is increased to two units, then the total area of the sphere becomes $4\pi \times 2^2$, or 16π square units. Triple the radius of the sphere, and the total area is equal to $4\pi \times 3^2$, or 36π square units. This means that the same amount of light will be spread over 4 times or 9 times as much area. The light per unit area, then, will vary inversely as the square of the distance from the source. Twice as far away means $\frac{1}{4}$ as much light; three times as far, the light drops to $\frac{1}{9}$ as much.

This inverse-square law underlies several of the great forces in nature as well. The gravitational attraction of two bodies varies this way. If the distance between them is doubled, the force of attraction is only $\frac{1}{4}$ as much. The orbits of all heavenly bodies (and of man-made satellites) are controlled by this relationship. The pull of the earth on the moon, at a distance of about 60 earth radii, is only $\frac{1}{3600}$ as much as it would be on a like body at the earth's surface.

T 6

The forces of magnetism and electrostatics behave the same way. Two charged bodies will attract or repel each other, depending on their charges, in an inverse proportion to the square of the distance between them. Magnetism and electrostatics are not in the subject matter of this unit, but when the student doubles the distance between a light source and the energy-measurer, only ¼ as much temperature change should result.

ORBITS IN THE SKY

Even though the force of gravity between the earth and the moon is only a small fraction of what it would be if the moon were much closer, the pull on the two massive bodies is tremendous. Why, then, a student may ask, does the moon continue to circle instead of spiraling into the earth's surface? What other forces are present that affect its observed behavior? And, of course, similar questions could be asked about the earth and the other planets as they orbit around the sun.

Galileo, and later Newton, stated some rules that apply to all bodies at rest or in motion. One of these has to do with a property called inertia. Simply stated, it says that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line, unless acted upon by an external force. So the moon, in motion around the earth, tends to travel at all times in a straight line. Now the question, if you had no prior knowledge of the situation, would be, "Why, then, doesn't the moon travel in its straight line and fly off into outer space?"

But you have already heard of an external force—one that varies inversely as the square of the distance. It acts inward, toward the earth, at a right angle to the instantaneous straight-line motion of the moon. At the moon's distance, this gravitational attraction is just sufficient to deflect the moon continually from its straight-line path into its curved orbit around the earth. Thus it is also with the earth and the other planets, and with all other orbiting bodies.

What, then, is this curved path that is followed by orbiting bodies? There was no doubt in the minds of the early scholars on this point. A perfect circle was the only path befitting a celestial object. Of course, they also believed the only appropriate center for all the circles was the earth, and so the sun, moon, the known planets, and all the stars revolved around this terrestrial ball. To believe this about the sun and moon caused little difficulty. But the apparent paths of the planets were so erratic that complicated models of eccentric arms moving around invisible points in space became necessary to explain the motions. By A.D. 1500, Mars required 25 of these eccentric arms, or epicycles, to make the model work.

Copernicus revolutionized astronomical thinking by placing the sun at the center of the orbit circles for the planets. By using only one or two eccentrics, he was able to make his model fit all the observations. The moon revolved around the earth in a perfect circle, and the earth in turn made a perfect circle around the sun. It is interesting to note that, without instruments, we today would have a difficult time proving that the distance to the sun and to the moon is subject to change, or in other words, that the orbits of the moon and the earth are not perfect circles. Telescopic observations made daily at the Naval Observatory in Washington, however, show a change in the apparent size of the sun, moon, and the planets. Either these heavenly bodies are changing in size, or they are changing in distance from the earth.

Kepler, using the careful observations of his mentor Brahe, decided that the distances must change. He postulated three laws that went a long way toward solving the remaining difficulties of the Copernican model. Briefly stated, they are as follows:

1. Planets move in elliptical orbits, with the sun at one focus of the ellipse.
2. The line joining the centers of the sun and a planet sweeps over equal areas in equal time intervals.
3. The cube of the mean distance from the sun divided by the square of the period is the same for all planets.

The first law explains why the apparent size of the sun (and the moon, where the law also applies) is variable. The second law gives a reason for an observation made by Hipparchus, a Greek astronomer in the second century B.C. He noted that the number of days from the first day of spring to the first day of fall was greater than the days from autumn to spring again. He reasoned that the relative motion must be slower in the summer (or that the distance traveled was greater in the summer). The third law gives a scale to the solar system, because T, the period in years, is directly observable, either totally or in part, and R, the mean distance in astronomical units, can be computed from $R^3 = T^2$.

It probably should be pointed out that gravity requires a body to move in an orbit that can take only four shapes. They are called conic sections because they are formed when a cone is cut in any one of four possible ways by a plane. If the cut is parallel to the base, the conic is a circle. If the cone is cut above the base but not parallel to it, an ellipse is formed. If the cut is parallel to one edge of the cone, a parabola results; a cut parallel to the axis of the cone gives a hyperbola.

Which of the orbits a body will follow is determined by its speed. At the slowest possible speed, the orbit is a circle. Any speed from this to 1.4 times as much results in an ellipse. If the speed is increased beyond this point, a parabola results, and the body escapes the gravitational field of the attracting body. If it moves still faster, a hyperbolic orbit is formed. Only in the cases of a circle and an ellipse will the orbit continue around the attracting body in a closed path.

RELATIVITY IN THE SKY

There is no stationary platform from which we can make measurements. When we observe the apparent motions of celestial objects, we have to remind ourselves that we are on a rotating, revolving earth that is traveling through space as a part of a moving solar system, which in turn is moving in a galaxy. Add to these motions the slow precession of the earth on its axis, and there is little wonder that the ancients had difficulty in determining which body was indeed doing the traveling.

Fortunately, the astronomical distances are so great in relation to the speeds of these various motions that we need concern ourselves only with a rotating and revolving earth for our work in this unit. But even here there is difficulty in deciding which of the relative motions can be attributed to a particular body. The principal argument for the acceptance of the Copernican model of a heliocentric system was that it simplified the explanation of the observations. When Galileo built a telescope and discovered moons revolving around Jupiter and observed the changing phases of Venus, he felt that he had some proof for the theory of Copernicus.

The underlying idea of Einstein's General Theory of Relativity can possibly sum up the problems of all these motions. In essence it says that we can measure the motion of an object only relative to other objects; there is no such thing as absolute motion of a body relative to space. In appearance, it makes little difference whether the earth is stationary, with the moon and sun revolving around it in varying paths; or whether the sun is stationary, with a rotating earth and its revolving companion moon both revolving around it.

AN OVERVIEW

As the student begins this unit, he is confronted with the question "How do astronomers get accurate information about objects like the moon and the planets without actually going to them?" Since the sun is the most available stellar body for the student to observe, he begins his study of this question by trying to make measurements of the sun.

His first observations involve the spectroscope. From it, he learns that the sun gives off a continuous spectrum of light except for a few dark Fraunhofer lines. These, he learns, result from sunlight passing through an atmosphere around the sun. By observing both the dark-line (absorption) spectra of the sun and the bright-line (emission) spectra of several elements, the student is led to the conclusion that it is possible to predict from sunlight the presence of specific elements in both the core and the atmosphere of the sun, and that this is also possible with other stars.

These observations with the spectroscope lead the student to the need for a more accurate and convenient temperature measurer—a solar-energy measurer. The student builds this solar-energy measurer (which the astronomer calls a pyrheliometer) out of copper, a thermometer, and candle soot. With it, he learns that he can measure the wattage of a radiating source of heat and light if he knows the distance of the source from his measuring device. If he doesn't know this distance, the student finds he can only express the heating effect of a source in terms of its equivalent heating effect relative to a known wattage source at a specified distance from his solar-energy measurer. In the case of measuring the wattage of the sun, the student recognizes that he must first determine the distance from the earth to the sun. T9

In exploring possible methods of measuring the distance of objects too far away to measure by direct means, the student begins by examining a range finder as used in a camera as a possible method. The method fails, but the student learns that a much larger base line and sighting angle hold promise for solving his problem. He then uses the radar distance to Venus of 26 million miles as a base line and constructs a scale drawing of the earth, the sun and Venus when Venus is in a position of maximum angular separation (46°) from the sun as seen from the earth. Using his scale drawing, the student then determines the distance from the earth to the sun to be about 93 million miles.

Using a pinhole and a translucent screen, the student develops a method of measuring the size of an object. He uses the distance from the object to the pinhole and from the pinhole to the screen and the size of the image projected on the screen. With his newly found distance to the sun and a solar image of ½-cm diameter, he finds the diameter of the sun.

Next the student uses the angular change in the shadow of an object to compute the sun's apparent speed in the sky. In doing this, he also discovers the relativity of the solar motion and the effect on the system of time that is used. He observes the apparent path of the sun, and tries to determine if it is the same every day.

The student now returns to the question of the power of the sun. He applies his earlier finding of how the wattage of a source increases with an increase in distance to produce the same heating effect on a surface. The student then uses his own measurements to compute the power of the sun.

The unit concludes by summarizing the methods employed by the student to make inferences about the sun, including its power, distance from the earth, and composition. The student is then given data about other stars and is asked to make as many of his own inferences as he can about them. He also uses the same method that he used with Venus to determine the nearest distance from the earth to Mercury. Using this distance and other data that he found earlier, he finds the diameter of Mercury.

GENERAL INFORMATION

Each chapter of the Teacher's Edition contains an equipment list for that chapter. The same is true for each excursion. In addition, the last page of each chapter alerts you to preparations necessary for the following chapter. Among the materials listed will be some items that must be supplied locally. For Chapter 1, these include scissors, string, white paper, a fluorescent light source, glasses or baby-food jars, matches, distilled water if necessary, and colored pencils or crayons if desired; for Chapter 2, paper clips and matches; for Chapter 3, manila folders or cardboard and white paper; for Chapter 4, beans or other small objects; for Chapter 5, cardboard, scissors, single-edged razor blades, and a needle or other pointed instrument; for Chapter 6, cardboard, string, white paper, and scissors. In addition, glasses or baby-food jars are needed for Excursion 1-1, and white cardboard for Excursion 5-1. You will note repeated use of cardboard, so tablet backs, cardboard shirt-stiffeners, thin cartons, or cut-up boxes should be stockpiled.

GET IT READY NOW FOR CHAPTER 1

You will probably want to have the spectroscopes assembled, the alcohol burners filled, the nichrome wire cut into 10-cm lengths and the 150-watt bulbs in their receptacles. Depending on your room facilities, you may have to make provision for extension cords to go to the nearest wall outlet. For dispensing the three salts, set up a system that will minimize contamination. The source of fluorescent light should be identified. Make a test of your tap water in a flame to see if any appreciable color results; if it does, you may want to use distilled water (not much is required) with the salts.

It would be advisable to spend some time with the class on alcohol burner safety rules. Reasonable care in handling will guard against accidents. A suggested list (you can probably think of more) might include the following.

1. Avoid refilling burners in an area where they are being used or near any open flames.
2. Do not carry a lighted burner around the room.
3. Avoid working over lighted burners.
4. Use care to avoid tipping the burner over.
5. Do not get the end of the spectroscope so close to the burner that damage results.
6. Do not fill burners more than half to two-thirds full.
7. Extinguish and cap a burner when it is not in use.

Pails of sand, fire extinguishers, and a fire blanket should be standard equipment in every room, and the students should be instructed in their use. At this same safety session, it might be wise to reinforce the cautions in the text against looking at the sun, either directly or through any instrument.

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The genesis of some of the ISCS material was from a summer writing conference in 1964. The participants were:

Frances Abbott, *Miami Dade Junior College* Ronald Atwood, *University of Kentucky* George Assousa, *Carnegie Institute* Colin H. Barrow, *University of West Indies* Peggy Bazzel, *F.S.U.* Robert Binger (deceased) Donald Bucklin, *University of Wisconsin* Martha Duncan Camp, *F.S.U.* Roy Campbell, *Broward County Board of Public Instruction, Fla.* Bruce E. Cleare, *Tallahassee Junior College* Ann-cile Hall, *Pensacola, Florida* Charles Holcolmb, *Mississippi State College* Robert Kemman, *Mt. Prospect, Ill.* Gregory O'Berry, *Coral Gables, Florida* Elra Palmer, *Baltimore* James Van Pierce, *Indiana University Southeast* Guenter Schwarz, *F.S.U.* James E. Smeland, *F.S.U.* C. Richard Tillis, *Pine Jog Nature Center, Florida* Peggy Wiegand, *Emory University* Elizabeth Woodward, *Augusta College* John Woolever, *Sarasota, Florida*

Foreword

A pupil's experiences between the ages of 11 and 16 probably shape his ultimate view of science and of the natural world. During these years most youngsters become more adept at thinking conceptually. Since concepts are at the heart of science, this is the age at which most students first gain the ability to study science in a really organized way. Here, too, the commitment for or against science as an interest or a vocation is often made.

Paradoxically, the students at this critical age have been the ones least affected by the recent effort to produce new science instructional materials. Despite a number of commendable efforts to improve the situation, the middle years stand today as a comparatively weak link in science education between the rapidly changing elementary curriculum and the recently revitalized high school science courses. This volume and its accompanying materials represent one attempt to provide a sound approach to instruction for this relatively uncharted level.

At the outset the organizers of the ISCS Project decided that it would be shortsighted and unwise to try to fill the gap in middle school science education by simply writing another textbook. We chose instead to challenge some of the most firmly established concepts about how to teach and just what science material can and should be taught to adolescents. The ISCS staff have tended to mistrust what authorities believe about schools, teachers, children, and teaching until we have had the chance to test these assumptions in actual classrooms with real children. As conflicts have arisen, our policy has been to rely more upon what we saw happening in the schools than upon what authorities said could or would happen. It is largely because of this policy that the ISCS materials represent a substantial departure from the norm.

The primary difference between the ISCS program and more conventional approaches is the fact that it allows each student to travel at his own pace, and it permits the scope and sequence of instruction to vary with his interests, abilities, and background. The ISCS writers have systematically tried to give the student more of a role in deciding what he should study next and how soon he should study it. When the materials are used as intended, the ISCS teacher serves more as a "task easer" than a "task master." It is his job to help the student answer the questions that arise from his own study rather than to try to anticipate and package what the student needs to know.

There is nothing radically new in the ISCS approach to instruction. Outstanding teachers from Socrates to Mark Hopkins have stressed the need to personalize education. ISCS has tried to do something more than pay lip service to this goal. ISCS' major contribution has been to design a system whereby an average teacher, operating under normal constraints, in an ordinary classroom with ordinary children, can indeed give maximum attention to each student's progress.

The development of the ISCS material has been a group effort from the outset. It began in 1962, when outstanding educators met to decide what might be done to improve middle-grade science teaching. The recommendations of these conferences were converted into a tentative plan for a set of instructional materials by a small group of Florida State University faculty members. Small-scale writing sessions conducted on the Florida State campus during 1964 and 1965 resulted in pilot curriculum materials that were tested in selected Florida schools during the 1965–66 school year. All this preliminary work was supported by funds generously provided by The Florida State University.

In June of 1966, financial support was provided by the United States Office of Education, and the preliminary effort was formalized into the ISCS Project. Later, the National Science Foundation made several additional grants in support of the ISCS effort.

The first draft of these materials was produced in 1968, during a summer writing conference. The conferees were scientists, science educators, and junior high school teachers drawn from all over the United States. The original materials have been revised three times prior to their publication in this volume. More than 150 writers have contributed to the materials, and more than 180,000 children, in 46 states, have been involved in their field testing.

We sincerely hope that the teachers and students who will use this material will find that the great amount of time, money, and effort that has gone into its development has been worthwhile.

Tallahassee, Florida
February 1972

The Directors
INTERMEDIATE SCIENCE CURRICULUM STUDY

Contents

Notes to the Student

The word *science* means a lot of things. All of the meanings are "right," but none are complete. *Science* is many things and is hard to describe in a few words.

We wrote this book to help you understand what science is and what scientists do. We have chosen to show you these things instead of describing them with words. The book describes a series of things for you to do and think about. We hope that what you do will help you learn a good deal about nature and that you will get a feel for how scientists tackle problems.

How is this book different from other textbooks?

This book is probably not like your other textbooks. To make any sense out of it, you must work with objects and substances. You should do the things described, think about them, and then answer any questions asked. Be sure you answer each question as you come to it.

The questions in the book are very important. They are asked for three reasons:

1. To help you to think through what you see and do.
2. To let you know whether or not you understand what you've done.
3. To give you a record of what you have done so that you can use it for review.

How will your class be organized?

Your science class will probably be quite different from your other classes. This book will let you start work with less help than usual from your teacher. You should begin each day's work where you left off the day before. Any equipment and supplies needed will be waiting for you.

Your teacher will not read to you or tell you the things that you are to learn. Instead, he will help you and your classmates individually.

Try to work ahead on your own. If you have trouble, first try to solve the problem for yourself. Don't ask your teacher for help until you really need it. Do not expect him to give you the answers to the questions in the book. Your teacher will try to help you find where and how you went wrong, but he will not do your work for you.

After a few days, some of your classmates will be ahead of you and others will not be as far along. This is the way the course is supposed to work. Remember, though, that there will be no prizes for finishing first. Work at whatever speed is best for you. *But be sure you understand what you have done before moving on.*

Excursions are mentioned at several places. These special activities are found at the back of the book. You may stop and do any excursion that looks interesting or any that you feel will help you. (Some excursions will help you do some of the activities in this book.) Sometimes, your teacher may ask you to do an excursion.

What am I expected to learn?

During the year, you will work very much as a scientist does. You should learn a lot of worthwhile information. More important, we hope that you will learn how to ask and answer questions about nature. *Keep in mind that learning how to find answers to questions is just as valuable as learning the answers themselves.*

Keep the big picture in mind, too. Each chapter builds on ideas already dealt with. These ideas add up to some of the simple but powerful concepts that are so important in science. If you are given a Student Record Book, do all your writing in it. *Do not write in this book.* Use your Record Book for making graphs, tables, and diagrams, too.

From time to time you may notice that your classmates have not always given the same answers that you did. This is no cause for worry. There are many right answers to some of the questions. And in some cases you may not be able to answer the questions. As a matter of fact, no one knows the answers to some of them. This may seem disappointing to you at first, but you will soon realize that there is much that science does not know. In this course, you will learn some of the things we don't know as well as what is known. Good luck!

EQUIPMENT LIST

Per student team

1 spectroscope
1 sheet of white paper
2 pegboard backs
1 alcohol burner
1 medicine dropper

per class

1 incandescent light source (150-watt bulb in receptacle)
1 fluorescent light source
Distilled water (if necessary)
Strontium chloride
Sodium chloride
Lithium chloride
Methanol (for burners)
Matches
Scissors
Crayons or colored pencils (optional)
3 petri dishes (for "unknowns")
3 10-cm lengths of nichrome wire

The Message of Sunlight

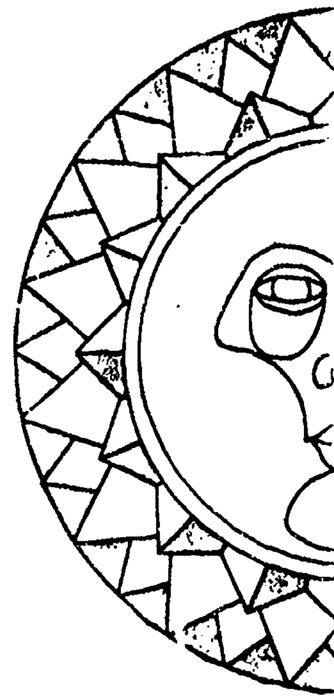
Chapter 1

3 petri dishes
3 10-cm lengths of nichrome wire
3 3-cm lengths of masking tape
1 glass or baby-food jar
2 10-cm lengths of string

Excursion 1-1 is keyed to this chapter.

CHAPTER EMPHASIS

The student is introduced to the use of the spectroscope and the ways in which it aids in making inferences about the composition of light sources.



Space probes have photographed the surface of Mars and of the moon. The Mariner space probes actually sampled the atmosphere of Mars, while the Surveyor space probes sample the soil of the moon. Now men have walked on the moon's surface and brought back rock samples and detailed photographs. It may surprise you to learn that these developments have led to few unexpected results. Most of the information collected supported what astronomers already believed. How did astronomers get such accurate information about objects like the stars, the moon, and the planets without actually going to them? This is the question you will tackle in this unit.

Since you are in school during the day, a good place to start is to study the sun and measure some of its characteristics. Some of the questions about it that you should try to answer include these:

1. What is the sun made of?
2. How much energy does the sun give off?
3. How can the distance to the sun be measured?
4. How large is the sun?
5. How can the motion of the sun be described?

[illegible] may think you can answer some of these questions [illegible] Perhaps, for example, you've read somewhere how [illegible] to the sun. But remember, you should also learn [illegible]surements of the sun are made. Finding out will [illegible]ch more thought than simply looking up a number [illegible] Once you know how to find such answers, you [illegible] to investigate celestial objects on your own.

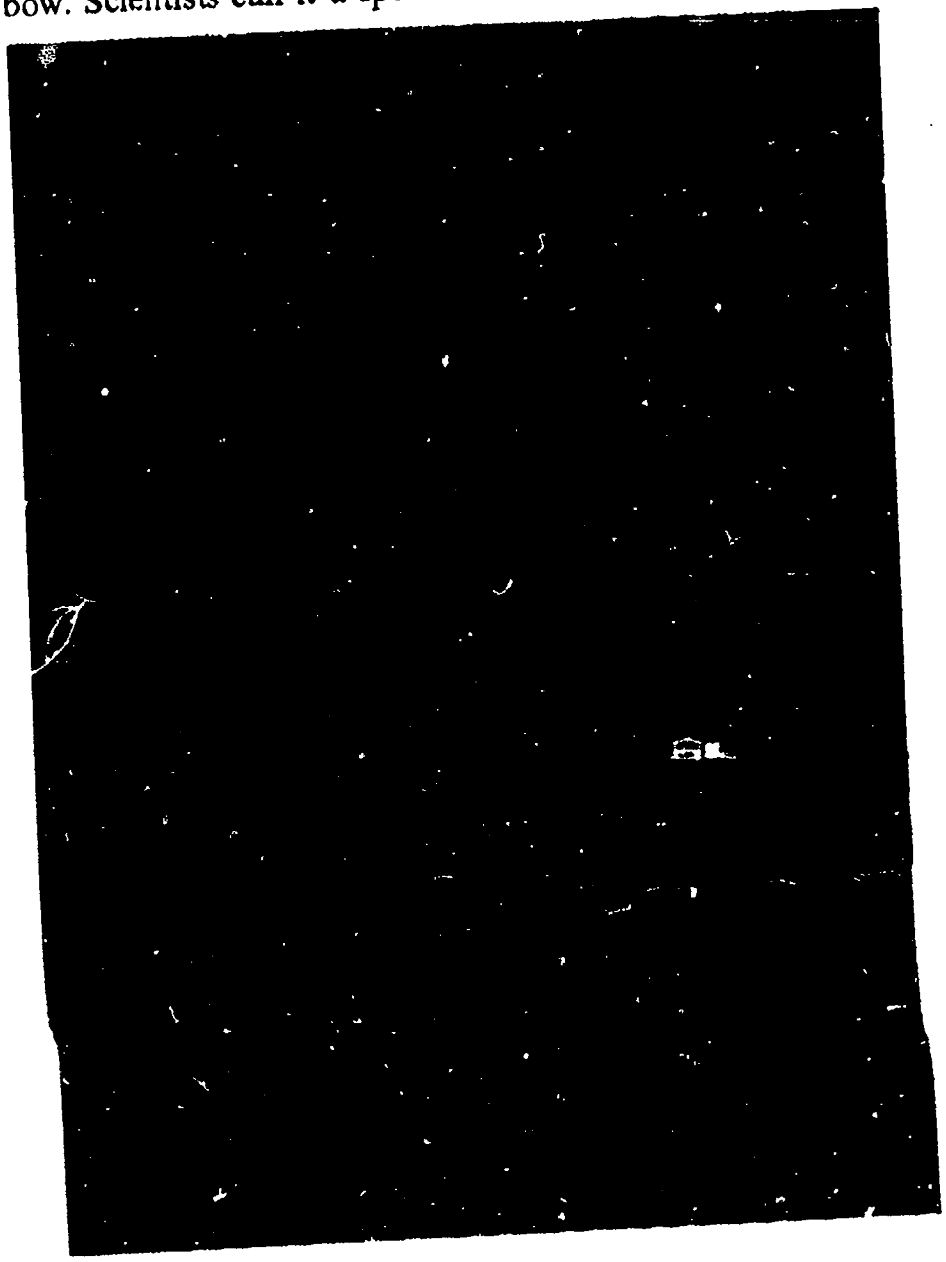
MAJOR POINTS

1 A spectroscope spreads light into its component colors.
2 A diffraction grating is the part of the spectroscope that spreads the light
3. Sunlight and incandescent bulbs form a continuous spectrum
4 A fluorescent lamp forms a continuous spectrum with bright lines on it
5 Different elements, when heated to incandescence, show specific bright lines of color
6 Bright lines of particular colors in the spectrum can be used to predict the presence of definite elements in a substance.
7 The presence of helium was first suspected by the specific lines formed in the sun's spectrum

Getting started

Although you may not realize it, the sun is constantly sending you information about itself. Unfortunately, you can't read the information like a newspaper. The information is in the form of light. Figuring out what it tells you about the sun is rather like cracking a code.

One of the ways to read sunlight is to observe how it behaves when it passes through certain materials. You've probably seen an example of this after a rainstorm. Light passing through droplets of rain at a certain angle is broken up into a series of colors. Most people call the result a rainbow. Scientists call it a spectrum.



On the next page, students begin using the spectroscopes. You will probably want to have them assembled, with the gratings and slits in place. This will avoid the danger of students getting fingerprints on the plastic gratings during assembly. Fingerprints tend to cut down the efficiency of the spectroscope. Warn students against touching the plastic, before they begin using it. Gratings can be cleaned with methanol (burner alcohol) and a soft cloth or cotton. Do not scrub. Extra gratings are supplied in the kit, and in the event that cleaning will not suffice, you will have to install a new grating. A student who cannot distinguish colors will be at a disadvantage. If you have students who are color-blind, team them up with ones who are not. But be sure that it is not just a case of looking for the spectrum in an incorrect manner. The student may only need a little additional help in using the spectroscope.

Although it is not necessary for the student to know, the rainbow is produced in a somewhat different manner than the spectrum from a diffraction grating is produced. In a rainbow, the differential bending of the colors of light as they pass from one medium to another (water droplets to air) in a process called refraction forms the color spectrum. In the grating, light is diffracted—spread out—as it passes through thousands of tiny slits, and a color spectrum is formed.

Begin your study of the sun by looking carefully at the spectrum formed when its light passes through a device called a spectroscope. Before you start, however, here is an important warning.

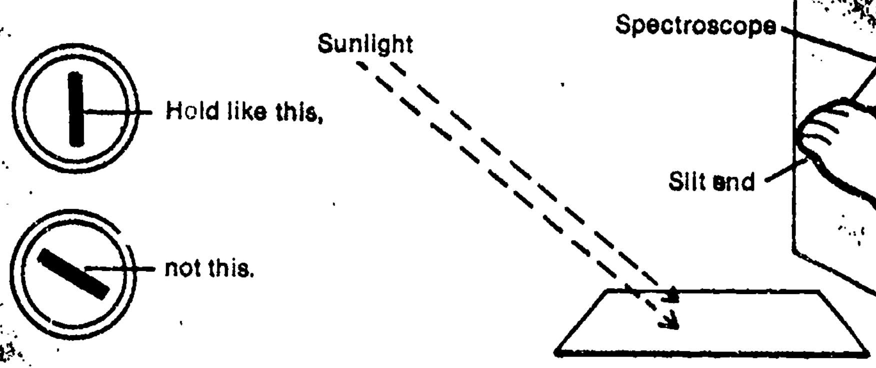
Students may notice a second spectrum farther out on both sides. This may tend to confuse them. Actually it is spread out wider and is much dimmer than the primary spectrum, but all the colors are in the same order. The fact that it is spread out wider tends to make the separate colors more discernible

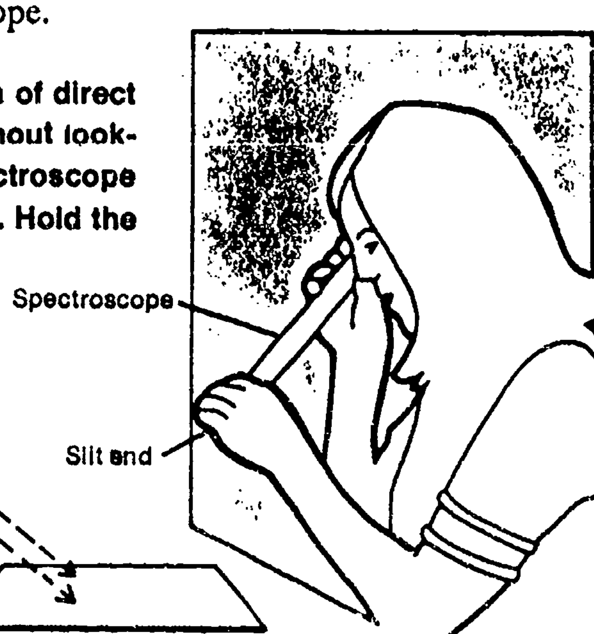
Safety Note *Never look directly at the sun through any instrument or with your unaided eye. This can cause serious damage to your eyes.*

1-1. Answers will vary according to visual acuity and care in observation. Red, orange, yellow, green, blue, violet (or more or less) should be named. The student can begin at either end of the spectrum, but the order is important.

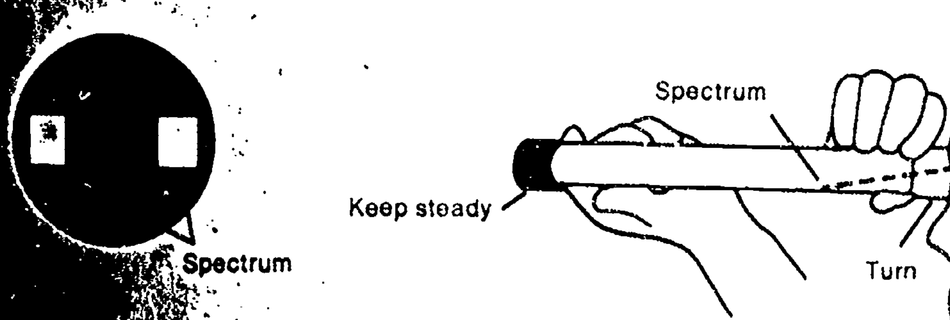
Pick up a spectroscope from the supply area. Be careful not to touch the plastic disk in the eyepiece. The oil from your skin can soil the disk and ruin the spectroscope.

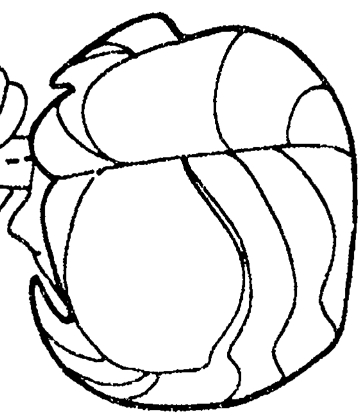
ACTIVITY 1-1. Lay a sheet of white paper in a patch of direct sunlight. (This is a safe way to observe sunlight without looking directly at the sun.) Point the slit end of the spectroscope toward the paper with the slit pointing up and down. Hold the eyepiece snugly against your eye.





ACTIVITY 1-2. As you look through the spectroscope, look to the side of the tube until you see a rainbow (spectrum) clearly. Turn the eyepiece without turning the slit until the spectrum is as wide as you can make it.





[illegible] in the order you see them, as many colors of [illegible] of sunlight as you can. If you look sharply, [illegible] be able to see several.

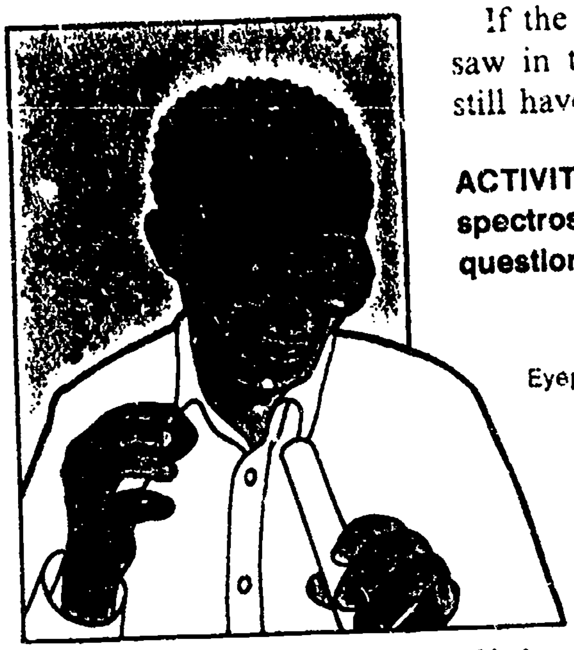
1-2. The order of the list of colors should be the same or exactly reversed. The number of colors listed, however, may well vary. It would probably be possible to list a large number of colors depending on the gradations. For instance, in the color system devised by Albert Munsell, there are 20 different colors, which he calls hues. When degrees of brightness and richness of color are considered, the result is 427 different color samples in the system.

Compare your list of colors with the spectrum photograph in Figure 1-1.

☐ 1-2. How do the number and order of your list of colors compare with those in the photograph (Figure 1-1)?

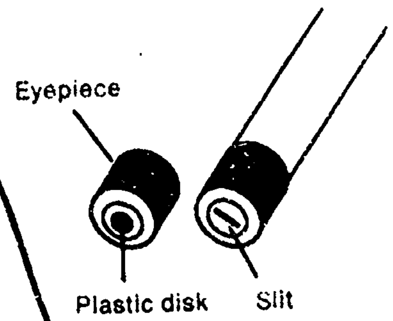
[redacted]

Figure 1-1



If the photograph looks different from the spectrum you saw in the spectroscope, try the experiment again. If you still have trouble, ask your teacher or a classmate for help.

ACTIVITY 1-3. Remove the eyepiece and the slit end from the spectroscope. Experiment with them until you can answer question 1-3.



Note: *Be careful to keep your finger off the plastic disk in the eyepiece.*

1-3. The plastic disk (diffraction grating) is the primary cause. Using just the disk, a rather broad, faint spectrum is visible when one looks toward a light source (but not toward the sun). Students may also note a spectrum formed when light is reflected from the disk. The same effect can be noted when light reflects off an LP record. If you have one handy, you might want to show this to them.

☐ **1-3.** Which causes the spectrum to appear, the plastic disk or the slit? How do you know?

The plastic disk is called a diffraction grating. Thousands of tiny parallel lines have been marked on it. These lines cause the light to spread out into the color spectrum you've seen. This kind of spectrum is called a continuous spectrum because one color continues right into the next.

Using the spectroscope

Earlier, it was said that sunlight carries information about the sun. Now you've seen that sunlight can be spread out into a spectrum. Can the spectrum from sunlight tell you something about the nature of the sun? Is the sun like other sources of light? Perhaps the spectroscope can help you find out.

Somewhere in your classroom your teacher has set up a glowing light bulb. Carry your spectroscope to this area and use it to look carefully at the light from the bulb.

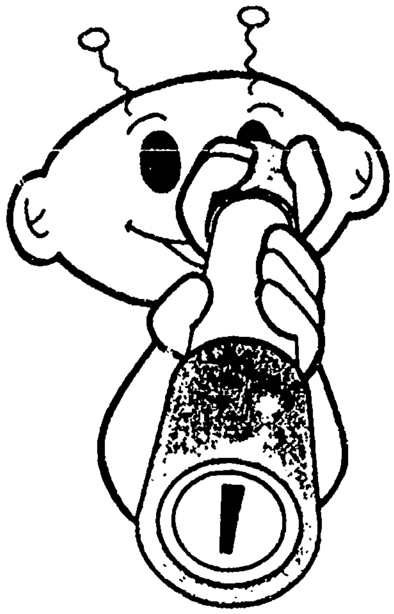
☐**1-4.** In the space provided in your Record Book, list the colors in the order you see them in the spectrum produced by the bulb. If you find any differences between this spectrum and the one produced by sunlight, list them. Look especially for differences in how strongly certain colors show up and for any bright or dark lines.

☐**1-5.** Next, use your spectroscope to examine the light from a fluorescent tube. Once again, list the colors in the spectrum in the order you see them. Also, describe any differences between the spectrum from the fluorescent tube and the spectrum formed by sunlight.

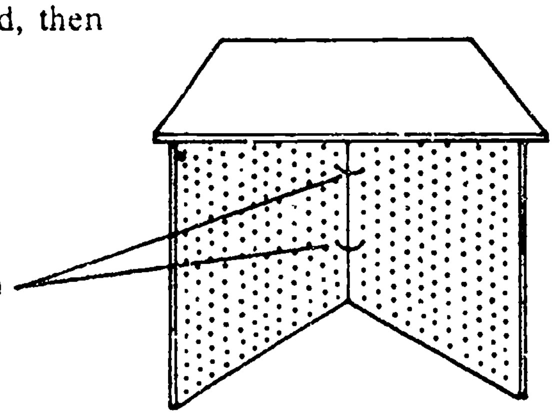
If you made careful observations, you should have noticed some bright lines in the fluorescent-tube spectrum that you didn't see either in the sun's spectrum or in the spectrum from the light bulb. Also, some of the colors may have shown up more clearly in one spectrum than another. What do these differences mean?

To find out, you'll need to work with a partner. You will be using the spectroscope to look at the light given off from heated substances. Therefore, you will need to work in semi-darkness. If a part of your room cannot be darkened, then rig your own work space as shown in Activity 1-4.

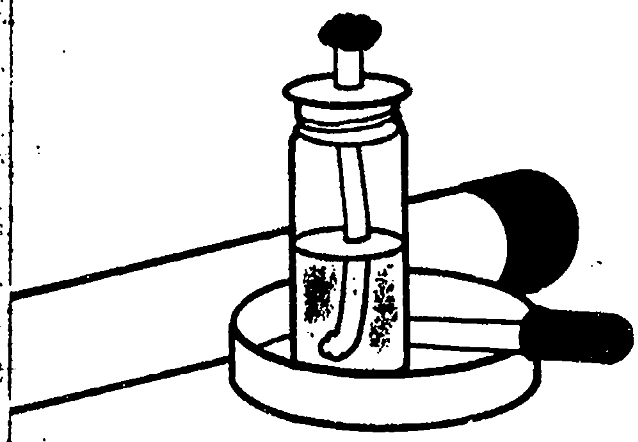
The classroom may have incandescent lights that the student can observe. If not, use the 150-watt bulb and the receptacle on a table adjacent to a wall outlet. Try to have it located so that daylight will not be observed at the same time. Likewise, you may have fluorescent lighting that can be observed in the room. If not, the student may have to be sent to a kitchen, laboratory, etc., where a tube is located. He should see a continuous spectrum, with several pronounced bright lines superimposed. Most outstanding should be yellow, green, and violet lines.



Activity 1-4, use the two 10-cm pieces of ...ng to tie the vertical pegboard backs to-



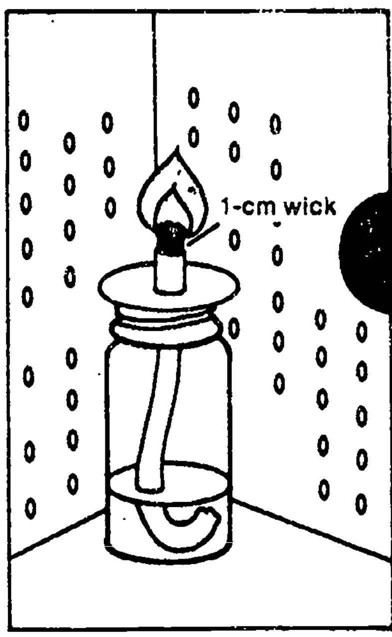
ACTIVITY 1-4. Set up two pegboard backs as shown. Put another piece of pegboard or other nonburnable shield across the top of the pegboards to give more shade.



Now get the following materials from the supply area:

3 pieces of nichrome wire, each 10 cm long
1 alcohol burner
3 petri dishes
1 spectroscope
1 small container of water
1 eyedropper
3 pieces of masking tape, each 3 cm long
Lithium chloride crystals
Strontium chloride crystals
Sodium chloride crystals

Clean baby-food jars or other containers may be used in place of the petri dishes, if desired.

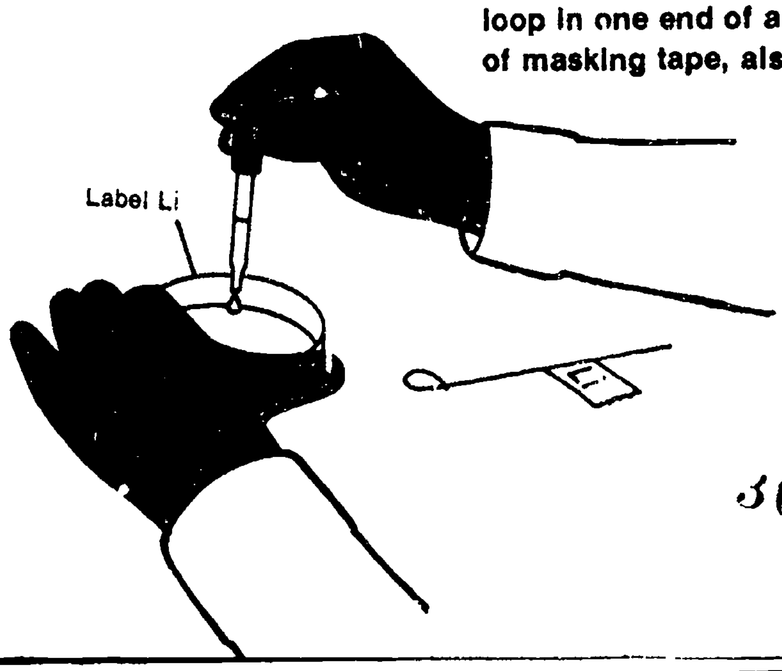


ACTIVITY 1-5. Pull 1 cm of the wick out of the alcohol burner. A well-trimmed wick should not be black at the end. Light the burner and look at the spectrum of the flame. (It's likely to be very faint.)

☐ **1-6.** Compare the spectrum of the alcohol lamp with the spectrum of sunlight that you looked at earlier.

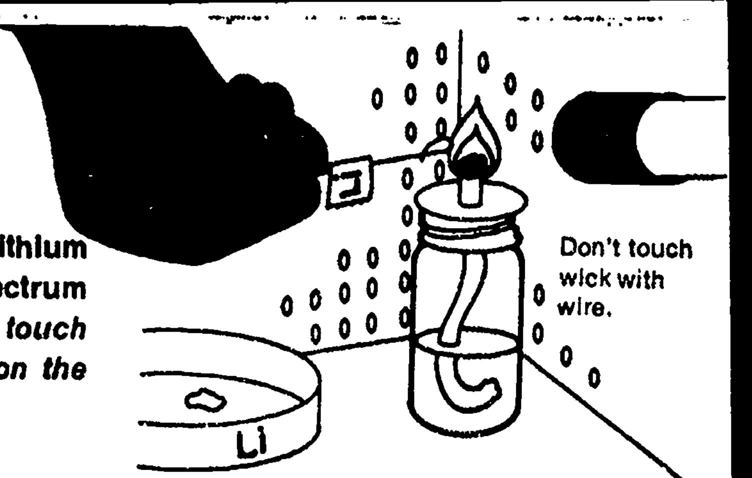
☐ **1-7.** Did you see any bright lines in the spectrum of the alcohol lamp?
If so, what colors were they?

ACTIVITY 1-6. Mix the crystals of lithium chloride with 2 drops of water in a petri dish labeled "Li" (lithium). Make a small loop in one end of a nichrome wire and attach a small piece of masking tape, also labeled "Li."



A very small amount of lithium chloride, strontium chloride, and sodium chloride is all that is necessary. In this and the succeeding activities, it is most important to avoid contamination of the samples and to keep solutions from getting on the wick of the burner. The nichrome loops, once made, can be re-used by other students if they are kept with the respective samples. Loops may be cleaned by rinsing in clean water, dipping in concentrated HCl, and heating in the flame until they show no color. You should probably test the tap water to see that it gives no appreciable color in the flame. If it does, use distilled water with the crystals.

The spectra from the three chemicals are faint. Have students hold the spectroscopes as close as possible to the flame.

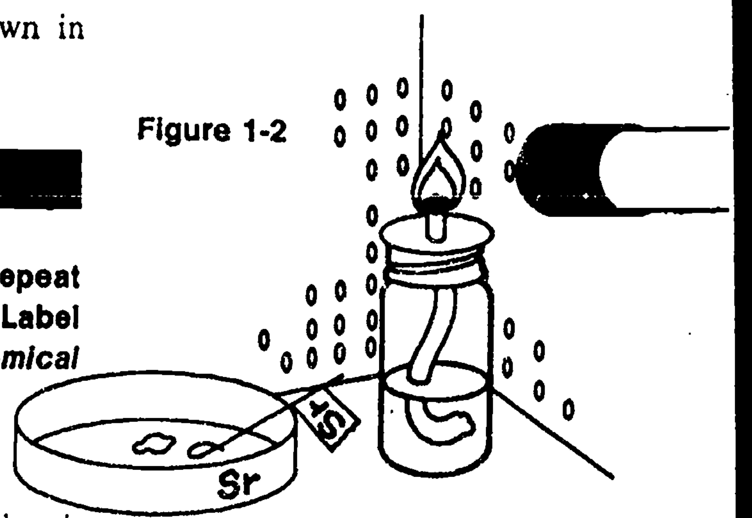


Keep wicks well trimmed. If salts get on the wicks, trim with scissors.

ACTIVITY 1-7. Dip the loop of nichrome wire into the lithium chloride solution. While your partner looks at the spectrum of the alcohol flame, put the loop into the flame. *Do not touch the wick with the loop. Try not to get any chemicals on the wick.* Take turns looking at the spectrum.

☐**1-8.** In the space provided in your Record Book, show the position of any bright lines you saw in the spectrum. Compare your sketch with the lithium spectrum shown in Figure 1-2.

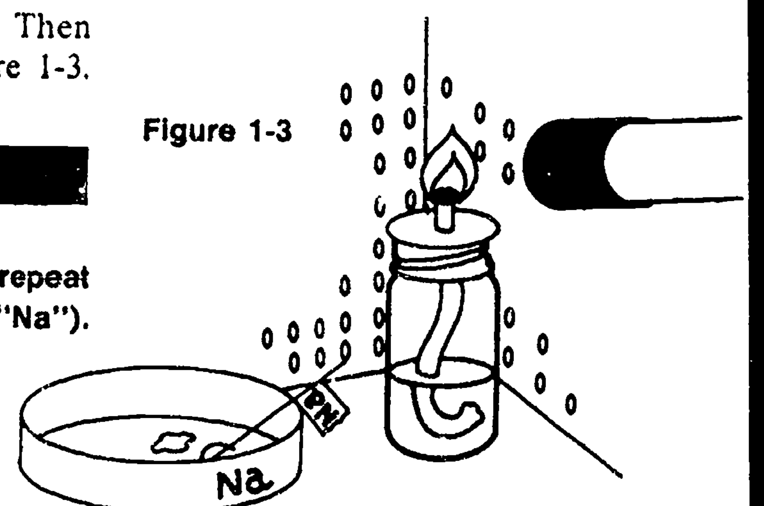
Figure 1-2



ACTIVITY 1-8. Using a clean dish and a clean wire, repeat Activities 1-6 and 1-7, using strontium chloride crystals. Label the dish and wire "Sr." *Again, do not get any of the chemical on the wick.*

☐**1-9.** In the space provided in your Record Book, sketch any bright lines you saw in the strontium spectrum. Then compare your sketch with the Sr Spectrum in Figure 1-3.

Figure 1-3



ACTIVITY 1-9. With a third clean dish and clean wire, repeat Activities 1-6 and 1-7, using sodium chloride (label "Na").

☐**1-10.** Sketch any bright lines you saw in the sodium spectrum. Then compare your sketch with the Na spectrum in Figure 1-4.

You may want to have colored pencils or crayons available so that students can show the spectral lines in color. Some lines are especially difficult to see. Encourage students to try hard but not to spend the whole period searching for a line.

Figure 1-4

You might want to ask students how they could be sure that the bright lines were due to the lithium, strontium, or sodium, and not to the chloride. You could have a sample of sodium carbonate (washing soda) or sodium bicarbonate (baking soda) that they could try in the flame with a clean wire. They will see the bright sodium lines. Incidentally, students will probably show a single yellow line for the sodium spectrum. This is as it should be. There are actually two bright lines, but they are so close together that the simple spectroscope cannot resolve them.

The spectrum of an element heated in a fairly colorless flame is just a few bright lines. This type of spectrum is called a bright-line spectrum. Each element produces a definite set of bright lines. Scientists have found that they can identify an element by its bright lines as surely as they can identify you by your fingerprints. The bright lines you saw earlier in the fluorescent-tube spectrum were due to the gases in the tube (mostly mercury vapor).

From time to time in this unit, you will be asked to do "problem breaks." These are problems for you to solve, without much help from your book or from your teacher. The problems will usually help you understand what you are studying in the chapter. But that's not their major purpose. They are designed to give you practice in problem solving, and in setting up your own experiments. You should try every problem break—even the tough ones. And in most cases you should have your teacher approve your plan before trying it. The first problem break in this unit is coming up next.

Problem Break 1-1 calls for the student to identify substances from the spectra they produce. A suggested procedure is as follows:

Use three separate, clean petri dishes or baby-food jars. In the first, make a solution of a mixture of sodium chloride and lithium chloride; in the second, use a mixture of sodium chloride and strontium chloride; in the third, use strontium chloride and lithium chloride. Have a clean wire with each, and number the containers and the wires 1, 2, and 3. Be sure to keep track of your mixtures by number, so that when a student checks his prediction with you, telling the number he used, you can match them up. It might be wise to prepare containers of the three mixtures and put out only a small amount at a time. This would help guard against contamination.

PROBLEM BREAK 1-1

Now here's some detective work for you. Your teacher has prepared a solution of one, two, or three of the substances you just tested (sodium chloride, lithium chloride, and strontium chloride). Your job is to find out which substance or substances was used.

☐ **1-11.** In the space provided in your Record Book, show the position of any bright lines you identify.

☐ **1-12.** Compare the sketch you made with the sketches you made in answer to questions 1-8, 1-9, and 1-10. What substance or substances do you predict are in the unknown solution?

Check your prediction with your teacher.

Astronomers use spectroscopes to identify the elements in the stars. In fact, the spectral lines of the element helium were first observed in sunlight. When the substance that produced these lines was finally found on the earth, it was named helium (from the Greek word *helios,* meaning "sun").

The spectrum of helium is shown in Figure 1-5. You should notice a peculiar difference in this spectrum when it is compared to others you have observed.

Figure 1-5

Perhaps you would like to learn more about the kind of spectrum shown in Figure 1-5. You can find out how they were discovered and how to see one yourself by doing **Excursion 1-1.**

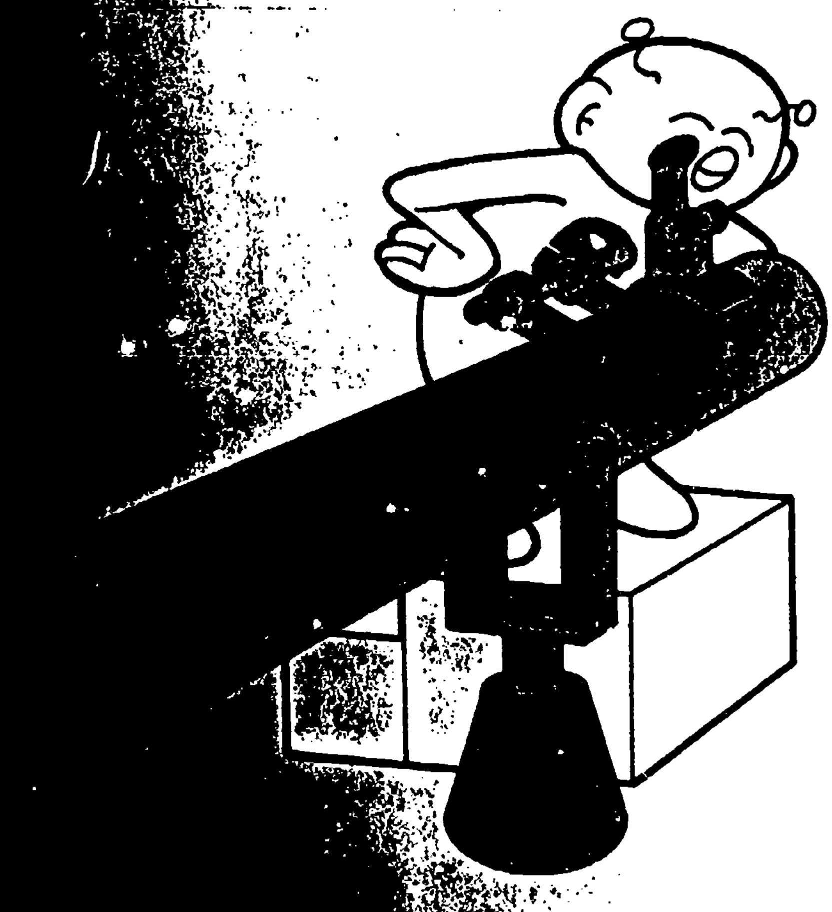
Bright lines and dark lines in spectra can tell astronomers a great deal about the composition of stars and planets. Most of what we know about the sun and its atmosphere is a direct result of information from spectra.

In Chapter 2 you will see how to take the first step in measuring the amount of energy released by the sun. Fortunately you won't have to go there to do it.

Before going on, do Self-Evaluation 1 in your Record Book.

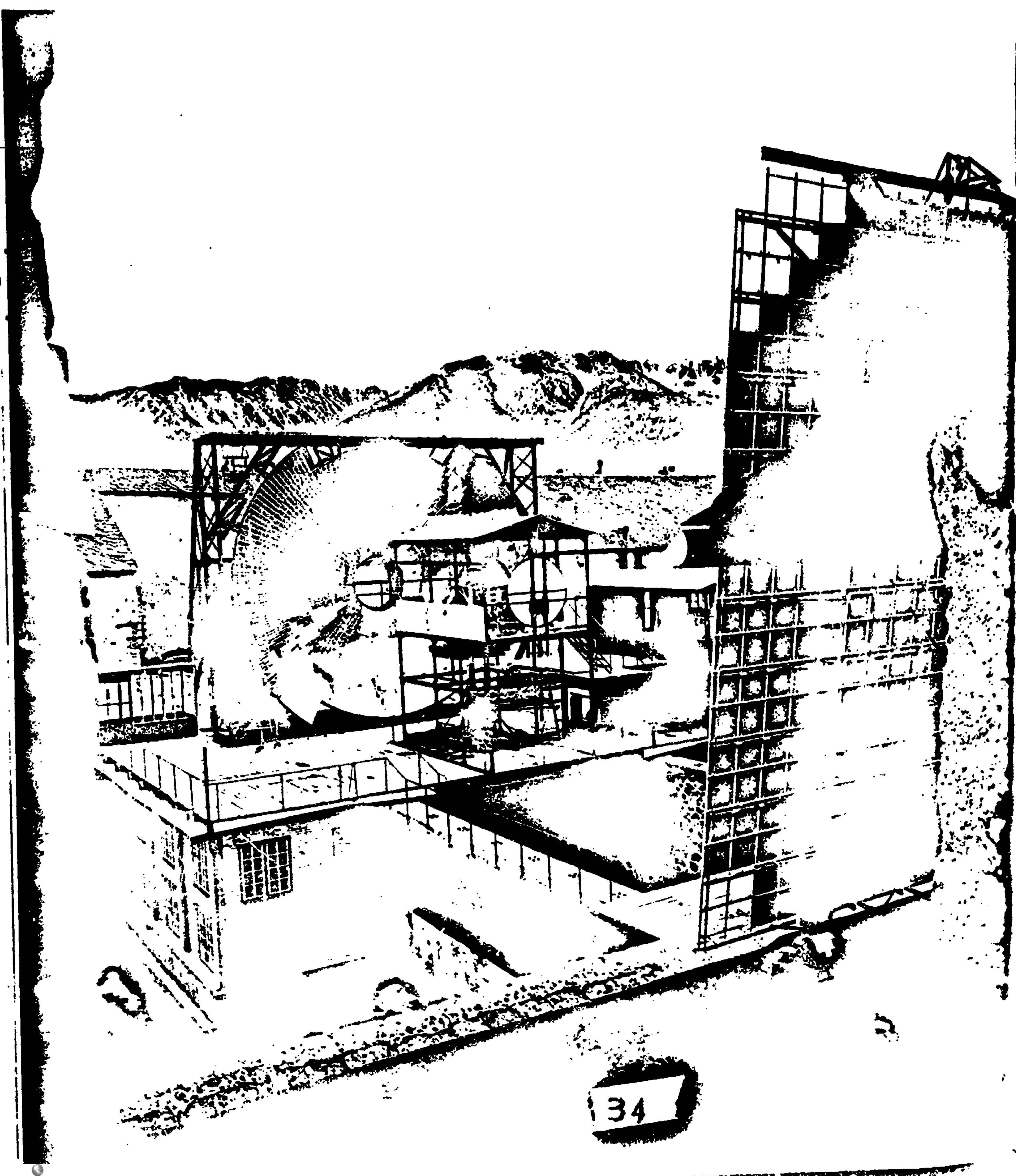
EXCURSION

Excursion 1-1 is concerned with a different kind of spectrum—one of absorption or dark lines. It is fairly difficult and exacting.



GET IT READY NOW FOR CHAPTER 2

You will need 6-cm × 3-cm copper strips. These should be cut from the 30-cm × 30-cm copper sheets that are supplied. Each sheet will yield 50 strips. Probably one sheet will suffice, as the strips can be reused by other students once they are cut to size. You will need to make provisions for extension cords from the wall outlets if power is not available at the student stations. Students will be using 5 or more receptacles with various wattage bulbs for extended times in the chapter. Depending on how widely spread your students are, you might want to consider procuring additional receptacles to augment the 5 that are furnished. Any screw-type socket receptacle that will hold a light bulb upright can be used. You will need paper clips and matches, which must be supplied locally.



EQUIPMENT LIST

Per student team

1 copper strip, 6 cm × 3 cm
1 Celsius thermometer
1 paper clip
1 socket receptacle
1 150-watt bulb
2 100-watt bulbs
1 60-watt bulb
1 50-watt bulb
1 meterstick
1 pegboard back

Per class

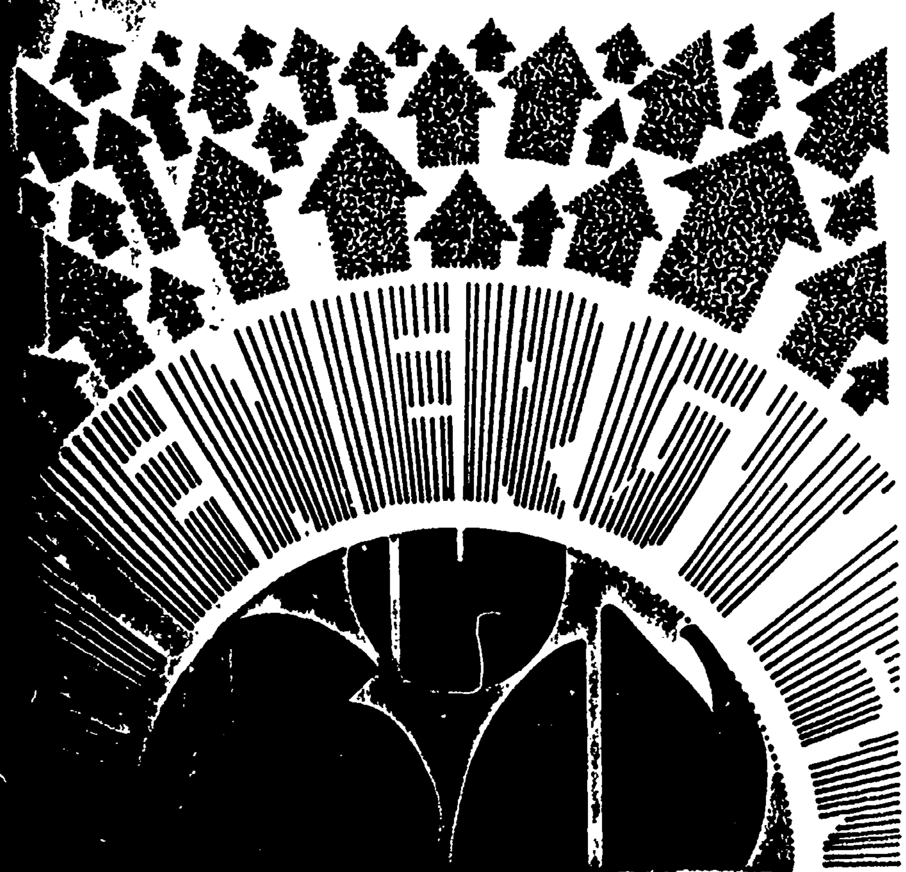
Pieces of dowel
Candles
Matches

Watts New?

Excursion 2-1 is keyed by a Checkup.

Everybody knows that the sun gives off lots of energy. In fact, you may have heard that all energy on the earth comes, in one way or another, from the sun. But what does it mean to say "lots of energy"? How much is "lots"? That is the problem for this chapter—to get an idea of how much energy the sun gives off.

To be sure you are ready to begin the next activity, you need to know some things about energy. The following checkup will help you find out whether you are ready to go ahead.



CHAPTER EMPHASIS

Using a simple radiant-energy measurer, the student determines the variables that affect the readings, and compares the energy received from the sun with that from an incandescent bulb at a particular distance.

Chapter 2

MAJOR POINTS

1. A solar-energy measurer (pyrheliometer) can be constructed.
2. Temperature change can be used as a measure of radiant energy received.
3. The temperature change of the solar-energy measurer varies with time, up to a certain point.
4. The amount of energy received varies with the wattage (energy per second) of the bulb.
5. The amount of energy received varies with the distance between the source and the solar-energy measurer.
6. In order for the energy received by the solar-energy measurer to remain constant, the radiant energy of a source must increase at a greater rate than the distance from the source increases.
7. It is possible to determine the distance from the solar-energy measurer that a 50-watt bulb must be in order to cause the same temperature change that the sun causes.
8. To measure the energy given off by the sun, it is necessary to know the distance to the sun.

This chapter might be considered the most important one in the unit. Using simple apparatus that the students construct themselves, a very realistic measurement can be made that will lead to finding the power of the sun in a later chapter. Its completion depends only on a measurement of the distance to the sun, which is made in Chapter 4. Those who are well-versed in physics may object to the apparent discrepancy in usage of terms. Energy is measured in joules (or newton-meters), whereas the watt is a measure of power in joules per second. Time, therefore, is the factor connecting the two terms. Experience has shown that the disparity presents no serious problems for the students, however, and the matter is resolved in a later chapter. Incidentally, you probably will want to have 2 or 3 students working together on the activities

Checkup. In order to understand the purpose of this chapter, the student needs an elementary concept of energy. Those who did not participate in Levels I or II of ISCS, or who have forgotten, will profit from doing Excursion 2-1, a review of the energy concept. This checkup is the mechanism for getting them into the excursion. You may want to check answers to the four questions, to see that those who need help are getting it.

CHECKUP

In your Record Book, place a check mark in front of each correct answer. There may be more than one correct answer per question.

1. Work is
a. force
b. distance.
c. force × distance.
d. speed × time.

2. A measure of energy is
a. force.
b. force × distance.
c. speed × time.
d. work.

3. Energy can
a. exist only in the form of heat.
b. exist in more than one form.
c. be transferred from one system to another.
d. cause changes in matter.

4. Energy is always
a. conserved.
b. destroyed.
c. needed to overcome forces.
d. a measure of the time needed to do work.

EXCURSION

Check your answers on page 77 of **Excursion 2-1.**

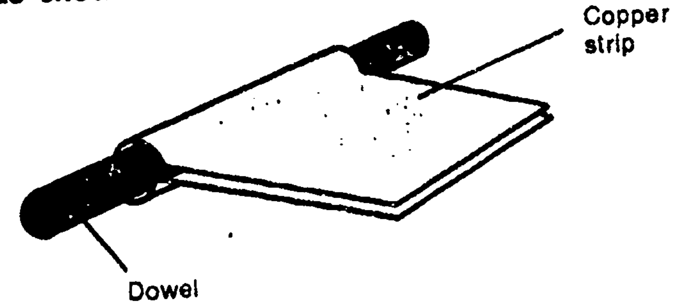
In the interest of economy, you will probably want to have the copper strips precut instead of having each student cut one. Note that the piece of dowel, candle, and matches are "classroom" items, and can be kept on the supply table to be used only when needed.

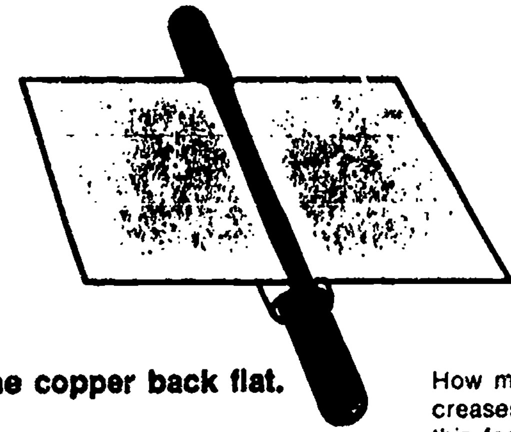
To begin making a sun-energy indicator, you will need these things:

1 strip of copper, 6 cm × 3 cm
1 Celsius thermometer
1 piece of dowel, the same diameter as the thermometer bulb
1 candle
Matches
Paper clip

If reasonable care is taken in bending the copper, not only will it fit tightly around the thermometer bulb, thus transfering maximum heat to the bulb, but it also will be reusable by other students.

ACTIVITY 2-1. Pinch the strip of copper tightly around the dowel as shown.





ACTIVITY 2-2. Bend the ends of the copper back flat.

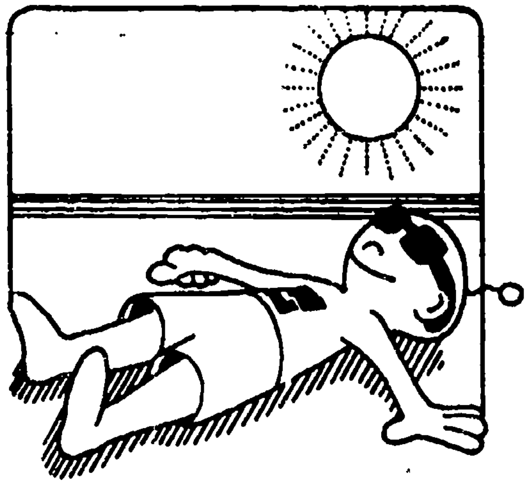
As you know, that part of the sun's energy that reaches the earth is in the form of light. A large portion of this light energy changes to heat energy when it reaches the earth's atmosphere and surface. This heating effect is what causes objects put in sunlight to get hotter. How much the temperature of an object increases depends on

1. how big the object is,
2. how well it absorbs heat,
3. how quickly it conducts heat, and
4. how long it is heated.

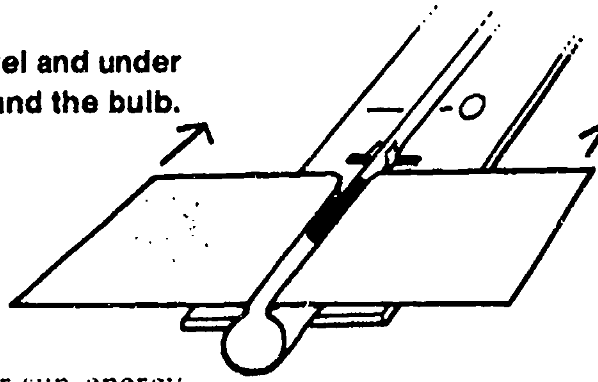
Each of these factors affects how much change in temperature will be observed when the object is placed in the sun.

All of this means that you can get an idea of how much heat is absorbed by an object by measuring its temperature before and after placing it in the light. All you need is an object to be heated, and a thermometer.

How much the temperature of an object increases also depends on its specific heat, but this factor is not vital to the experiments in the chapter, as long as it is allowed to heat to its equilibrium temperature.



ACTIVITY 2-3. Slide the copper strip from the dowel and under the bulb of the thermometer. Gently pinch it around the bulb. ***Use care so as not to break the thermometer.***



By now, you've probably figured out how your sun-energy indicator will work.

☐**2-1.** What do you predict will happen to the copper strip if it is placed in sunlight?

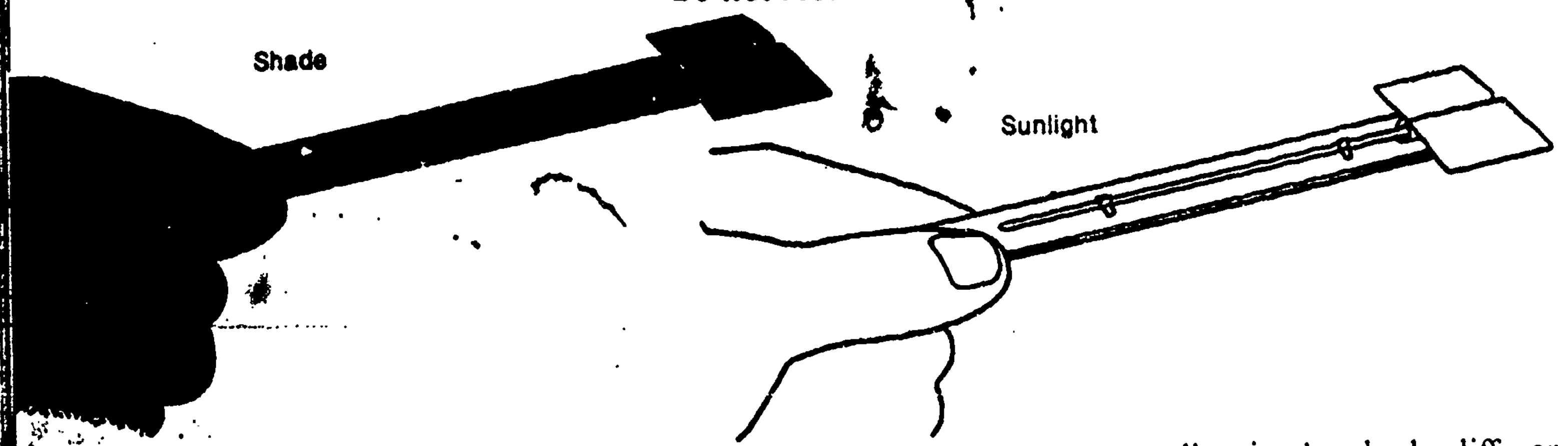
☐**2-2.** What is the purpose of the thermometer?

2-1 and 2-2 The copper strip should increase in temperature. The thermometer should measure the increase. (Note, however, that the thermometer does not measure the heat content of the copper, but only one factor of it.)

Now let's test the energy indicator you've built.

The reason that it should not rest on any surface is that heat could be conducted to or from it more readily, as well as being reflected to it. Of equal importance, however, is protecting it from the wind or from drafts.

ACTIVITY 2-4. Hold the instrument in the shade for a couple of minutes. Then move it into the sun for a few more minutes. Do not rest it on any surface.



2-3. It should show a temperature increase of up to 4°C in sunlight.

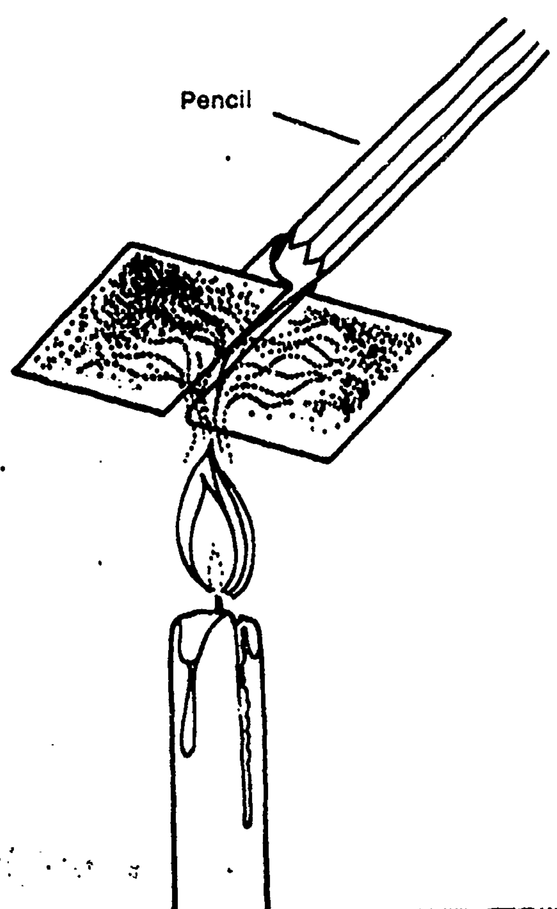
□**2-3.** Was the thermometer reading in the shade different from that in the sun? (If so, how much?)

If the thermometer didn't show a temperature change, something is wrong. The copper strip should have absorbed enough energy to affect the thermometer. If it didn't, check Activities 2-1, 2-2, and 2-3 to be sure that you put the instrument together correctly.

You should make one improvement in your sun-energy indicator before you use it. You probably noticed that the temperature change was slow in occurring. The amount of temperature change was probably rather small, too. It would help matters if the copper absorbed energy more quickly than it does.

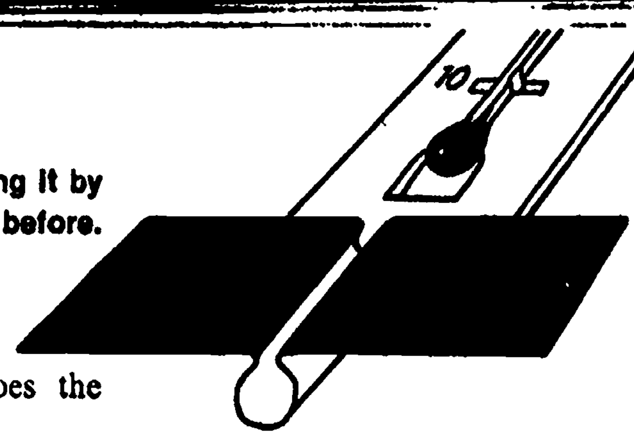
Copper is a shiny metal. This means that it reflects some light. If you could cut down its shininess, the copper would convert more light energy to heat.

□**2-4.** What could you do to the copper to make it absorb more of the sun's energy?



ACTIVITY 2-5. Slide the copper strip off the thermometer. Insert a pencil or dowel in the bend of the strip. Hold the copper over a lighted candle. Try to cover the flat surface evenly with soot from the candle. *Warning Do not hold the thermometer over the candle, as it will get hot and break.* If you get wax on the strip, you must clean it and start again.

Carbon black is preferred to black paint because it tends to be a better absorber and conductor of heat energy. It can be messy, however, and students may have to be warned about keeping their fingers out of the soot.



ACTIVITY 2-6. Let the copper strip cool. Then, holding it by the unblackened loop, attach it to the thermometer as before.

Test your instrument in a sunny spot.

☐**2-5.** At room temperature, what temperature does the sun-energy indicator show?

☐**2-6.** What temperature does the instrument show after being in direct sunlight for a few minutes?

☐**2-7.** By how many degrees did the temperature change?

Remove the sun-energy indicator from the sunlight and let it return to room temperature.

☐**2-8.** Why do you think copper was a good choice of metal?

2-8. Probably the most important reason is that copper is a good conductor of heat. Also, from a practical standpoint, it is easily shaped (malleable).

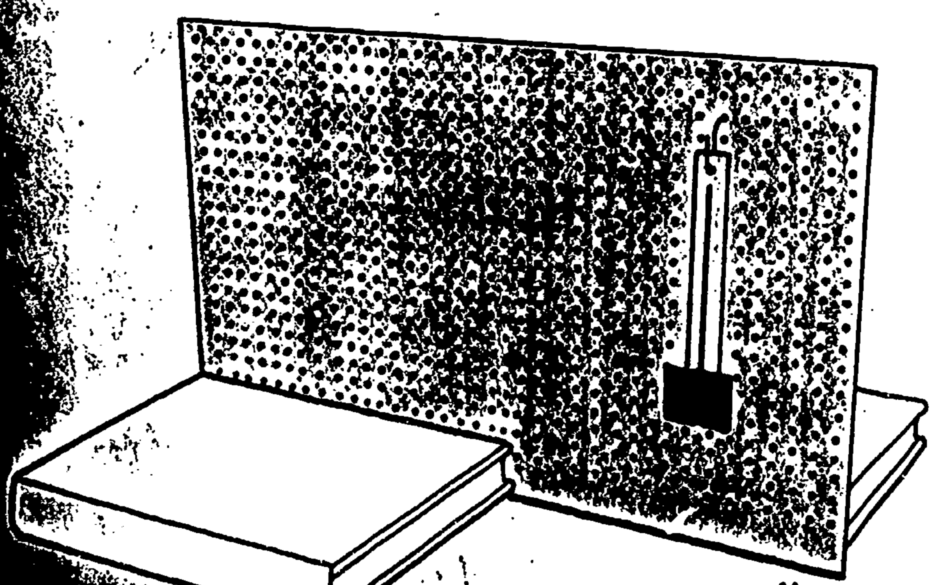
With this instrument you should be able to get an idea of how much energy is received by the copper strip from the sun in a given amount of time.

By now you may be seeing some problems in using the sun-energy indicator. Suppose, for example, you got a reading in the sun 20° higher than in the shade. This would tell you that the copper strip had absorbed energy. But it would certainly not tell you how much total energy the sun gives off. To learn that, you would need to know several other things. The next activities will help you find out what they are. Pick up a pegboard and a paper clip.

In making readings of temperature change with the pyrheliometer throughout the chapter, be sure that students measure the change under constant conditions. For example, if the amount of change in sunlight is made outside, then the beginning temperature should also be read outside. If the change is to be measured indoors (as on a window ledge, with sunlight coming through the glass), then the beginning temperature should be that of the room.

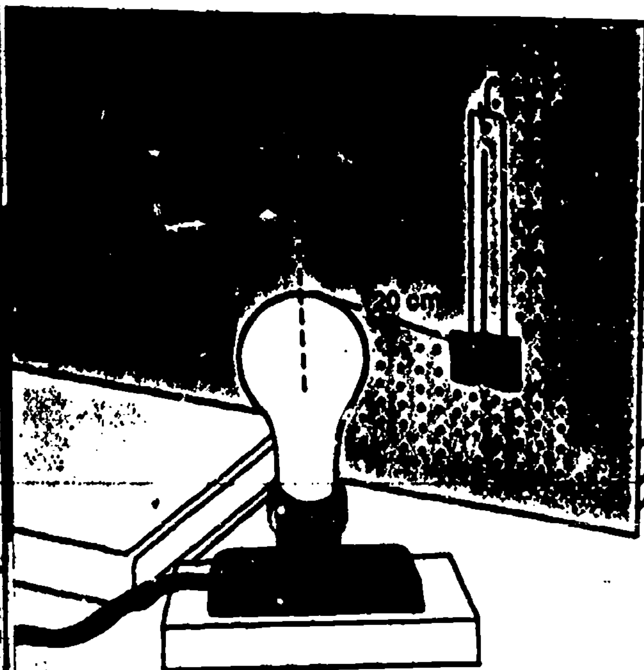
ACTIVITY 2-7. Hang the sun-energy indicator in an upright position as shown. You can make a hanger from a paper clip.

In this activity and the ones that follow, the books may be placed at the other end of the pegboard, away from the instrument.



Carry the stand with the attached instrument to where your teacher has set up a series of light bulbs.

You will use these bulbs as a light source. They will represent the sun.



ACTIVITY 2-8. Place the pegboard so that the blackened surface of the copper strip is 20 cm from the center of one 150-watt bulb in the parallel circuit.

Have students adjust the height of the pyrheliometer so that the copper strip is on the same horizontal level as the center of the light bulb.

Record the temperature of the thermometer in Table 2-1 of your Record Book. Then turn on the lamp. Every 30 seconds, record the thermometer reading. Complete the table by calculating what the total temperature change has been up to each of the times indicated (new temperature minus the temperature at 0.0 time).

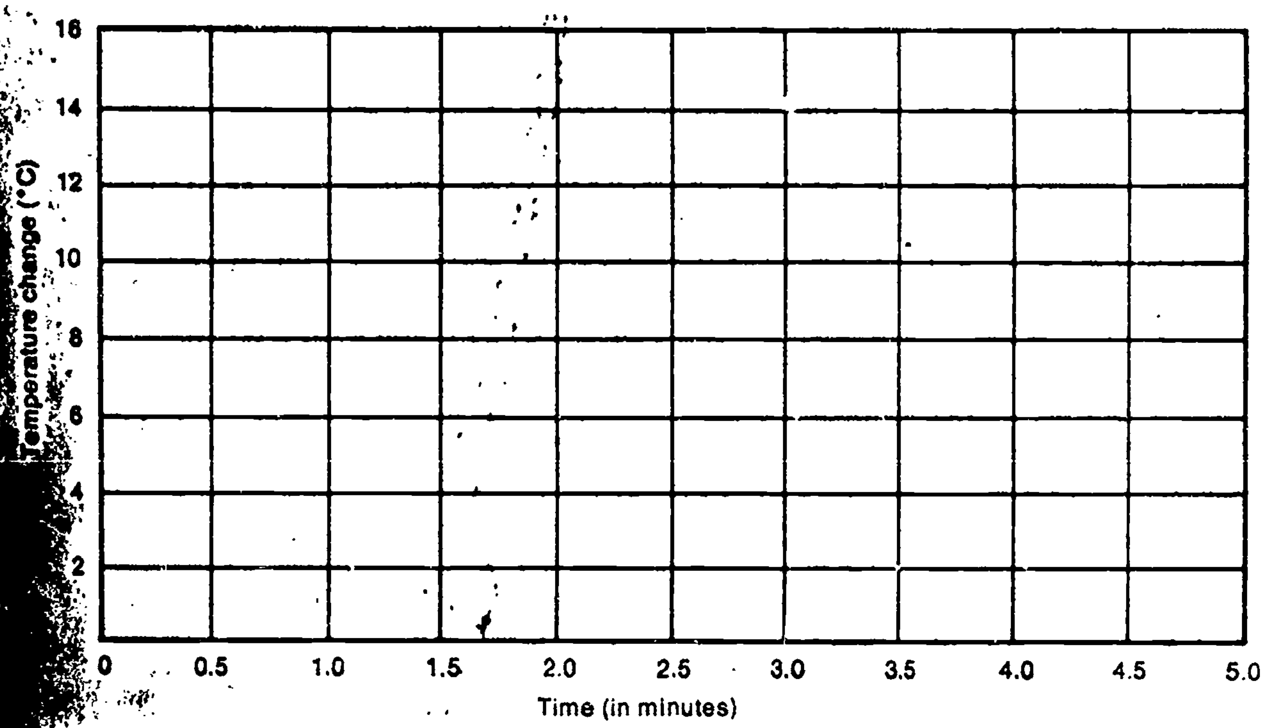
Table 2-1

Time (minutes)	Temperature (°C)	Total Temperature Change (°C)
0.0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		
4.5		
5.0		

The students are determining the equilibrium temperature of the strip and the time required to reach it. Thus time is one of the variables asked for in question 2-11 on the next page. Other variables named might be size (wattage) of the bulb, distance to light source, angle at which light strikes the strip, and size of the strip.

Graph your results on the grid of Figure 2-1 in your Record Book. Use the data from the Total Temperature Change column and from the Time column.

Figure 2-1



☐ 2-9. According to your graph, how many minutes passed before the temperature stopped rising?

2-9. Most probable answer is 3 to 3½ minutes.

☐ 2-10. Why do you think the temperature stopped increasing?

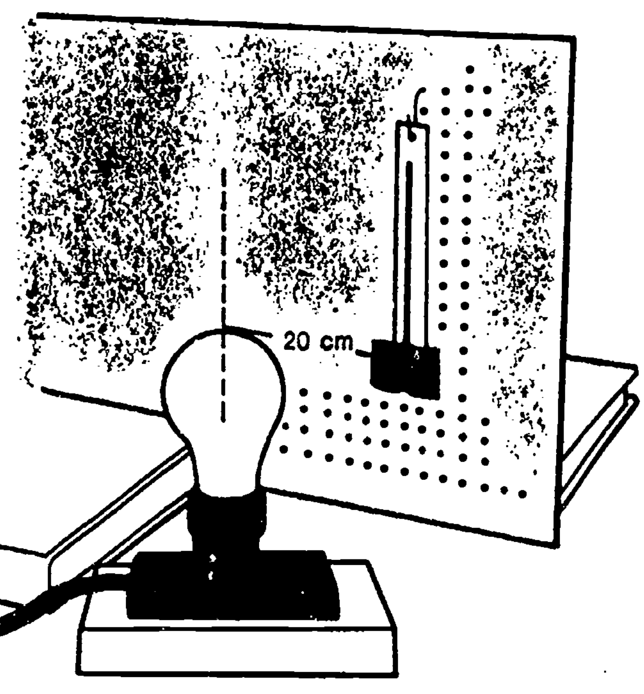
2-10. Equilibrium temperature was reached when the amount of heat lost by the strip equaled the amount of heat gained. This is a good concept to be acquired.

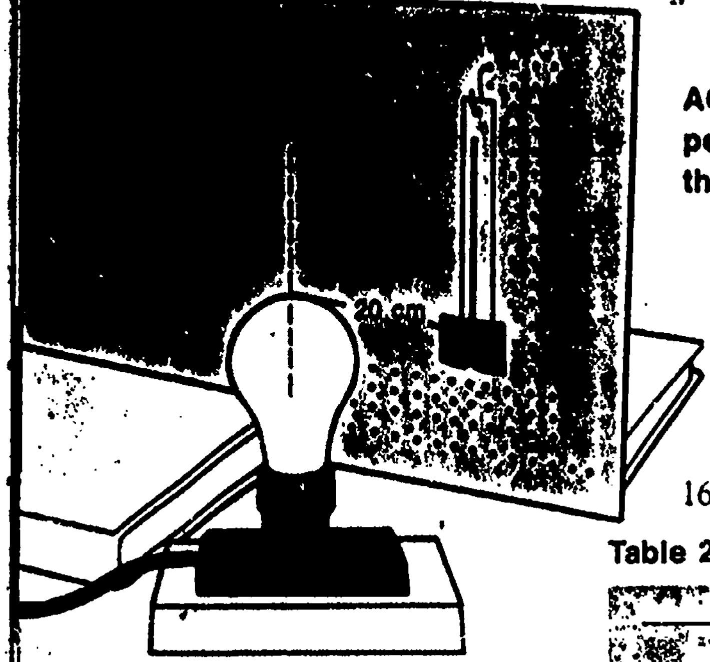
Place the sun-energy indicator away from the light so that it can cool to room temperature.

☐ 2-11. List at least three variables that you think might have affected how much temperature change you observed.

You should now investigate the effects of different amounts of light energy on the sun-energy indicator. You can use light bulbs of different sizes. Be sure to keep other variables, such as time and distance, constant.

ACTIVITY 2-9. Set up the sun-energy indicator and light source as shown. *Use a 60-watt bulb* and wait until the temperature reaches its maximum reading (about 5 minutes). Record the original and maximum temperature readings in Table 2-2 of your Record Book.





ACTIVITY 2-10. Allow the thermometer to return to room temperature. Repeat Activity 2-9, using a 100-watt bulb. Record the data in Table 2-2.

The point does not have to be made with the student but, correctly stated, the watt number on the bulb tells how much energy it produces *per second.*

Use data from the 0.0 and 5.0 lines of Table 2-1 on page 16 to fill in the spaces in Table 2-2 for the 150-watt bulb.

Table 2-2

Bulb	Original Temperature	Maximum Temperature	Temperature Change
60w			
100w			
150w			

The watt number on a bulb tells you how much energy it produces. The greater the wattage, the greater the energy produced.

☐**2-12.** Which of the following bulbs produces the most light energy: 150W, 60W, or 100W?

Complete t .e last column in Table 2-2, and graph your results in Figure 2-2 of your Record Book.

Figure 2-2

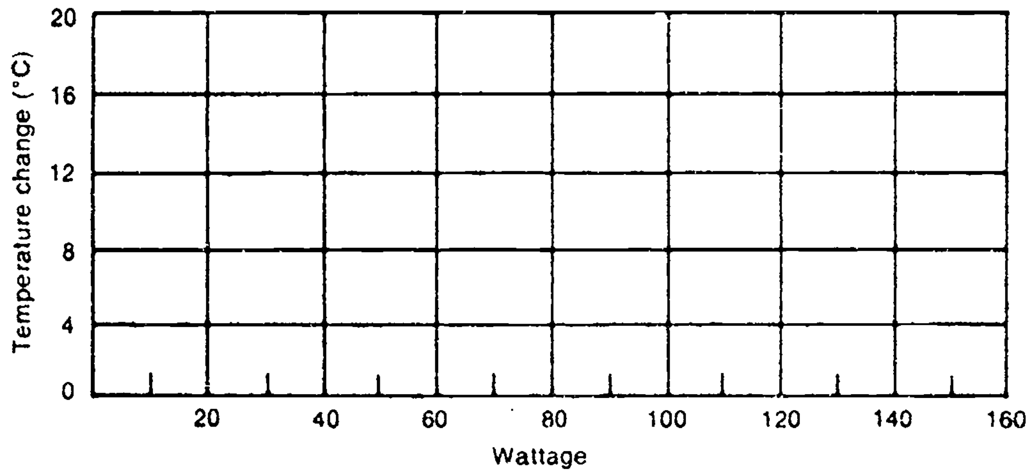


Figure 2-2. The graph should be a straight line. Of course, it should pass through the "0,0" point (no wattage, no temperature change) and show about 5°C at 60W, 8 C at 100W, and 12°C at 150W.

☐**2-13.** What happened to the temperature change as the wattage (amount of energy) of the bulb increased?

☐**2-14.** Look at your graph in Figure 2-2. Predict the amount of temperature change you would have recorded if you had used a 50-watt bulb.

2-14. The prediction should be about 4°C for a 50-watt bulb.

☐**2-15.** Suppose the 50-watt bulb had been placed 40 cm from the strip instead of 20 cm. Predict how this would have affected the amount of temperature change.

2-15. The student should be able to predict a decrease in the amount of temperature change. At this time he cannot reasonably be expected to know how great the decrease will be.

PROBLEM BREAK 2-1

Get a 50-watt bulb and test your predictions for questions 2-14 and 2-15. How much does the reading of the sun-energy measurer change when you double the distance between it and a light source? Suppose you tripled the initial 20-cm distance. Would the temperature reading decrease to one third of what it was at 20 cm?

In your Record Book, describe an experiment you could do to study the relationship between distance and temperature change. Have your teacher approve your design before doing the experiment. Record your data in your Record Book in the form of a graph with at least *eight data points.*

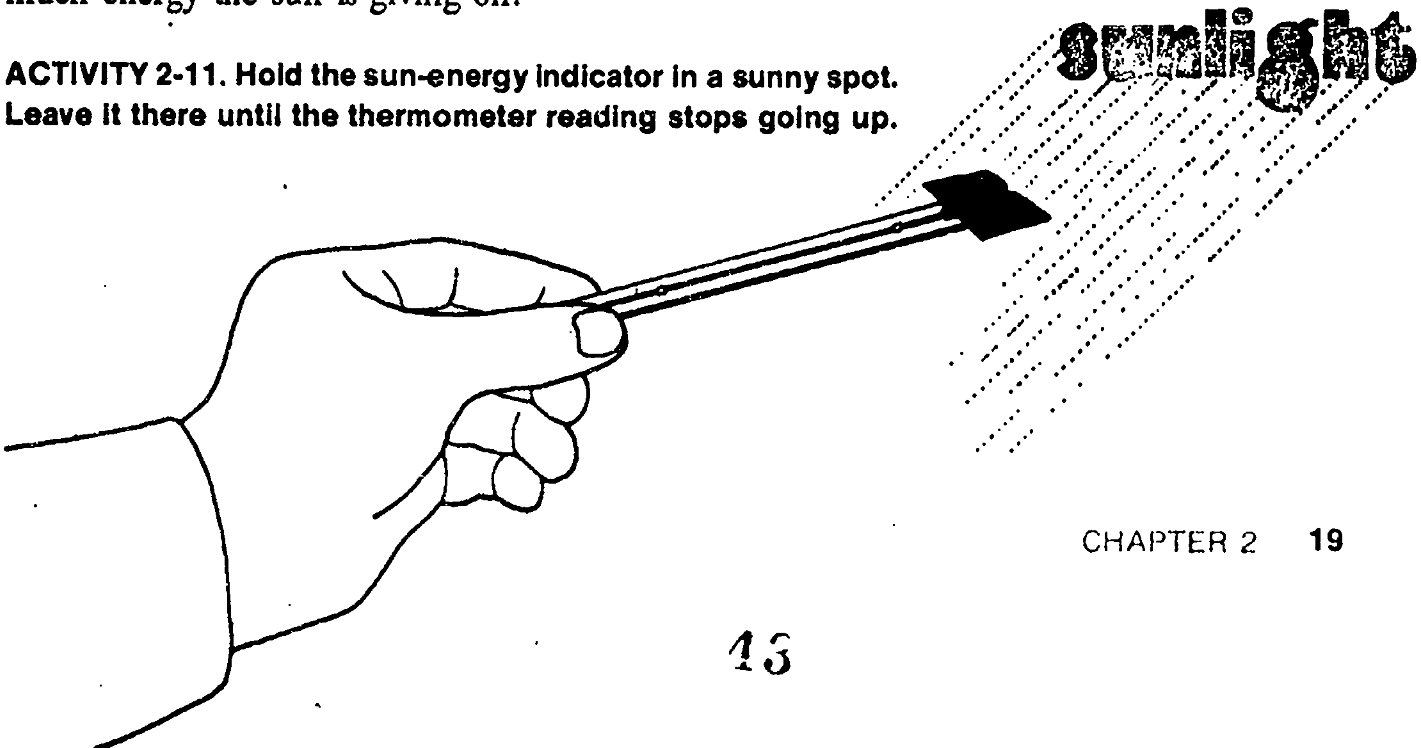
☐**2-16.** In your experiment, why should you keep the wattage of the light source constant at 50 watts?

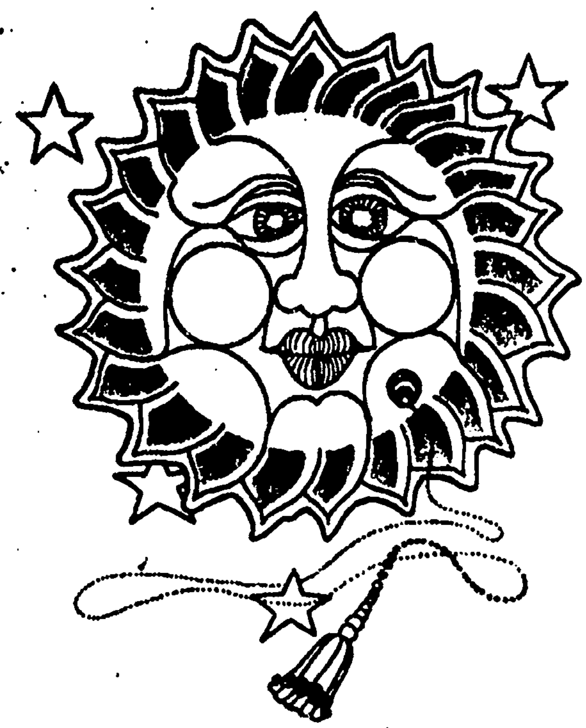
Problem Break 2-1. This is the most important point of the chapter. The information that the student gets from the graph provides the answer to question 2-18 on the next page. This answer in turn is the starting point for figuring the power of the sun in Chapter 7. Check student work carefully. Extra time here will be well spent. The eight data points can be gotten by spacing the center of the bulb at 5-cm intervals, starting at a point 5 cm from the strip.

See the Teacher's Edition of the Record Book for a sample graph for Problem Break 2-1. The student graph should look similar to that. Using the answer to question 2-17 on the vertical axis, the student can read the answer for question 2-18 on the horizontal axis. This is a graph of an inverse-square relationship.

Now let's return to the problem that started this chapter. Let's try to use your sun-energy indicator to find out how much energy the sun is giving off.

ACTIVITY 2-11. Hold the sun-energy indicator in a sunny spot. Leave it there until the thermometer reading stops going up.





□**2-17.** How much temperature change did the sun-energy indicator show?

Now look at your graph from Problem Break 2-1.

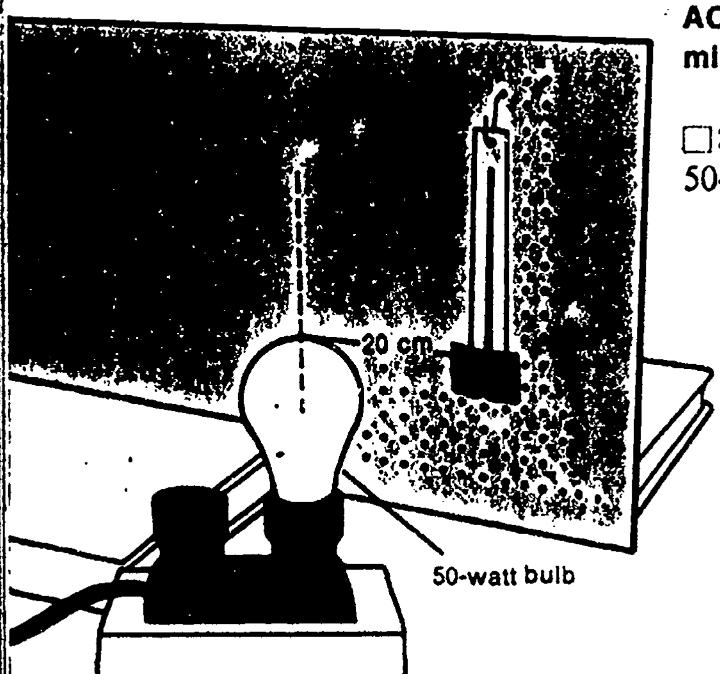
□**2-18.** At what distance from a 50-watt bulb must the indicator be placed to show the same temperature as it did in direct sunlight?

Test your answer to question 2-18 by placing the sun-energy indicator at the distance you gave.

You know that the sun gives off a lot more energy than a 50-watt bulb. But because it's so far from the earth, the energy that reaches the copper strip from the sun is no greater than that from the much closer bulb. The distance an object is from the light source has a great effect on the amount of energy received by the object. Therefore, when calculating the energy produced by the sun, its distance must be an important factor.

An accurate measure of the sun's energy must include its distance from the earth. In a later investigation you will measure that distance. For now, you can only get an idea of how great is the sun's total energy output. To do this, you will need to take your sun-energy measurer over to the area where the bulbs in parallel circuits are located.

ACTIVITY 2-12. Set up your apparatus as shown. After 5 minutes, note the temperature.

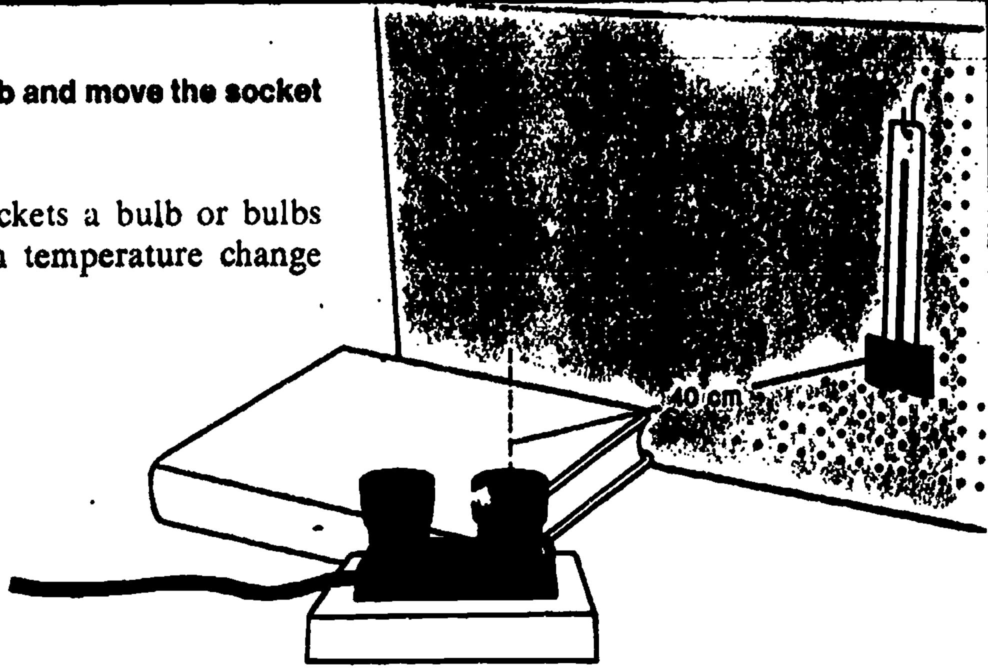


□**2-19.** Record the highest temperature reading from the 50-watt bulb at 20 cm.

There should be a temperature change of about 4°C with a 50-watt bulb at 20-cm distance. Whatever the room temperature, the highest temperature reading for question 2-19 should be about 4°C higher.

ACTIVITY 2-13. Remove the 50-watt bulb and move the socket 40 cm from the sun-energy measurer.

Your problem is to place in the sockets a bulb or bulbs that will produce the same maximum temperature change that you found in Activity 2-12.



☐ **2-20.** What wattage (energy) bulb or bulbs do you predict will produce this reading?

2-20. This is a difficult question, but if the student has done careful work and can read the graph, doubling the distance will cause ¼ as much temperature change. Therefore, to get the same temperature change, there must be 4 times the wattage. The answer would thus be 200 watts. This should check out for question 2-21 (four 50-watt bulbs), and in question 2-22 it would require 4 times as many again, or sixteen 50-watt bulbs.

Add bulbs to the sockets until you find one, or a combination, that produces roughly the reading you are looking for. Be sure that the bulbs are 40 cm from the sun-energy measurer.

☐ **2-21.** How many 50-watt bulbs would you need at 40 cm to give the same temperature reading that one 50-watt bulb gave at 20 cm?

☐ **2-22.** Suppose you moved the sockets to 80 cm. How many 50-watt bulbs would you have to use to produce the same reading as one 50-watt bulb at 20 cm?

Now think how many 50-watt bulbs you would need if you moved the socket out a mile from the energy indicator. You'd have to have a tremendously large source of energy to give the same reading.

The sun is many, many miles from the earth. With what you know now, you can be sure that the sun is giving off a tremendous amount of energy. To give a good estimate of how much, you will need to know how many miles away the sun is. That is the subject of the next chapter—the way to measure the distance from the earth to the sun.

GET IT READY NOW FOR CHAPTER 3

The range finders should be assembled. You will need manila folders or large pieces of cardboard taped in place on the range finders. The students will also need white unlined paper. You will also have to set up a sighting range. See the teacher notes in Chapter 3 for directions.

Before going on, do Self-Evaluation 2 in your Record Book.

EQUIPMENT LIST

Per student-team

1 range finder (assembled, with manila folder taped to pegboard)
1 sheet of white unlined paper

CHAPTER EMPHASIS

The student investigates the use of a simple range finder for measuring distances, and determines some of the variables and the limitations of the instrument.

Far-Out Sun

Chapter 3

Excursion 3-1 is keyed to this chapter.

MAJOR POINTS

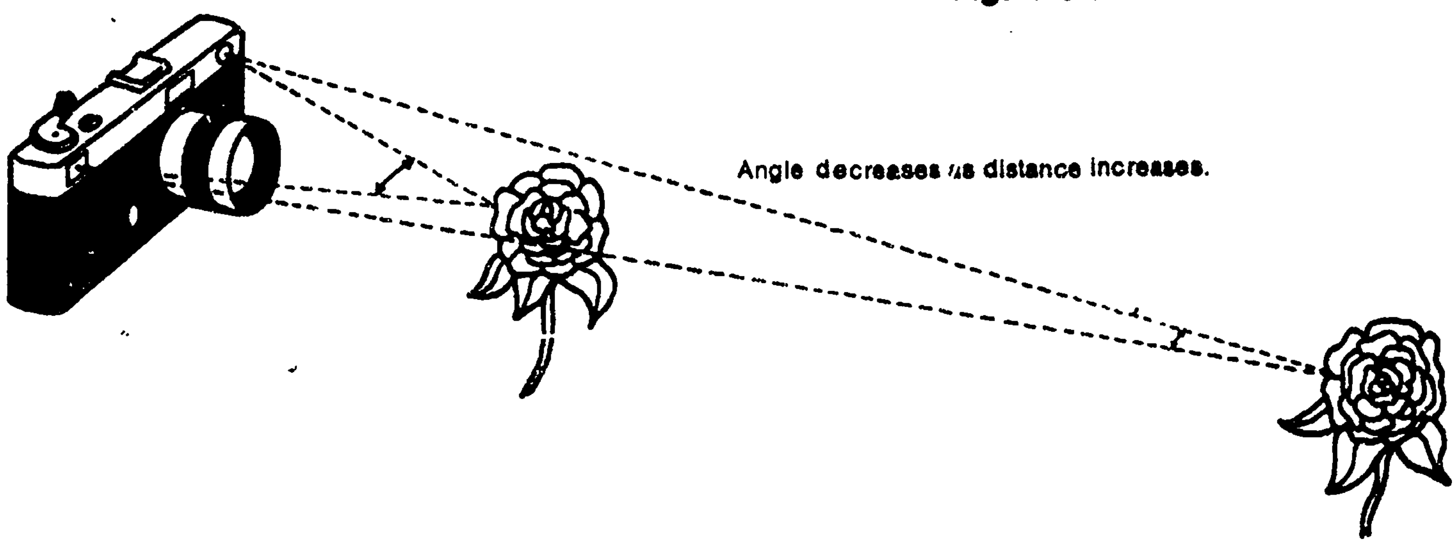
1. The range finder operates on the principle of angles and triangles.
2. A range finder can be calibrated by sighting objects at known distances.
3. As the distance to the object decreases, the angle between the sighting bar and the sighting line increases.
4. As the distance to the object increases, the sighting marks get closer and closer together.
5. The range finder loses its usefulness beyond about 15 meters.
6. The length of the range finder's base line is a limiting factor in the distance that can be measured.
7. In its present form the range finder is useless in measuring large distances, such as the distance to the sun.
8. Another limiting factor of the range finder is its inability to measure the sighting angle accurately.
9. Using any terrestrial distances the base line is still too short to give accurate angle measurements by the range-finder method.

Measuring the distance to the sun may seem like an impossible job to you. More than likely, you've always used a ruler or meterstick to measure distances, but such a device won't work for measuring the distance to the sun.

Actually, the problem won't be as difficult as you may think. In many ways, you're in the same boat as a hunter—or a photographer—who wants to know the distance to an animal. If he tries to use a ruler or tape measure, he won't get many shots.

Both camera and rifle manufacturers have solved the problem in the same way. Many guns and cameras include a device called a range finder. In using a range finder, a person looks at an object from two different angles. The device evaluates the distance to the object from the size of the angles formed. (See Figure 3-1.)

Figure 3-1

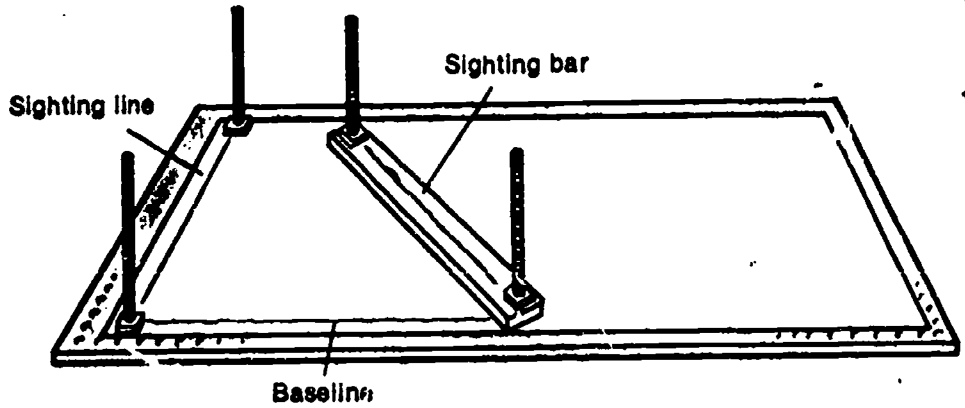


The range finders should be assembled with the manila folder or cardboard in place. The white paper should not be added until Activity 3-4, however.

It is important for the students to discover the usefulness and the limitations of the instrument themselves. Resist the temptation to legislate the distances and uses during this trial period.

You can use a simple homemade range finder that will help you measure the distance to the sun. Get one from the supply area.

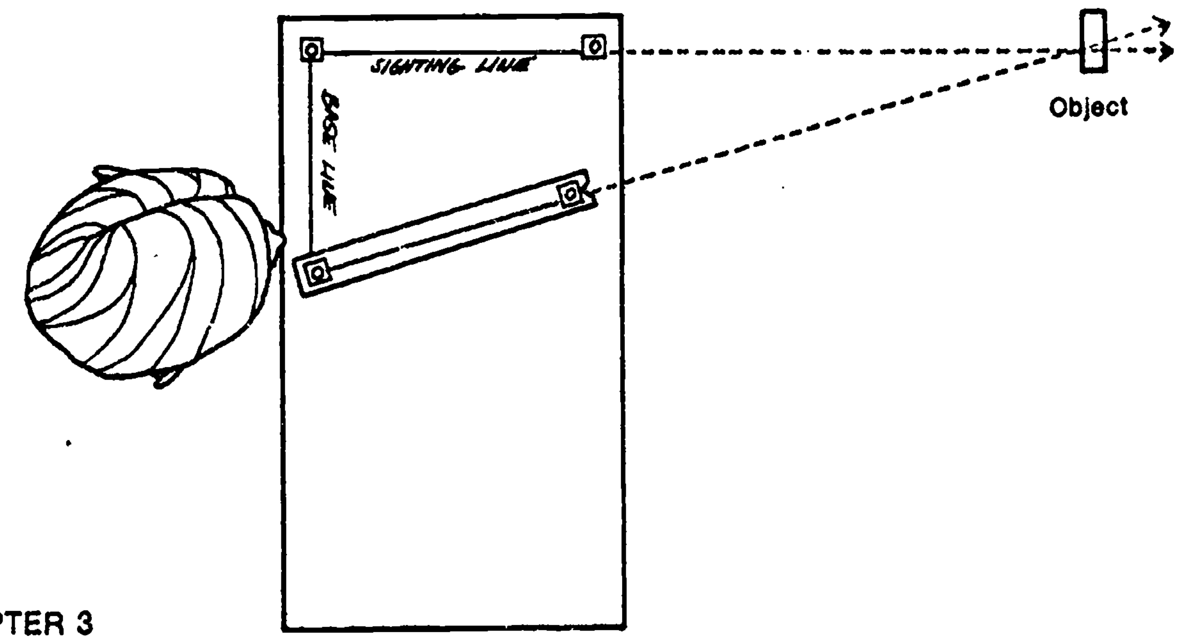
ACTIVITY 3-1. Look the range finder over carefully. Note particularly the labeled parts. Draw and label the sighting line and base line on your range finder if this has not been done.



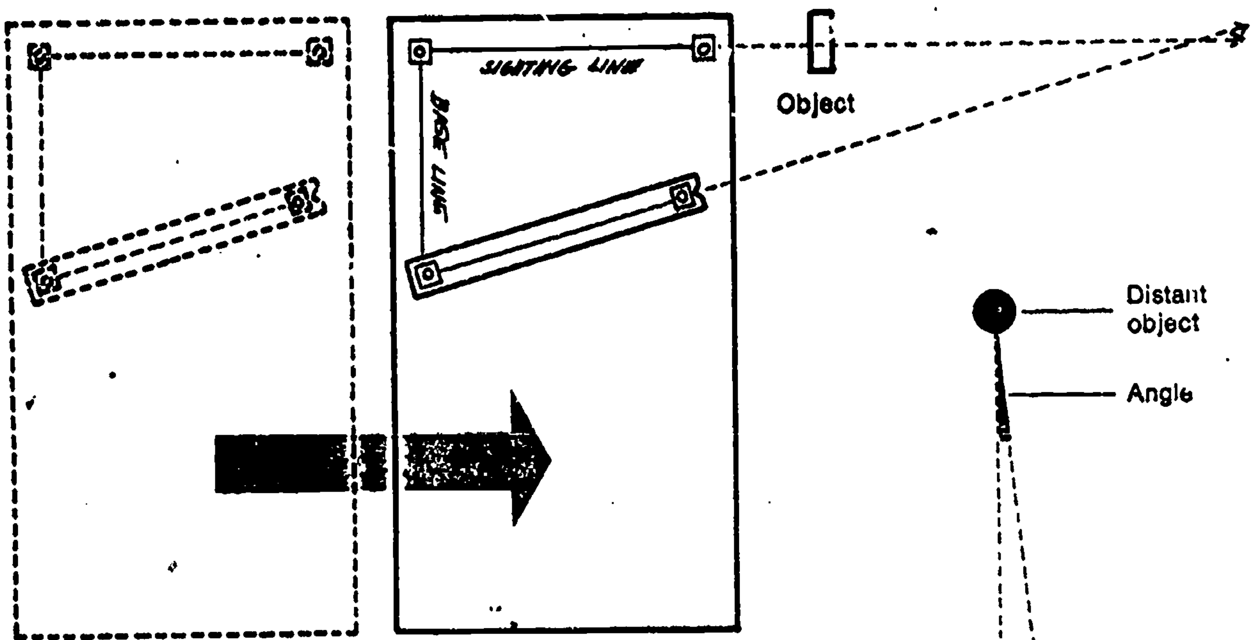
In using the range finder, a student should keep his sighting eye well back from the bolt. If he moves too close, the nearer bolt completely blocks the sight on the farther bolt.

Before you try to measure the distance to the sun with the range finder, you should learn how it works. Pick out an object to look at on the other side of your classroom.

ACTIVITY 3-2. Place the range finder on a flat surface and line up the sighting line with the object. Without moving the pegboard, adjust the sighting bar until it lines up with the object. When you are finished, both the sighting line and sighting bar should be lined up with the object.



ACTIVITY 3-3. Move the range finder along the sighting line until it is several feet closer to the object. *Don't change the position of the sighting bar.*

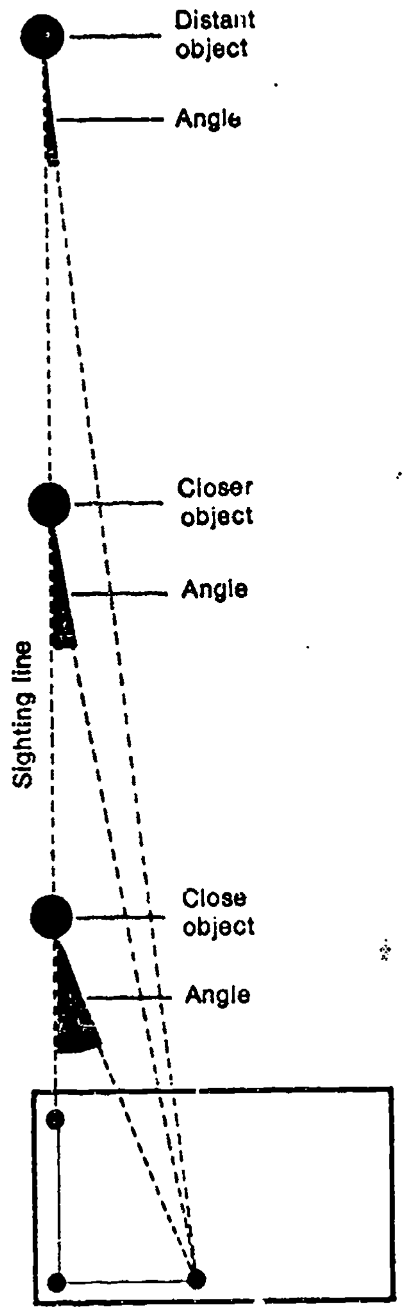


☐ **3-1.** Does the sighting bar still line up with the object after the range finder is moved? If not, what would you have to do to line it up?

☐ **3-2.** Suppose you were to move the range finder even closer to the object along the sighting line. Predict what you would have to do to align the sighting bar.

Perhaps you are beginning to understand the principle upon which the range finder works. As the device is moved closer to an object, the angle between the sighting bar and the sighting line changes.

☐ **3-3.** Suppose the distance from the range finder to an object increases. In what way do you predict the angle between the sighting line and sighting bar will change?

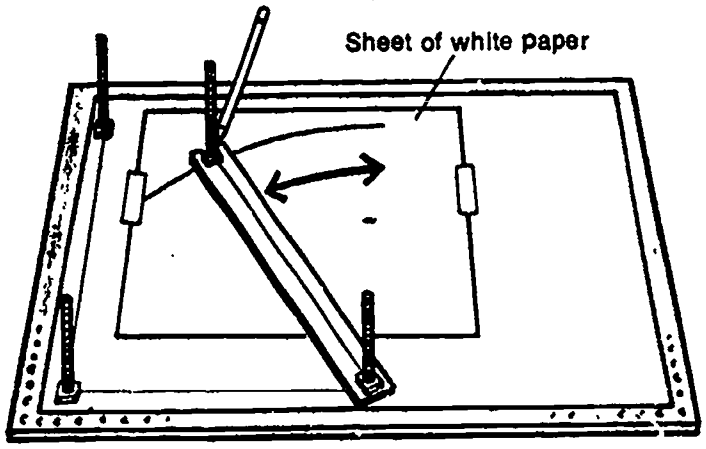


Test your prediction in question 3-3 by doing the next activity.

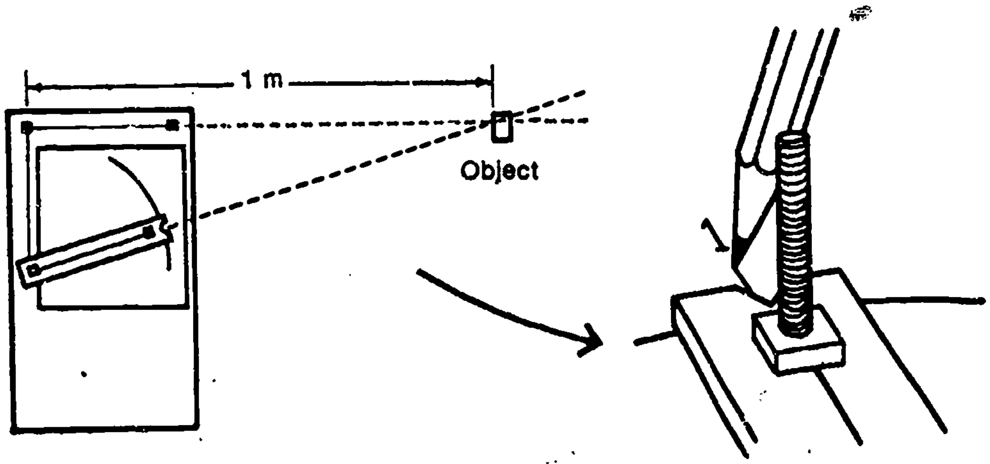
Your teacher has chosen an object in your room and placed marks on the floor at distances from it of 1, 2, 3, 4, 5, 10, and 15 meters.

Note that for the calibration of the range finder, beginning with Activity 3-4, you will need a sighting range set up somewhere in the room, with distances of 1,2,3,4,5,10, and 15 meters marked from some object to be sighted. The 15-meter distance (49 feet) is a little large for the average classroom. You may have to stop at a shorter distance, or you might be able to set up the range in a corridor. In the classroom, an excellent sighting object could be a distinct chalk mark on the front chalkboard.

ACTIVITY 3-4. With small pieces of tape, attach a sheet of white paper to the range finder as shown. Place the tip of a pencil into the groove at the end of the sighting bar. Turn the bar to draw part of a circle.

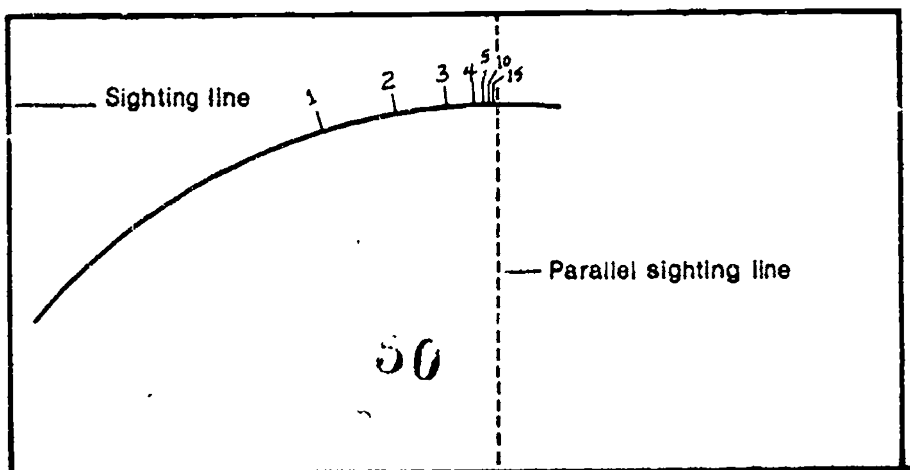


ACTIVITY 3-5. Place the range finder so that the sighting line rear bolt is at the 1-m mark on the floor. Line up the sighting line, and then the sighting bar, with the object. When you are sure the position of the bar is correct, make a mark on the circle as shown, and label the mark "1."



ACTIVITY 3-6. Repeat Activity 3-5 for distances of 2m, 3m, 4m, 5m, 10m, and 15m. When your scale is complete, it should appear similar to that shown. Label each mark.

The marks and the labeling for 5, 10, and 15 meters will be relatively close together. The numbers will have to be small, and a sharp pencil should be used for making the marks.

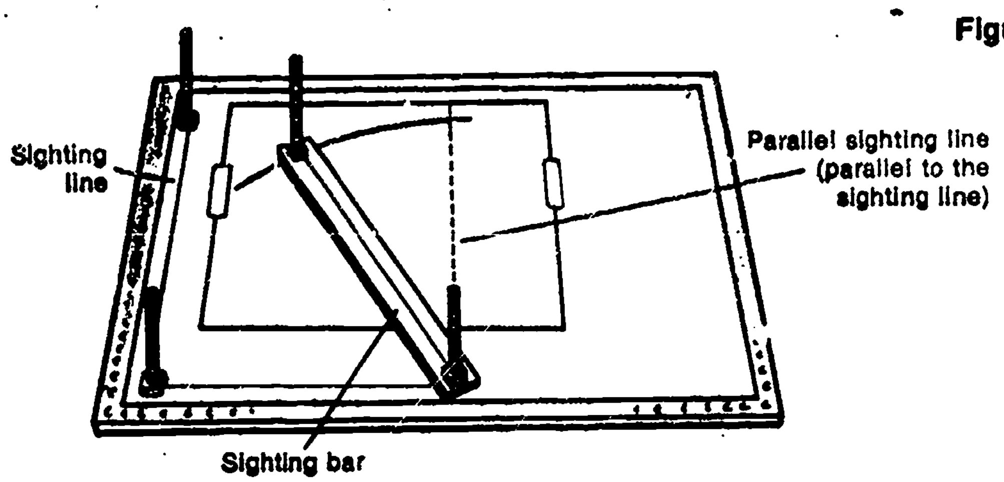


Practice using your range finder to measure the distance to objects not more than 15m away. Check your measurements with a meterstick. If they are inaccurate by more than ½m, repeat Activities 3-4, 3-5, and 3-6.

3-4. In question 3-3, the student should have predicted that as the distance gets greater the angle gets smaller. Whatever was predicted, however, the student should now clearly see this important relationship. The decreasing size of the angle and the resulting difficulty of accurate measurement become the limiting factor in the use of the instrument.

☐**3-4.** Was your prediction in question 3-3 correct? As the distance to an object becomes greater, what happens to the angle formed by the sighting bar and the parallel sighting line shown in Figure 3-2?

Figure 3-2



☐**3-5.** Suppose you lined up the sighting line and the sighting bar of the range finder in Figure 3-2 on an object a long way off (like a distant tree). Would you expect the angle between the sighting bar and the parallel sighting line to be large or small?

Check your prediction by using your own range finder. (Draw a parallel sighting line on your range finder if it will help you.)

Select two very distant objects, one of which is farther away than the other—a distant tree and building perhaps. Use the range finder to decide which of the objects is farther away.

☐**3-6.** Describe any problems you had in deciding which object was farther away.

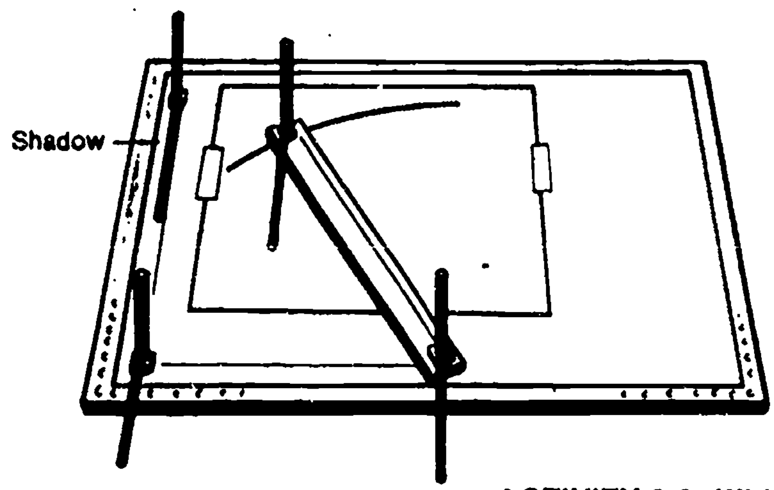
3-6 This is a good item to check the student's understanding of the activities. A variety of answers are possible. Hopefully, the student will discover that the motion of the sighting bar is so small that little difference can be seen in the two measurements. This is just another way of saying that the sighting angle is getting too small to measure accurately with the instrument.

Well, by now you should have a good understanding of how to use the range finder. It seems to work fine on short distances but not so well for distances beyond about 15 m. This may limit its usefulness for measuring great distances like the distance to the sun. See if it will.

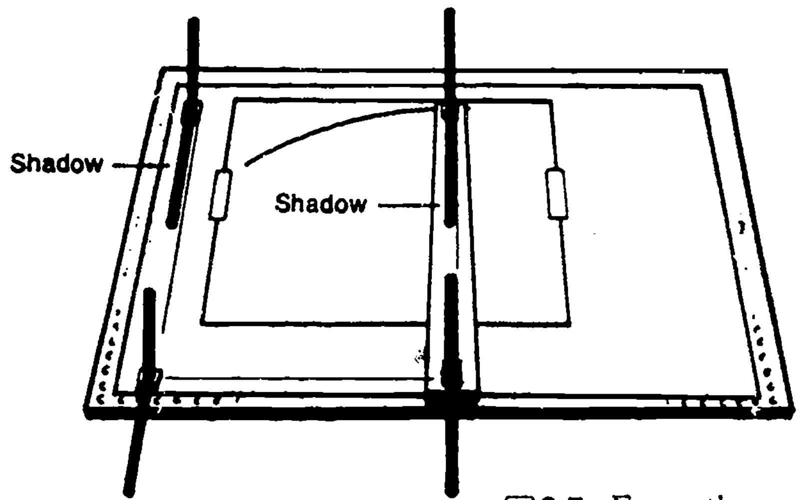
IMPORTANT: Do not allow the students to sight on the sun directly. Even though there is a safety note to the student, a personal word from you might be in order.

Safety Note *Because of the danger of looking at the sun directly, you must change slightly your method of sighting. Instead of lining up bolts, you will try to line up the shadows the bolts cast.*

ACTIVITY 3-7. Set the range finder in a patch of sunlight so that the shadow from the front bolt falls directly along the sighting line.



ACTIVITY 3-8. *Without moving the pegboard,* move the sighting bar until the shadow from its front bolt falls directly along the bar.



3-7. It is too far away to measure with the range finder. Actually, the sighting bar should be parallel to the sighting line. The angle between two parallel lines (if there is such a thing) is 0°. The angle has simply become too small to measure.

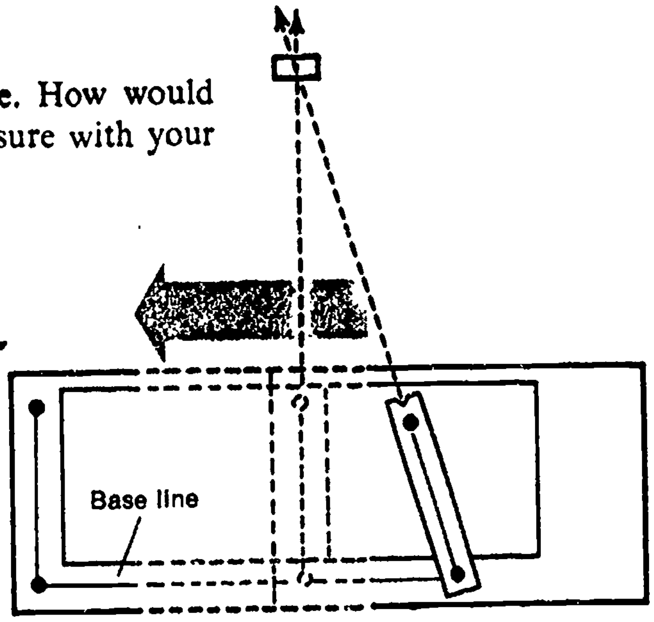
☐**3-7.** From the position of the sighting bar on your scale, what can you say about the distance to the sun?

Clearly, you have a problem. There seems to be a limit to the distance you can measure accurately with your range finder.

One variable that limits the distance that can be measured is the length of the range finder's base line.

□3-8. Suppose you lengthened the base line. How would this affect the greatest distance you can measure with your range finder?

The prediction in question 3-8 should have been that lengthening the base line would increase the greatest distance that could be measured. Actually, the increase would be proportional to the increase in the base line, because the size of the sighting angle is the critical thing, and the tangent of the angle is equal to the base line divided by the distance to the object. Thus, for a given angle, an increase in one factor would make a proportional increase in the other. An experiment to test this prediction might involve shifting the sighting bar on the range finder so that the base line is longer. With the existing configuration, it would be possible to shift the bar so that the base line is twice as long. Measurements could then be made of the effect on the spacing of the marks on the scale. Wider spacing (greater angular change) would be a good indicator of greater distance potential.



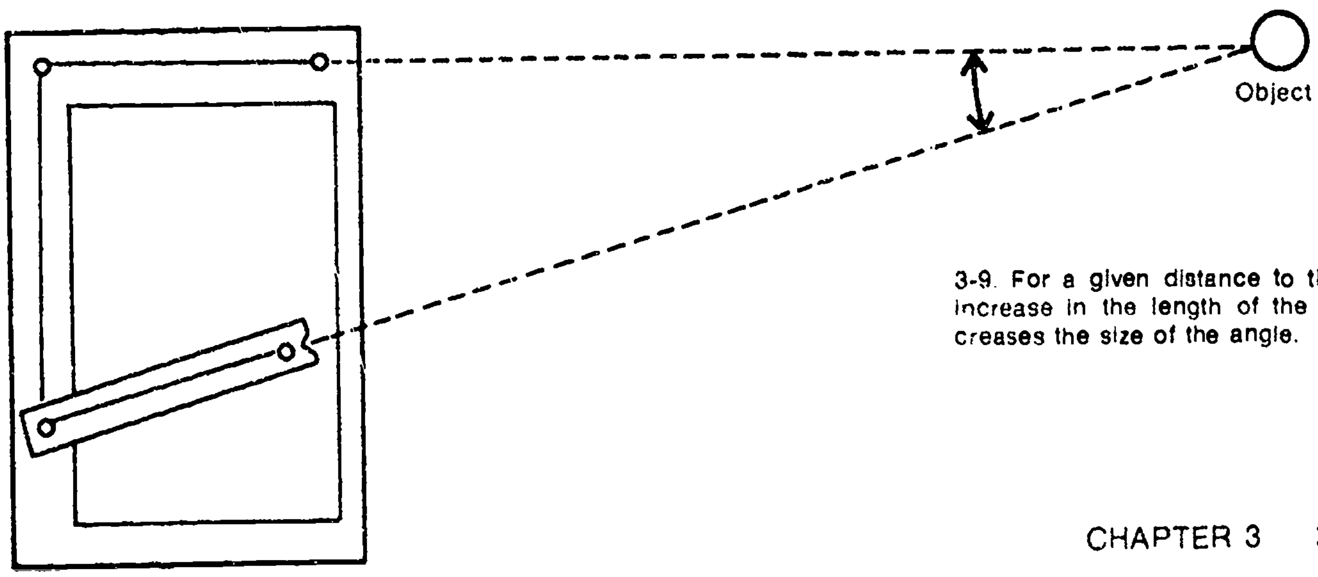
PROBLEM BREAK 3-1

Design an experiment to test the prediction you made in question 3-8. In your Record Book, describe what you would do and what measurements you would make. Check with your teacher and then do the experiment. Record your results and conclusions.

From your experiments, it should be clear that two variables limit the greatest distances that can be measured by your range finder. The first is the length of the base line. The second is the size of the smallest measurable angle between the sighting bar and the parallel sighting line (the sighting angle).

□3-9. In Figure 3-3, how would increasing the base line affect the size of the angle between the two sighting lines?

Figure 3-3



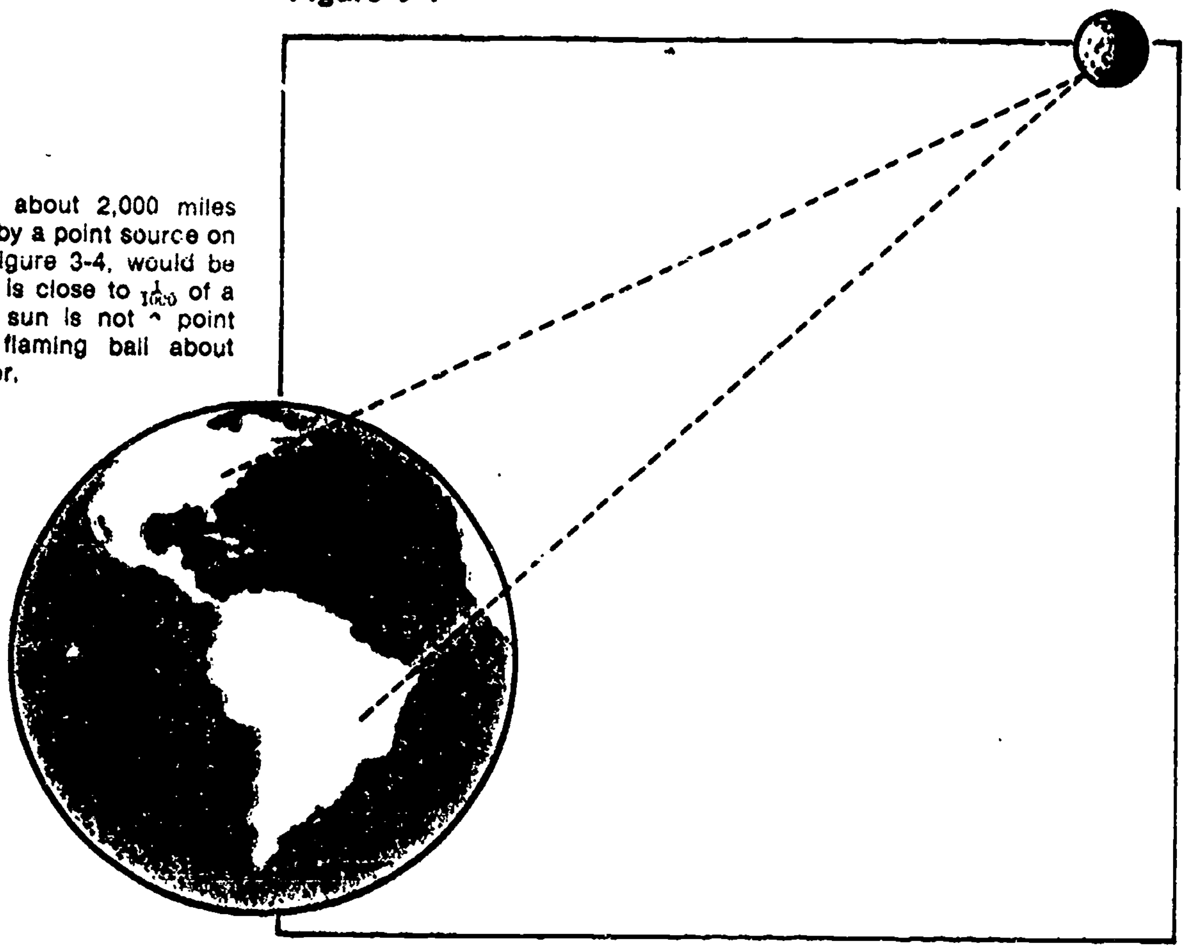
3-9. For a given distance to the object, an increase in the length of the base line increases the size of the angle.

Astronomers could make sightings from two observatories that are hundreds or even thousands of miles apart. Figure 3-4 shows how this can be done.

3-10. The angle would increase. For small angles (which these are) the increase would be proportional to the increase in the base line.

□ **3-10.** If you switched from a simple range finder to the system shown in Figure 3-4, what effect would this change have on the angle?

Figure 3-4



With two observatories about 2,000 miles apart, [illegible] angle formed by a point source on the s[illegible] as shown in Figure 3-4, would be about [illegible]. Four seconds is close to $\frac{1}{1000}$ of a degree. Of course, the sun is not [illegible] point source but, rather, a flaming ball about 865,000 miles in diameter.

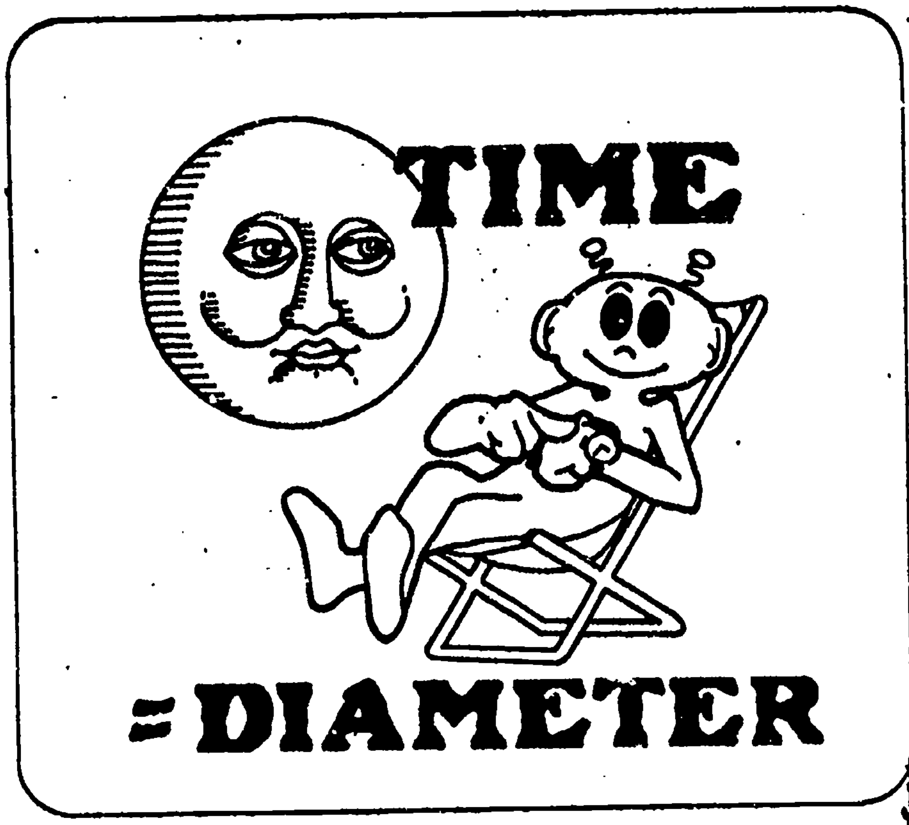
Modern instruments can measure angles of less than 1/1000 of a degree. To increase the base line, sightings of the sun can be made from widely spaced observatories. But even then, the angle turns out to be too small to measure accurately. Unfortunately, the range finder just can't do the job. You must find some other way to measure the distance to the sun. In the next chapter, you will search for a new approach to the problem.

Meanwhile, you might like to know that the distance to the moon has been measured by the range-finder method.

The average distance to the moon is about 240,000 miles. Knowing the distance to the moon makes it simple to find the size (diameter) of the moon.

If you would like to measure the diameter of the moon, **Excursion 3-1** will show you a method that is simple. All you need is a full moon, some time to sit still, and a watch.

Before going on, do Self-Evaluation 3 in your Record Book.

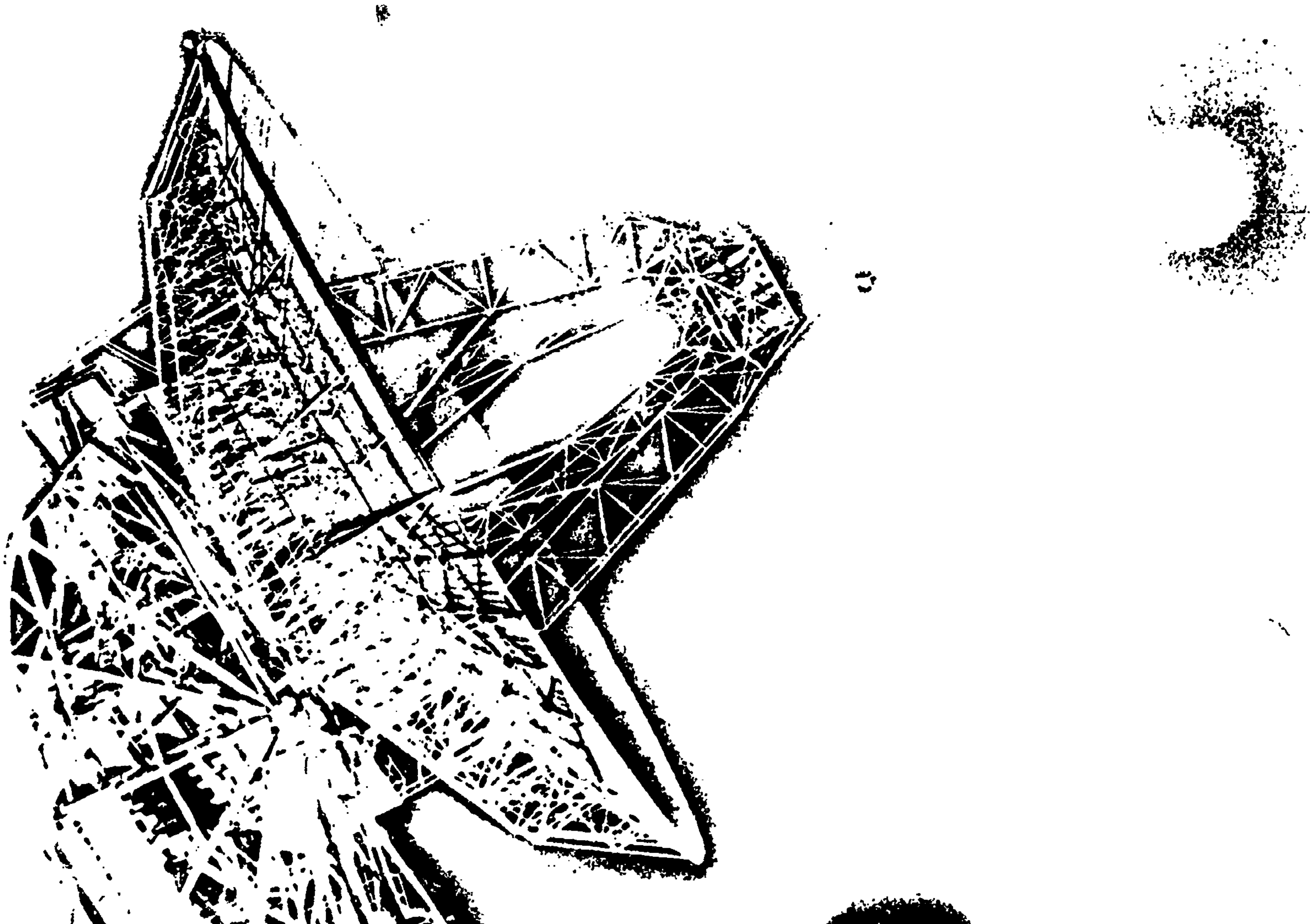


Excursion 3-1 is of general interest. As it requires a full moon, which will not be in the sky during school hours, it should be done at home. And it need not take a great deal of time.

EXCURSION

GET IT READY NOW FOP CHAPTER 4

No new equipment need be prepared. The activities call for students to use 3 beans or other small objects on which to sight. Many different things could be used. Large-headed roofing nails stand up well; thumbtacks would do.



EQUIPMENT LIST

Per student-team

1 protractor
1 drawing compass
3 beans (or other small objects)
1 metric ruler

CHAPTER EMPHASIS

Starting with the distance from Earth to Venus as a base line the range-finder method can be used to find the distance to the sun.

Chapter 4

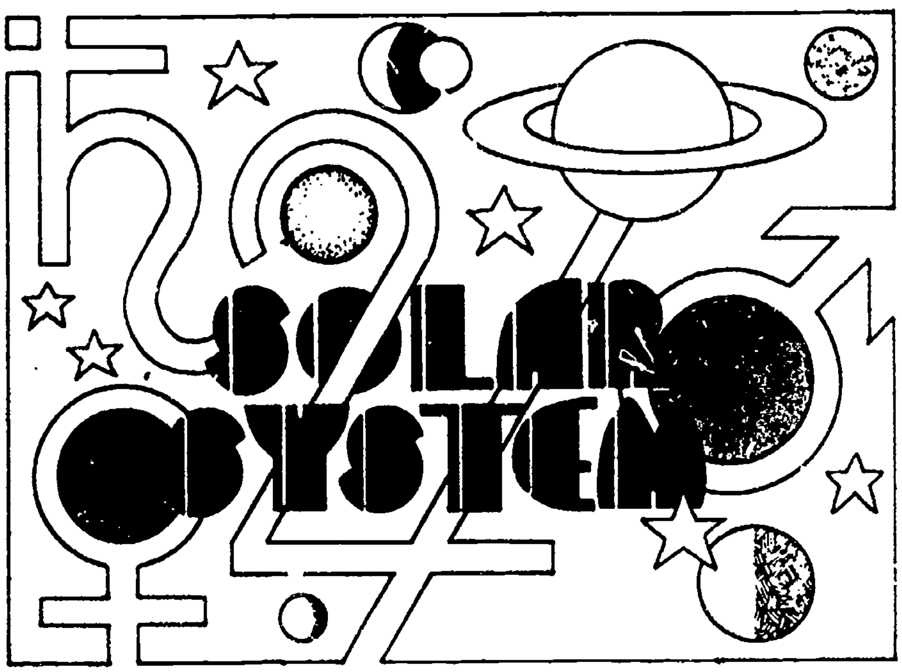
Measuring the Distance to the Sun—Another Approach

Excursions 4-1, 4-2, 4-3, and 4-4 are keyed to this chapter.

Excursion 4-1 is a short general-interest exercise requiring no equipment. It is titled "What's Radar?" and affords some practice in measuring distances by radio waves.

Some years ago, scientists discovered an interesting way to locate objects at a distance—the use of radar. Using radar, they could get good measurements of the distance to the moon and to some of the planets. They found, for example, that the planet Venus, when closest to the planet Earth, is about 26 million miles away. If you are interested in more information about using radar to measure distances, see **Excursion 4-1.**

The measurement of the distance to Venus has proved to be useful. This distance can be used in determining how far the sun is from Earth. Let's see how.



MAJOR POINTS

1. The sun is the center of the solar system.
2. Venus and Earth are planets in the solar system and move in nearly circular orbits in the same plane around the sun.
3. The Venus orbit is within the Earth orbit.
4. The angular speed of Venus is greater than that of Earth; therefore, Venus and Earth are constantly changing relative positions.
5. The angle between the lines of sight to two bodies is called the sighting angle.
6. The largest angle between the Earth-Venus line and the Earth-sun line occurs when the Earth-Venus line just touches the orbit of Venus.
7. Using the largest sighting angle, the orbit of Venus and the orbit of Earth can be drawn to scale.
8. Knowing the minimum distance from Earth to Venus, the distance from Earth to the sun can be calculated from the scale drawing.
9. The distance to the sun is about 93 million miles.

Figure 4-1 shows how the range finder that you used in the last chapter works. Take a close look at the figure; then answer question 4-1.

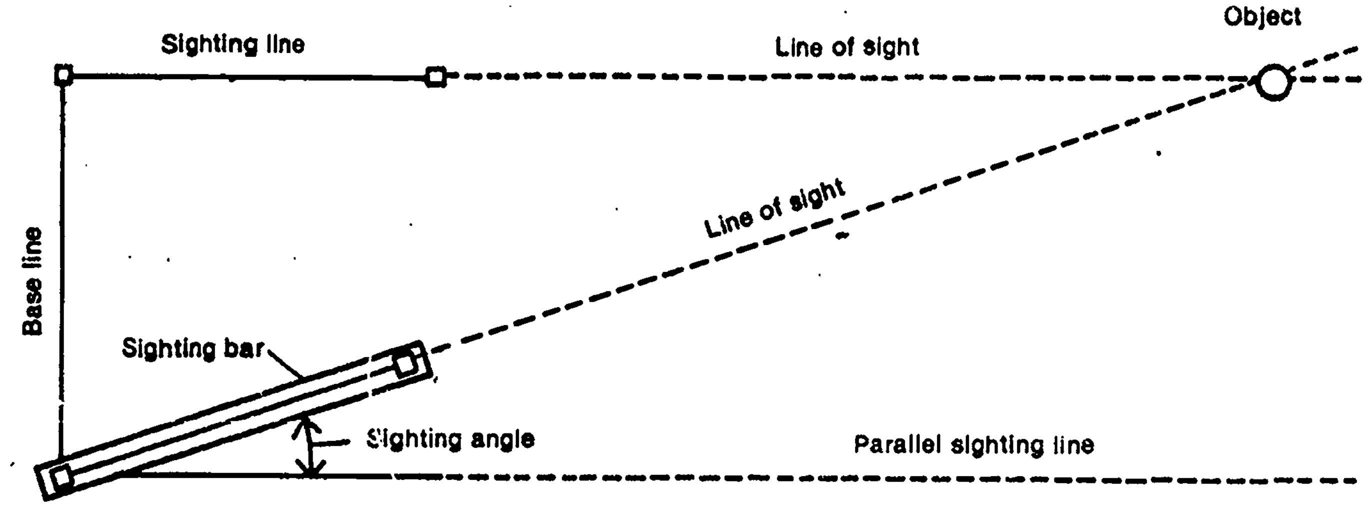


Figure 4-1

4-1. The base line is too short; thus the sighting angle is too small to measure.

☐**4-1.** Why can't the range finder you used in Chapter 3 measure large distances?

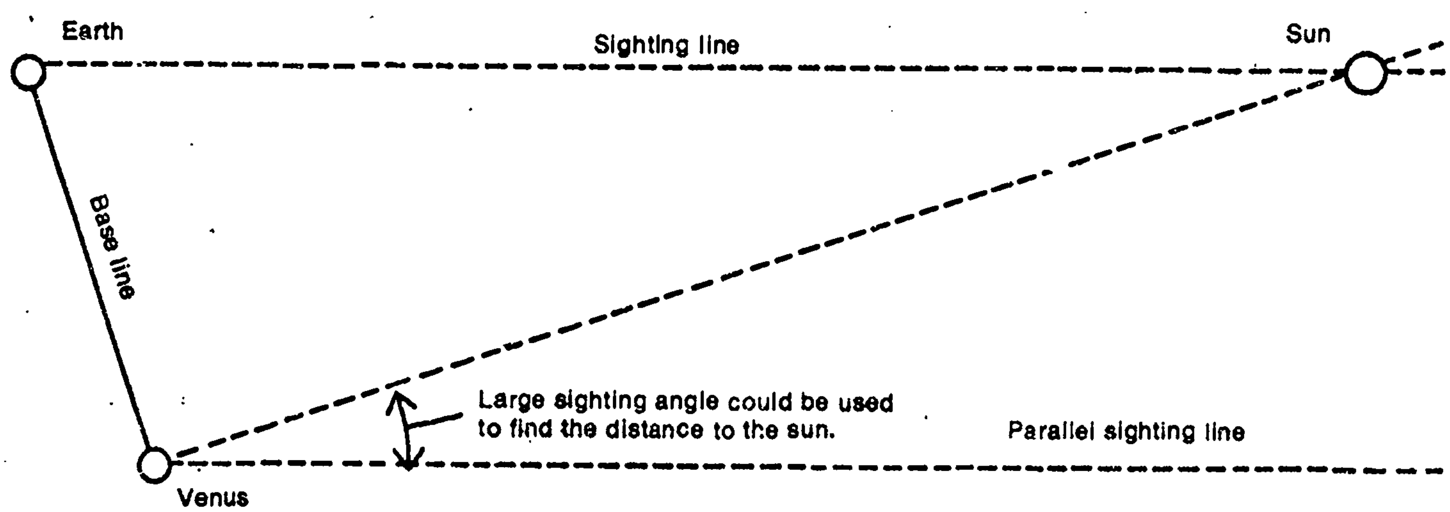
Even the distance across Earth is too small a base for the range-finder method to be used to measure the distance to the sun. But suppose you could use the distance from Earth to Venus as a base line (Figure 4-2).

Notice that in Figure 4-2, the base line is not perpendicular to the sighting line from Earth to the sun. This may confuse some students. You may have to point out that it is not necessary for it to be perpendicular, and the method still works as long as the sighting line and the parallel sighting line are parallel.

☐**4-2.** Do you know how long this base line from Earth to Venus is?

☐**4-3.** What other problems would there be in using the scheme diagrammed in Figure 4-2?

Figure 4-2



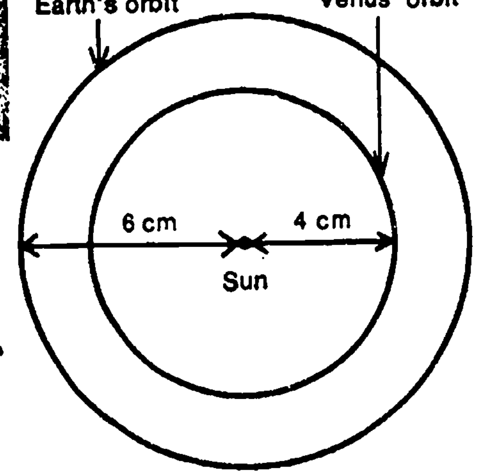
Obviously, you can't easily get to Venus to make a sighting of the sun. This alone makes the plan shown in Figure 4-2 impossible. But there is another way to make use of the distance between Earth and Venus. It requires that you first draw a model of the position of Venus in relation to Earth and the sun. Column 2 of Table 4-1 and the activities that follow will help you do this. Column 1 lists the assumptions you are making as you draw your model.

The list of assumptions in Table 4-1 is basic to the solution of the problem. Some worthwhile small-group discussion might ensue on the rationale for these assumptions. For instance, what reasons do we have for assuming that the sun is at the center of the solar system? that Earth and Venus revolve around the sun? that Venus and Earth move in the same plane?

Table 4-1

Assumption	Effect on Drawing
1. The sun is the center of the solar system.	1. Show sun as center of drawing.
2. Earth and Venus are planets revolving around the sun.	2. Venus and Earth can be shown as moving around the center (sun).
3. Venus and Earth move in the same plane.	3. Both Earth and Venus can be drawn on flat paper.
4. Both Venus and Earth move in roughly circular paths (orbits).	4. Show orbits as circles.
5. Venus is closer to the sun than Earth is.	5. Venus' orbit should be drawn smaller than Earth's orbit.

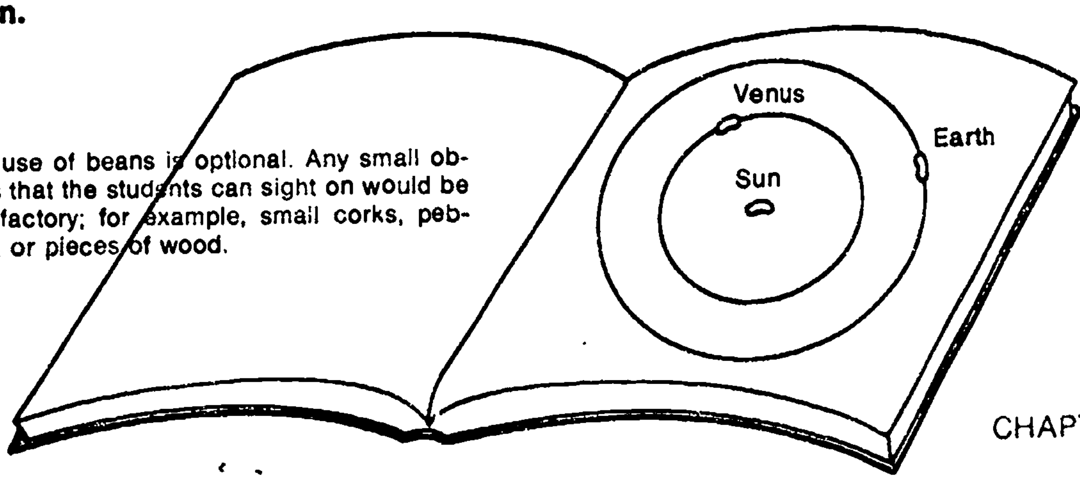
Assumption 4 (circular orbits): The orbit of Earth varies from 94,600,000 miles to 91,400,000 miles from the sun, with a mean of about 93 million miles. This is a variation of less than 2% above and below the mean. If this were accurately drawn as large as possible on a page in the Record Book, there would only be a difference of about 6 mm in the measurements, undetectable without drawing instruments. Venus' orbit varies from a circle even less.



ACTIVITY 4-1. In the space provided in your Record Book, use a compass to draw two circles as shown. Label the sun and the two orbits.

ACTIVITY 4-2. Place a bean anywhere on each of the two circles you've drawn. These will represent Earth and Venus. Place another bean in the center of the circle to represent the sun.

The use of beans is optional. Any small objects that the students can sight on would be satisfactory; for example, small corks, pebbles, or pieces of wood.

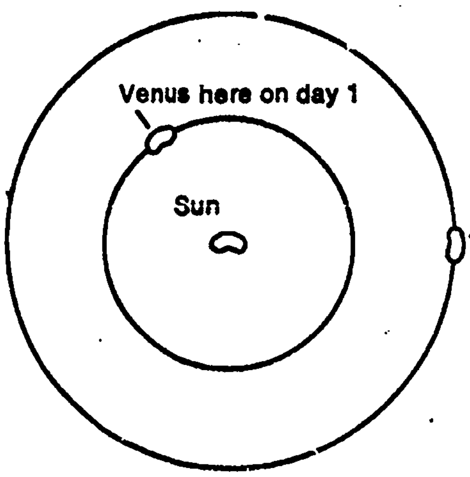


Astronomers have known for many years that Venus' orbit is within Earth's orbit, because Venus is always seen as a morning or evening "star." It never gets farther than about 46° from the sun and is never seen late at night, as are Mars and Jupiter.

Now, use your model—the beans and circles—to study the relative motions of Venus and Earth. To do this, you will have to add two more assumptions to your list:

1. Earth travels completely around its orbit once every 365¼ days.
2. Venus takes 225 days to make one complete revolution.

☐**4-4.** Suppose the planet Earth you just placed in orbit made a complete turn around the sun. How far would Venus have traveled in the same time? (Answer by drawing the new position of Venus in Figure 4-3 of your Record Book.)



4-4. Venus travels around the sun 365/225 times as fast as Earth does. This is 1.62 times as fast. Figure 4-3 should show Earth back in the same position from which it started and Venus making about 1⅝ revolutions from its starting point.

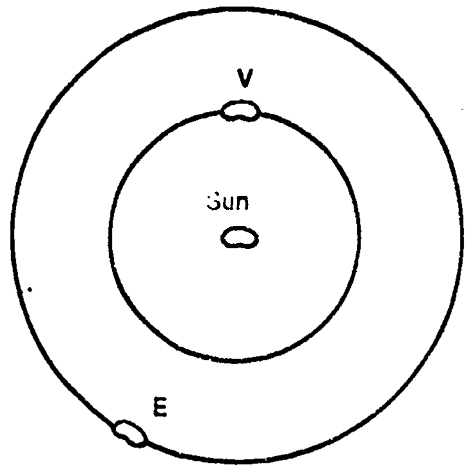
Figure 4-3

☐**4-5.** Does Venus travel faster, or slower, than Earth as it moves around the sun?

4-5. Faster. The more obvious reference is to angular speed. It travels one revolution (360°) in 225 days while Earth requires more than 365 days to revolve around the sun. Not so obvious, and not important for the student to know, is the fact that, being closer to the sun, Venus also travels at a faster linear speed by about 20%. Thus it not only has a shorter distance to go for one revolution, but travels the distance at a faster rate as well.

The last activity gives you an idea of what the paths of Venus and Earth are like. Your next problem is to visualize what the motion of Venus would look like from Earth. Once again, your model can help you.

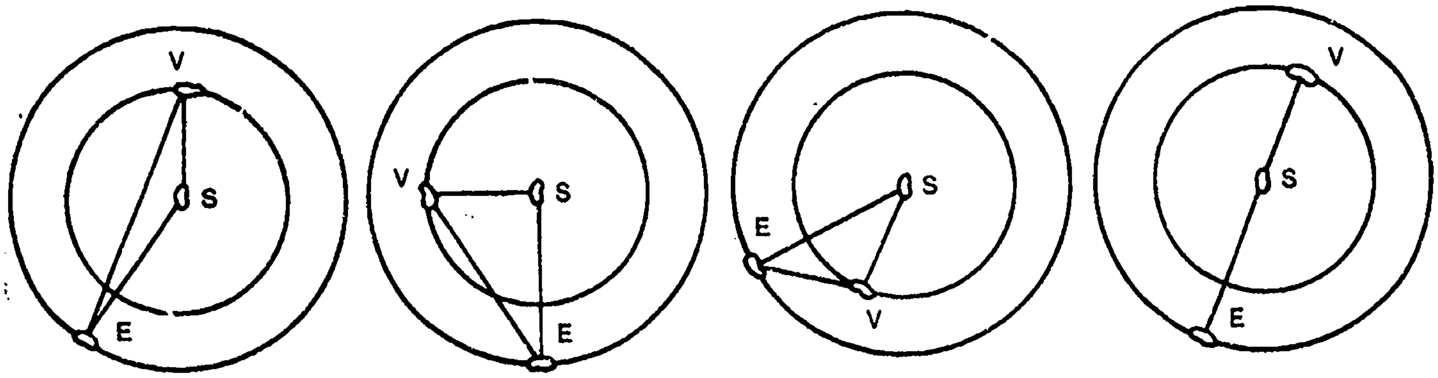
ACTIVITY 4-3. Arrange the beans as shown.



Unless the three beans are perfectly lined up, you can think of them as three points of a triangle.

Move Earth and Venus beans to other points along their circular orbits. Notice that the three beans always form a triangle (except when they are lined up). (See Figure 4-4.)

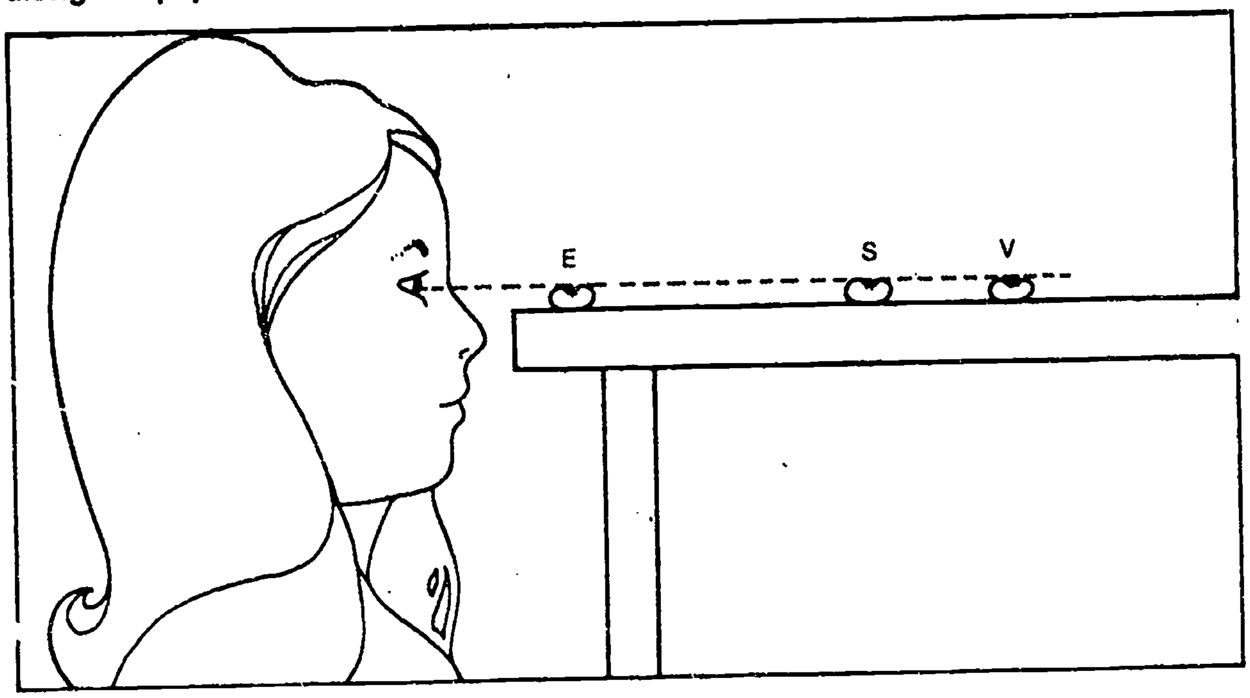
Figure 4-4



Imagine yourself standing on Earth looking at Venus and the sun. Activity 4-4 will help you visualize this.

This sighting of the angle between the two lines formed by the beans (or other objects) is somewhat difficult, but important. You may have to provide help to some students.

ACTIVITY 4-4. Look from behind the bean representing Earth along the paper toward the sun and Venus.



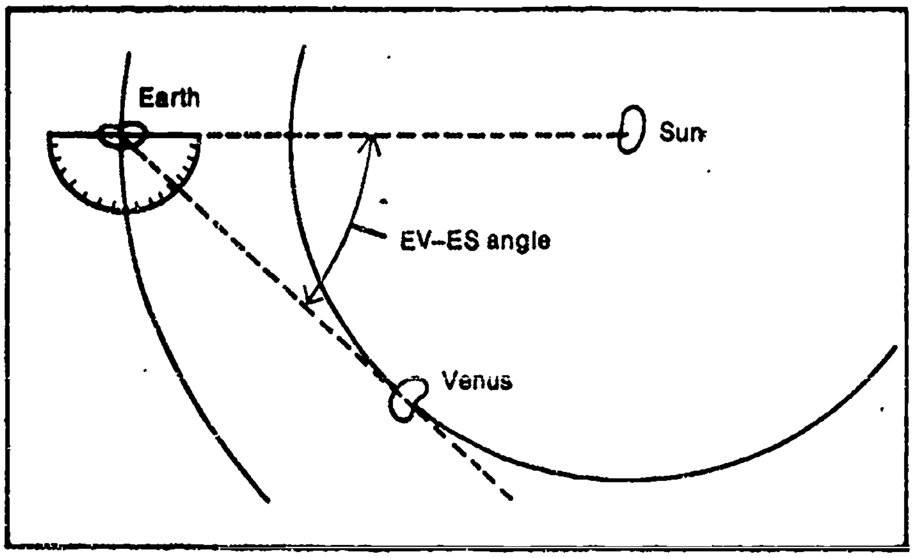
☐**4-6.** What measurement could you make to describe the position of Venus with respect to the sun?

Question 4-6 may not have been too easy. The angle formed where line EV (the line of sight from Earth to Venus) crosses line ES (the line of sight from Earth to the sun) can be used to describe the position of Venus with respect to the sun.

EXCURSION

Excursion 4-2 provides help on the use of a protractor. Protractors differ, and the student may need practice on the particular kind that is available, even though he has used one previously.

ACTIVITY 4-5. Experiment by moving Earth and Venus until you find the position at which the EV–ES angle is greatest. Measure this angle with a protractor. (See *Excursion 4-2* if you don't know how to use a protractor.)



□**4-7.** When would the EV–ES angle be the greatest?

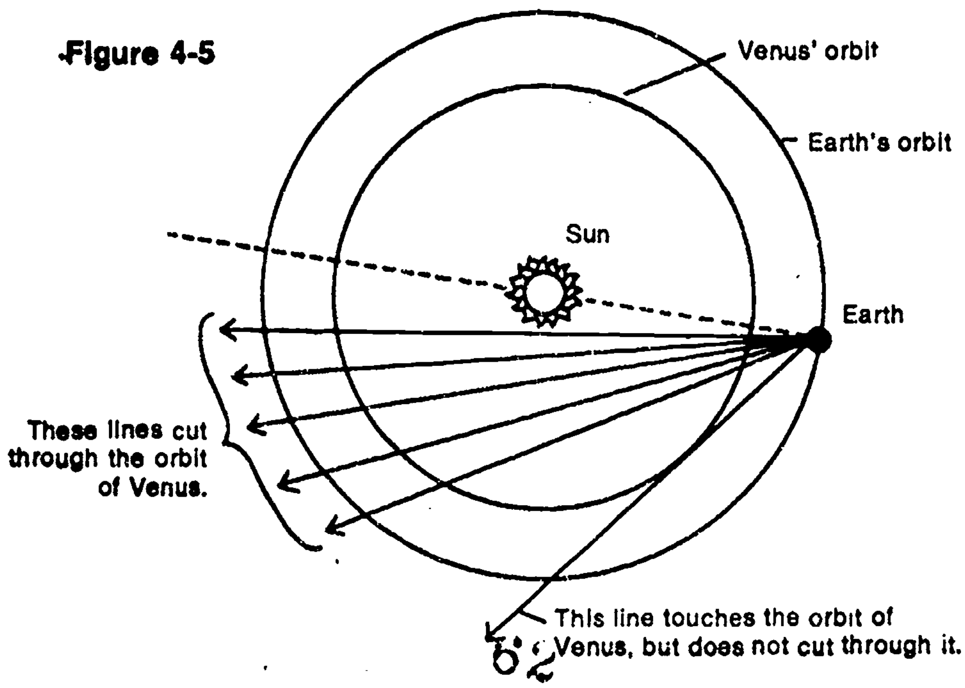
□**4-8.** What number of degrees are there in the greatest possible EV–ES angle?

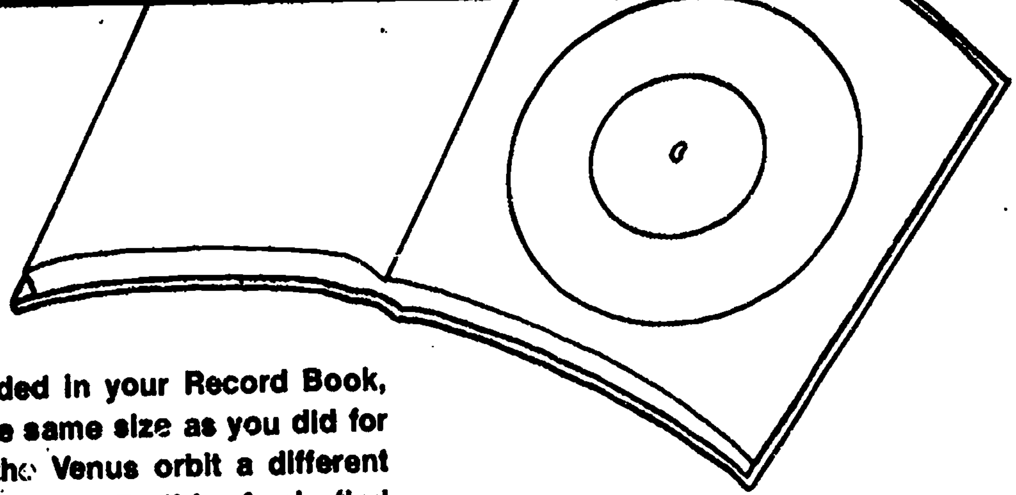
□**4-9.** When would the EV–ES angle be the smallest?

The number of degrees in question 4-8 may vary, but this is not important. More important is the concept in question 4-7: that the angle will be greatest when the line of sight to Venus just touches the orbit circle. Of course, the angle will be smallest (0°) when the sun, Earth, and Venus are in a straight line.

You should have seen that the greatest EV–ES angle occurs when the line of sight from Earth to Venus just touches, but does not cut, the orbit of Venus. (See Figure 4-5.)

Figure 4-5





ACTIVITY 4-6. In the space provided in your Record Book, draw a diagram of Earth's orbit the same size as you did for Activity 4-1. But this time, draw the Venus orbit a different size than before, keeping it smaller than Earth's. Again find the greatest EV–ES angle and measure it with a protractor.

☐**4-10.** How many degrees are there in the greatest possible EV–ES angle this time?

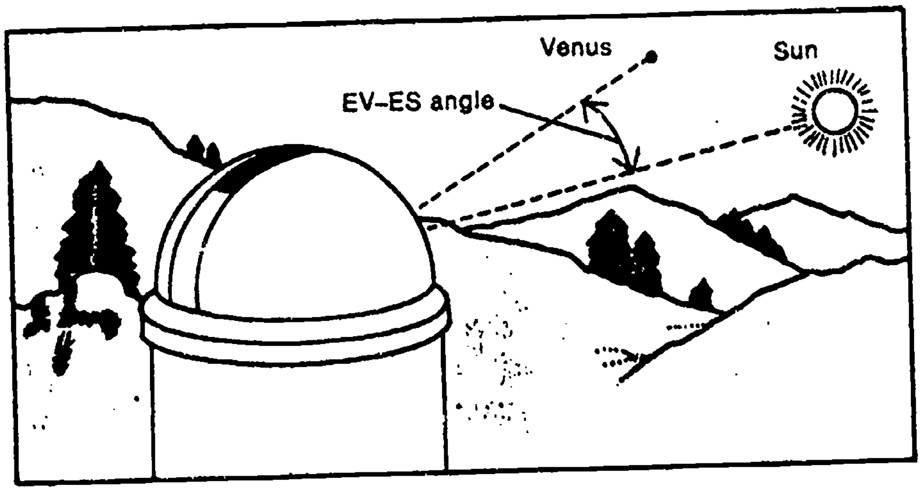
☐**4-11.** Does the greatest EV–ES angle occur again where the Earth–Venus line just touches but does not cross the orbit of Venus?

This activity and the following questions are included to provide additional practice on the concept of finding the greatest sighting angle.

The orbits of Earth and Venus are not perfect circles but, rather, slightly elliptical. This means that there are points on the Earth orbit where sightings to the Venus orbit can vary by a number of degrees. For instance, if the sighting is made when Earth is farthest out on its ellipse and Venus is closest to the sun on its ellipse, the angle will be smaller than if Earth is closest to the sun and Venus has swung out to its greatest distance. But using circular orbits of the average distances to the sun as the student is doing, the greatest angle is about 46°.

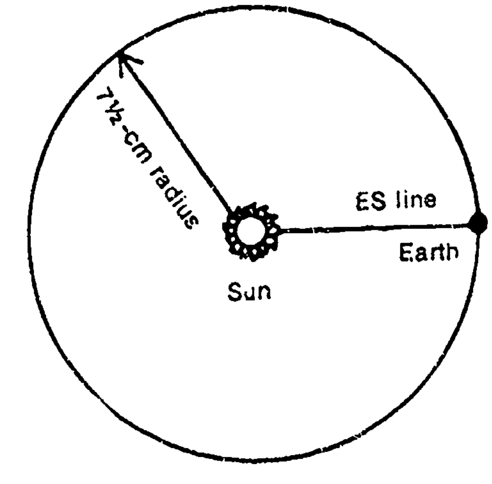
From this point on in the chapter, drawings will be made to scale and angles measured accurately. The success of the distance measurements to the sun depends on these accurate measurements.

Figure 4-6

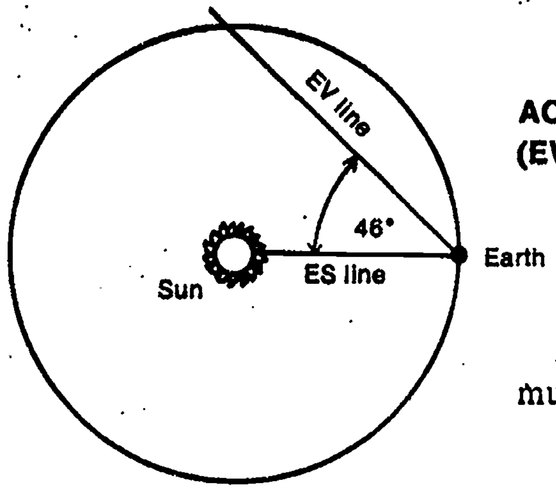


Measuring the real EV–ES angle is easy (see Figure 4-6). Astronomers have found that the average greatest EV–ES angle is 46 degrees. This figure can be used to find the distance from Venus to the sun.

But what does that have to do with measuring the distance from Earth to the sun? That was the question that started this discussion of EV–ES angles.

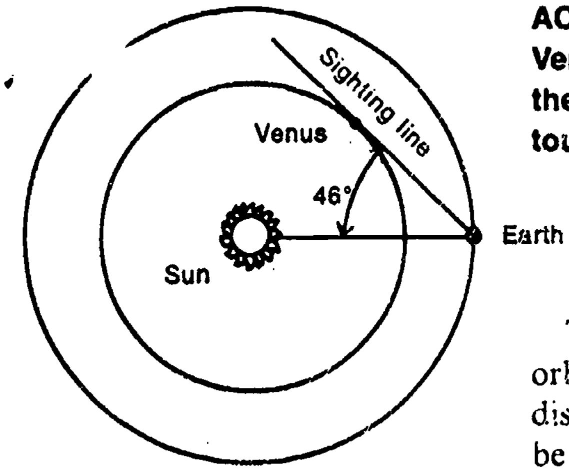


ACTIVITY 4-7. In the space provided in your Record Book, draw a 15-cm diameter circle to represent the orbit of Earth. Draw in an Earth–sun (ES) line as shown.



ACTIVITY 4-8. Using your protractor, draw in the Earth–Venus (EV) line for the largest EV–ES angle (46 degrees).

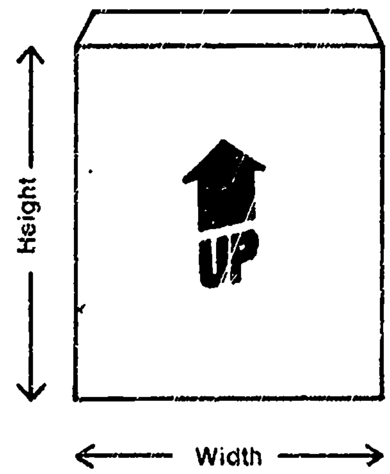
From your earlier work, you know that the orbit of Venus must just touch, but not cut, this EV line.



ACTIVITY 4-9. Using a compass, draw the orbit circle for Venus. Remember, the circle should just touch, but not cut, the sighting line. At the exact point where the sighting line touches Venus' orbit, make a small dot and label it "Venus."

The location of the "Venus" dot may be tricky. Geometrically, it is on the perpendicular from the sun to the EV line.

The drawing you just made is a scale drawing of the actual orbits of Venus and Earth. It can be used to determine the distance from Earth to the sun. Before you do this, however, be sure you know what a scale drawing is by doing the following checkup.



Scale: 1 cm = 4 ft

CHECKUP

Here is a scale drawing of a packing crate.

1. How high (in feet) was the crate from which the scale drawing was made?
2. How wide (in feet) was the actual crate?

Check your answers to this checkup on page 89 of **Excursion 4-3.** Excursion 4-3, keyed by the checkup, is remedial on the use of scale drawings.

☐ **4-12.** Measure on your scale drawing from Activity 4-7 the distance between Earth and Venus when they are closest together. This will be when Earth, Venus, and the sun are lined up, and the EV–ES angle is 0 degrees. (See art in margin on the next page.) Record this distance (in mm) on the bottom line of Table 4-2.

4-12. This distance should be about 21 mm.

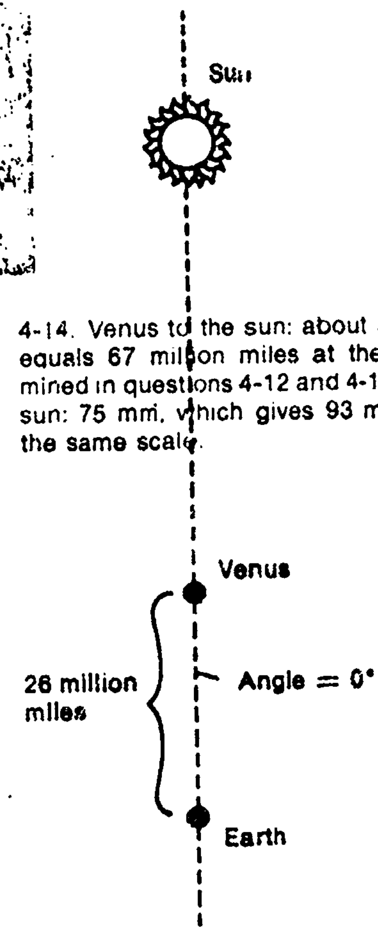
The distance you just measured in millimeters represents 26 million miles (see Table 4-2).

□**4-13. By your scale, how many miles are represented by each millimeter?**

4-13. Each millimeter represents about 1,240,000 miles (26,000,000 ÷ 21 = 1,238,095).

Table 4-2

	On Scale Drawing (mm)	Actual (miles)
Distance from Venus to the sun		
Distance from Earth to the sun		
Smallest distance between Earth and Venus		26 million



□**4-14. Using your scale drawing from Activity 4-7, measure (in millimeters) the distance from Venus to the sun and the distance from Earth to the sun. Record your measurements in Table 4-2.**

4-14. Venus to the sun: about 54 mm, which equals 67 million miles at the scale determined in questions 4-12 and 4-13. Earth to the sun: 75 mm, which gives 93 million miles at the same scale.

You now have enough information to complete the problem you started at the beginning of Chapter 3. From the data in Table 4-2 and your scale, you can calculate the distance of the sun from Earth and also the distance of the sun from Venus.

□**4-15.** Calculate the distance in miles from Venus to the sun and from Earth to the sun. Record the results of your calculations in Table 4-2.

A good check on your work is to see if the sum of your actual Venus-to-sun distance and Earth-to-Venus distance equals the Earth-to-sun distance. If the calculations of question 4-15 proved difficult, **Excursion 4-4** will help you.

Excursion 4-4 is a remedial excursion for those having calculating troubles.

EXCURSION

If you've done your work well, you now have the information you set out to find at the beginning of Chapter 3. You now know the distance from Earth to the sun. Using methods not too different from yours, astronomers have found the average distance from Earth to the sun to be roughly 93 million miles. Do your results agree?

Before going on, do Self-Evaluation 4 in your Record Book.

GET IT READY NOW FOR CHAPTER 5

There are several items that must be supplied locally. These include pieces of cardboard 4 cm square and pieces 13 cm by 20 cm. The cardboard backs from used tablets will do very well. You will also need single-edged razor blades, scissors, and a needle or other sharp instrument for making a small round hole.

EQUIPMENT LIST

Per student-team

1 telescoping tube with caps
1 piece cardboard, 13 cm × 20 cm
1 150-watt bulb and socket
1 meterstick
1 piece cardboard, 4 cm square
1 piece frosted acetate, 4 cm square
Tape

Per class

Scissors
Razor blade
Large needle or pin

CHAPTER EMPHASIS

The size of a distant object may be measured by projecting its image on a screen and using a simple mathematical relationship.

How Big Is the Sun?

Chapter 5

Excursion 5-1 is keyed to this chapter.

MAJOR POINTS

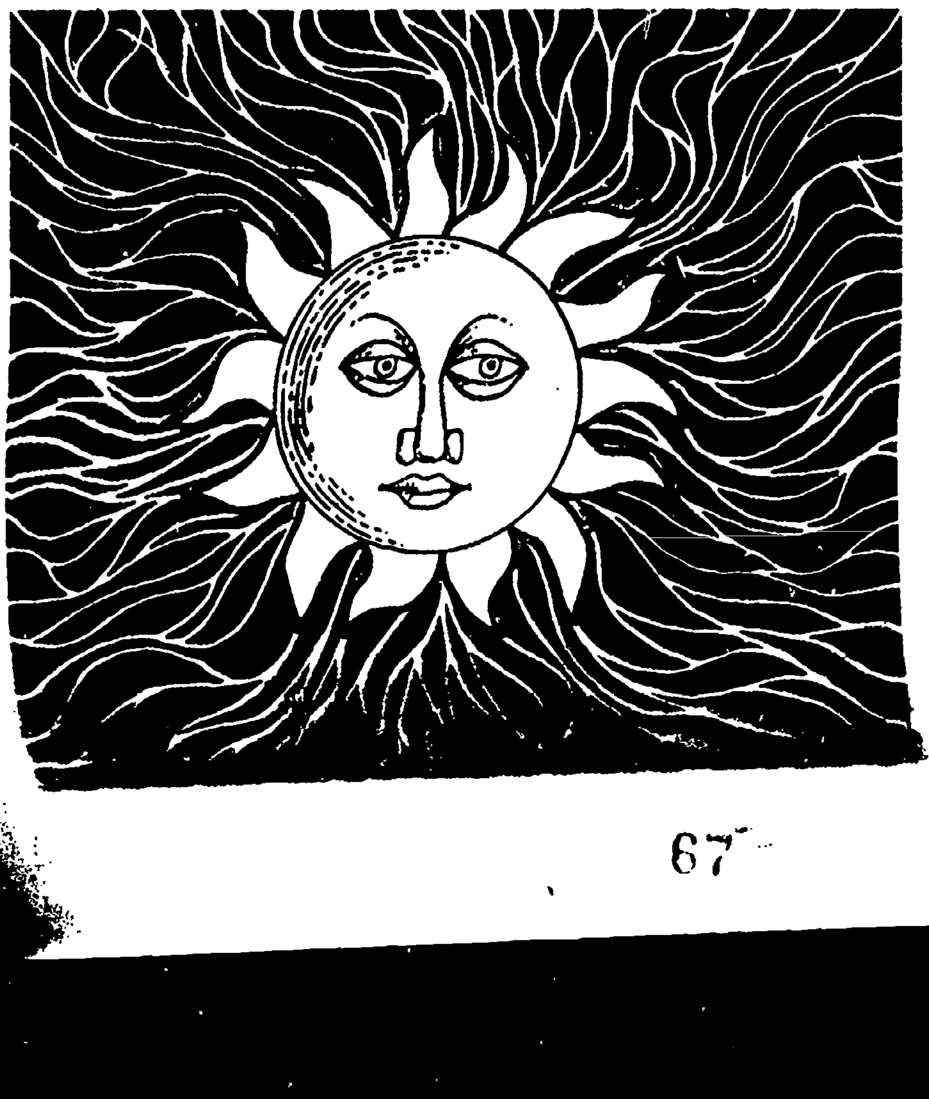
1. An image of a bright object can be projected through a pinhole onto a screen.
2. There is a mathematical relationship between size of object, size of image, distance from pinhole to object, and distance from pinhole to image.
3. This relationship can be used to find the diameter of the sun, when the distance to the sun is known.
4. The sun is a huge body more than 100 times the diameter of the earth.
5. It is possible to measure objects at great distances.

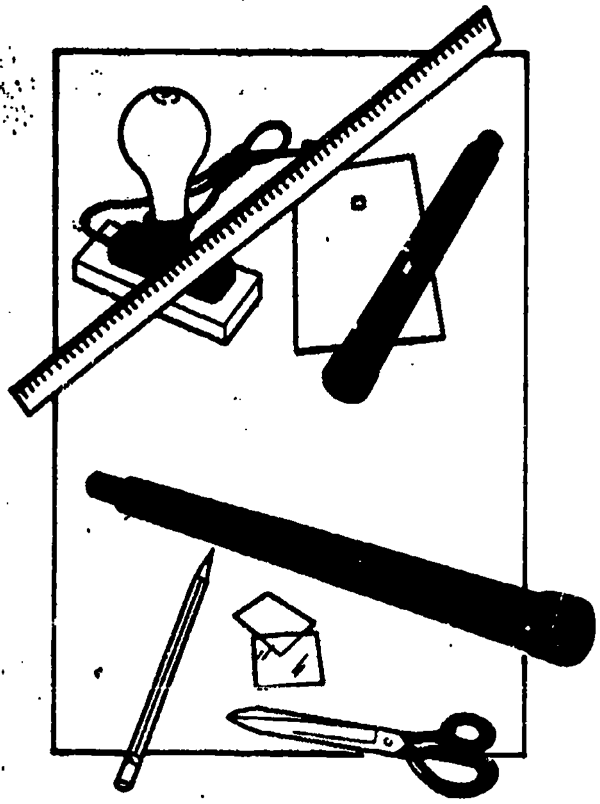
Once the pinholes, acetate screens, and the 1-cm square holes in the 13 cm × 20 cm cardboards are made, they can be used by all the students. In the interest of economy, accuracy, and safety (with the razor blade), you may want to have the apparatus prepared in advance. If so, you can follow the activities on the next two pages. In any case, the following hints on preparation may help.

1. Note that the cardboard disk and the frosted acetate disk are cut to different sizes because they fit into opposite ends of the telescoping tubes. The cardboard goes in the smaller end, the acetate in the larger. Use care in cutting so that they fit smoothly in the appropriate cap without wrinkling
2. Use a large needle, pin, or a sharp pencil to make the pinhole. Rotate the point as it is pushed through the cardboard in order to get a smooth, round hole
3. Use care in marking the 1-cm squares on the acetate. Be sure that the lines cross at right angles
4. Be sure that the 1-cm hole in the cardboard is square and lines up with the brightest part of the bulb when mounted

If at first you don't succeed, try, try again. That's the way the old saying goes. Your first try at measuring the distance to the sun wasn't successful. You couldn't get a base line that was long enough to use the range-finder method. So then you tried another approach, using the radar distance to Venus. This time you got the job done.

In this chapter you will try to make another measurement of the sun. This time you will try to find out how far it is across the sun. Obviously, measuring the distance across an object that is 93 million miles away is a bit more complicated



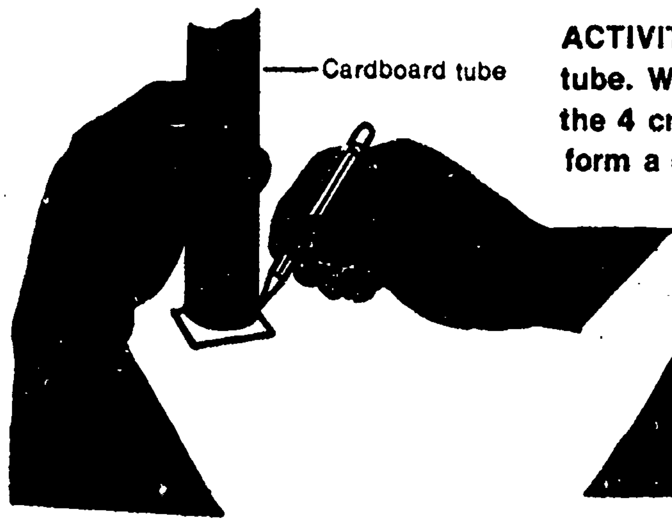


than just laying a ruler next to it. But with a little thought the job can be done fairly easily. To make your measurements, you and a partner will need these materials:

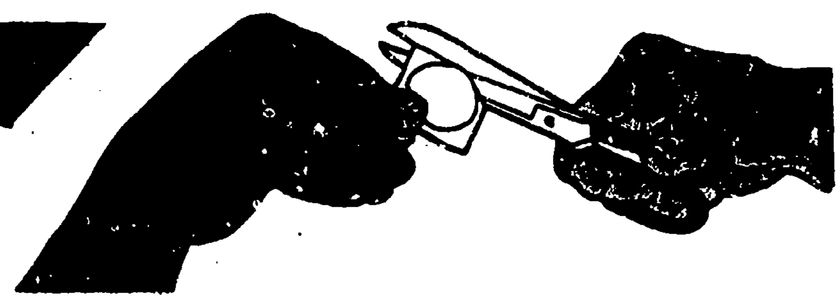
1 cardboard sighting scope with frosted acetate screen
1 piece cardboard, 13 cm × 20 cm with 1 cm² hole
1 150-watt bulb and socket
1 meterstick

If the sighting scope has not been assembled, Activities 5-1 through 5-4 show you how to construct the sighting scope. To do this, you will need:

1 telescoping cardboard tube, 40 cm long with end caps
1 piece of thin cardboard, 4 cm²
1 piece frosted acetate, 4 cm²
1 pair scissors
1 sharp pencil

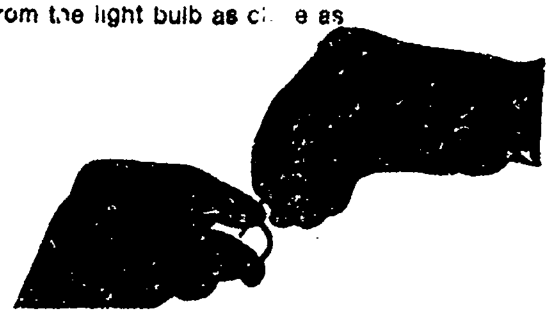


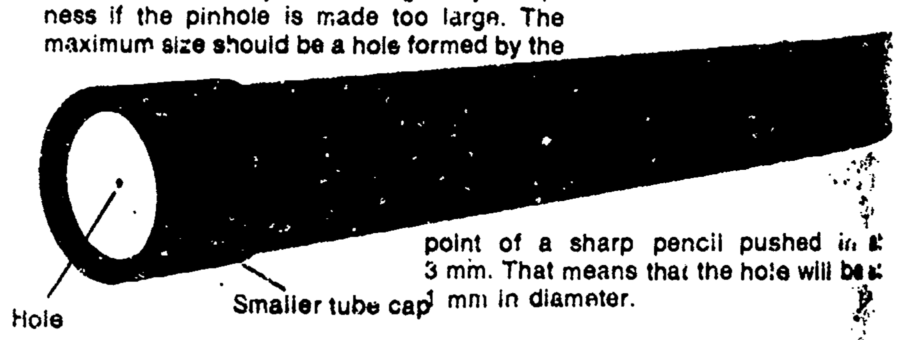
ACTIVITY 5-1. Remove the smaller cap from the cardboard tube. With a sharp pencil, trace the outside of the tube on the 4 cm × 4 cm piece of cardboard. Cut along the lines to form a disk.



ACTIVITY 5-2. Make a smooth pinhole in the center of the cardboard disk with a large needle or pin. Place this disk in the cap and replace the cap on the tube.

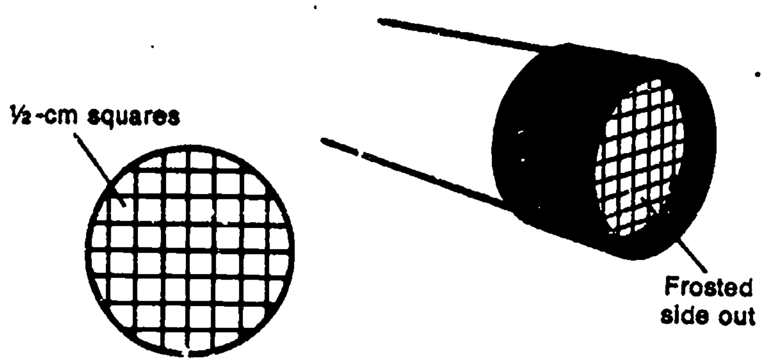
A larger pinhole allows more light to pass through, giving a brighter image. But a larger pinhole also gives a fuzzier, less distinct image. With the sun at a great distance away, this fuzziness is not pronounced, but with the bright square from the light bulb as close as it has to be, it is very difficult to get any sharpness if the pinhole is made too large. The maximum size should be a hole formed by the point of a sharp pencil pushed in a 3 mm. That means that the hole will be 1 mm in diameter.





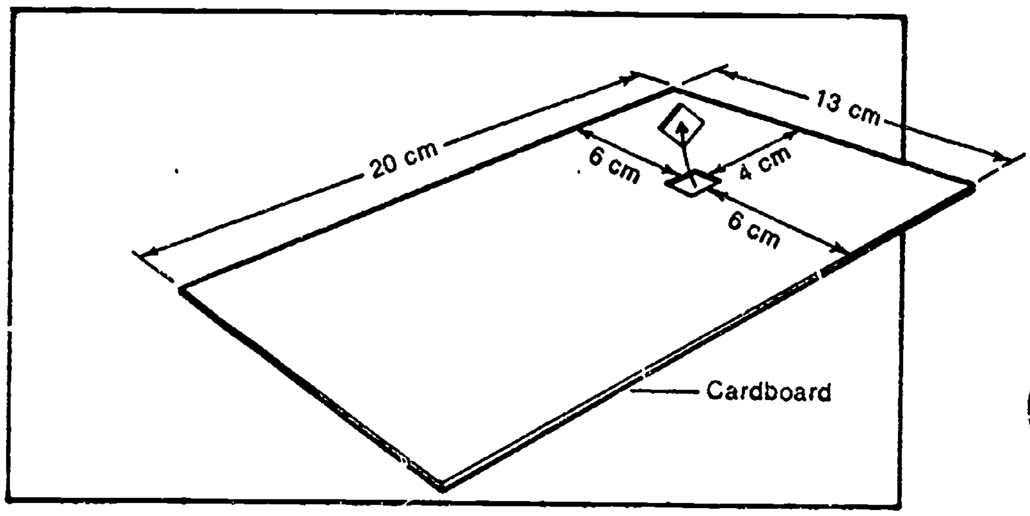
Prepare an acetate disk to fit in the larger cap.

ACTIVITY 5-3. Be sure you use a well-sharpened pencil to mark off 1/2-cm squares on the frosted side of the acetate disk. This must be carefully done. Place this disk in the tube cap, with the frosted side out. (Your frosted acetate disk, by the addition of the grid lines, has been made into what is comm·· only called a screen.)



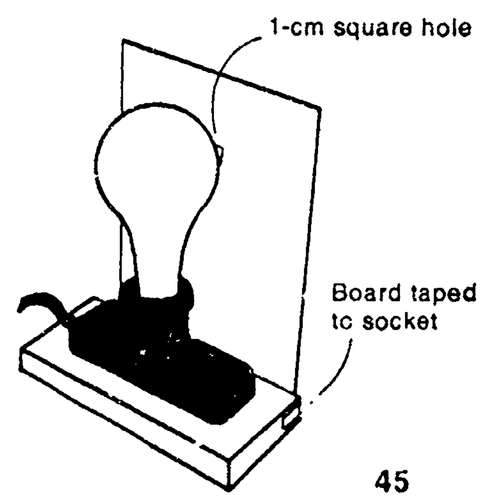
If the cardboard (13 cm × 0 cm) with the 1 cm^2 hole is available, skip to Activity 5-5.

ACTIVITY 5-4. Mark off a 1-cm square on a 13- × 20-cm cardboard sheet in the position shown. *Place it on something flat that can be used as a cutting surface.* With a razor blade, remove the square, leaving a hole in the cardboard.



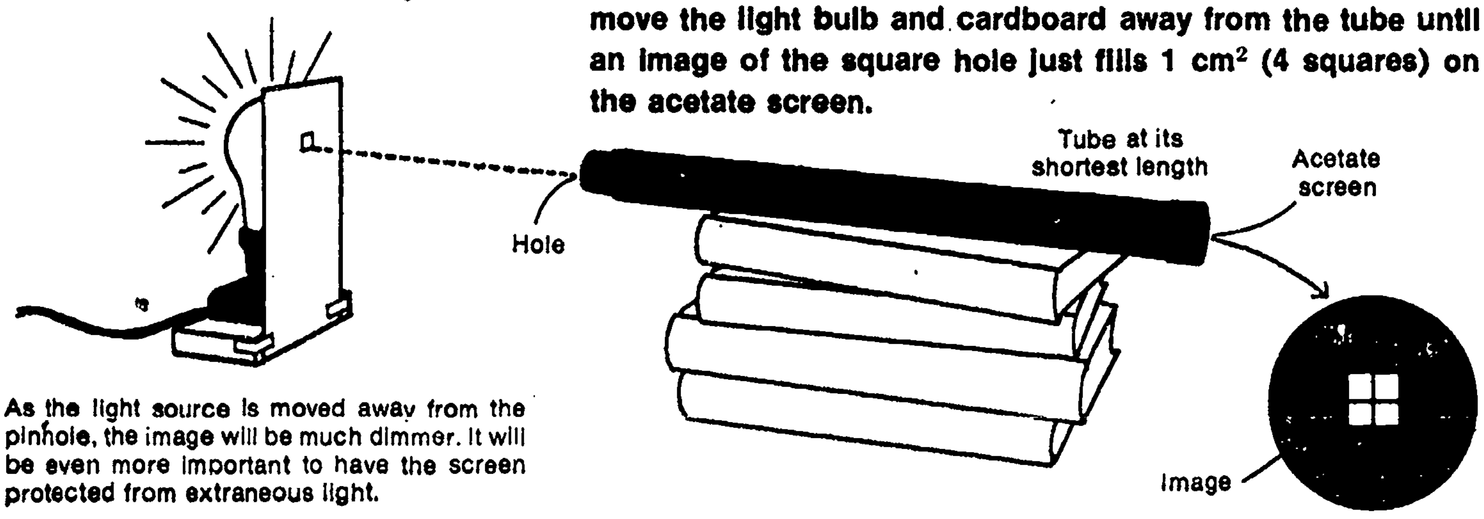
ACTIVITY 5-5. Tape the 13- × 20-cm cardboard in front of the light bulb as shown. Be sure the brightest part of the bulb is lined up with the square hole.

For what follows, you will need a level space behind the bulb of up to 3 ft and about 2 ft in front of the bulb.



In order to see the square image on the acetate screen, it is necessary to look straight into the screen. It helps if the screen is in a darker part of the room. You may want to use large cardboard cartons as light shields around the ends of the telescoping tubes.

ACTIVITY 5-6. Support the tube on books so that it is level and pointing straight at the square hole. Have the tube at its shortest length (small tube pushed in all the way). Gradually move the light bulb and cardboard away from the tube until an image of the square hole just fills 1 cm² (4 squares) on the acetate screen.



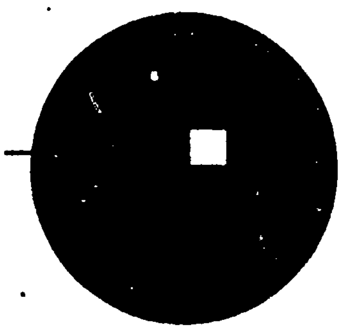
As the light source is moved away from the pinhole, the image will be much dimmer. It will be even more important to have the screen protected from extraneous light.

With the telescoping tube at its shortest length, the distances for questions 5-1 and 5-2 should both be about 42 cm.

☐**5-1.** What is the distance (in cm) from the pinhole to the square hole in the card?

☐**5-2.** What is the distance (in cm) from the pinhole to the screen (the length of the cardboard tube)?

Figure 5-1



If you have made careful measurements, you should have found the distance from the pinhole to the screen to be about the same as the distance from the pinhole to the square hole in the card.

Now move the cardboard with the square hole away from the pinhole until only one square on the screen is filled with the image. (See Figure 5-1.)

☐**5-3.** Now what is the distance (in cm) from the pinhole to the square hole?

The new distance you just measured should be about twice the distance from the pinhole to the screen.

☐**5-4.** How many times bigger is the distance across the square hole in the cardboard (1 cm) than the distance across the image ($\frac{1}{2}$ cm)?

Perhaps you are beginning to see some relationships here. The distance from the pinhole to the screen and the size of the image that forms are related. Although you may not see how as yet, you can use this relationship to measure the size of a bright object such as the 150-watt bulb. Let's see how this can be done.

Here's the relationship you need.

$$\text{Distance across the object} = \frac{\text{Distance from the object to the pinhole}}{\text{Distance from the pinhole to the screen}} \times \text{distance across the image}$$

You may recognize this mathematical relationship as the modified lens formula: $\frac{Ho}{Hi} = \frac{Do}{Di}$, where Ho = size of object, Hi = size of image, Do = distance from pinhole to object, and Di = distance from pinhole to image.

Here's an example of how the relationship can be used.

The distance from the pinhole to the square hole in the cardboard is 84 cm. The distance from the pinhole to the screen (the length of the tube) is about 42 cm. The width of the image on the screen is $\frac{1}{2}$ cm. All of this is shown in Figure 5-2.

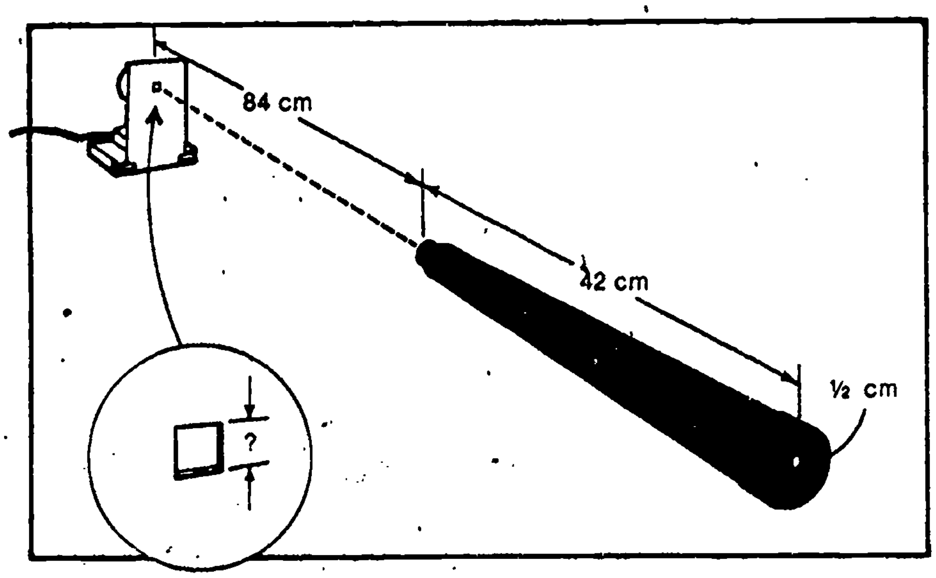
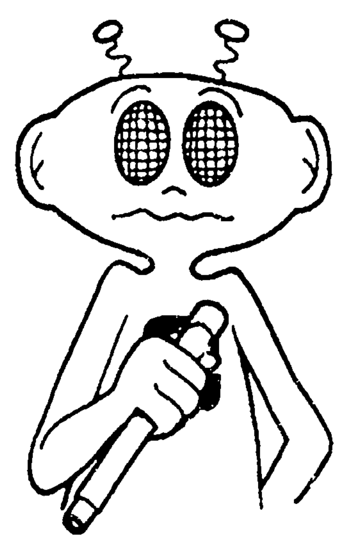


Figure 5-2

$$\text{Distance across the square hole} = \frac{84\text{ cm}}{42\text{ cm}} \times \text{distance across the image}$$
$$= \frac{84\text{ cm}}{42\text{ cm}} \times \tfrac{1}{2}\text{ cm}$$
$$= 2 \times \tfrac{1}{2}\text{ cm}$$
$$= 1\text{ cm}$$



Now check to be sure that your answers to questions 5-1, 5-2, 5-3, and 5-4 fit the relationship. For example, in order for your answers to 5-1 and 5-2 to fit, they must be equal. This is because the object and image width are the same size at that setting.

Figure 5-3B shows how you can calculate the distance across the sun in the same way that you just calculated the distance across the hole in the cardboard (Figure 5-3A). All you need do is set up the sighting scope so that the pinhole faces the sun. When the scope is lined up, the sun's image will fall on the screen.

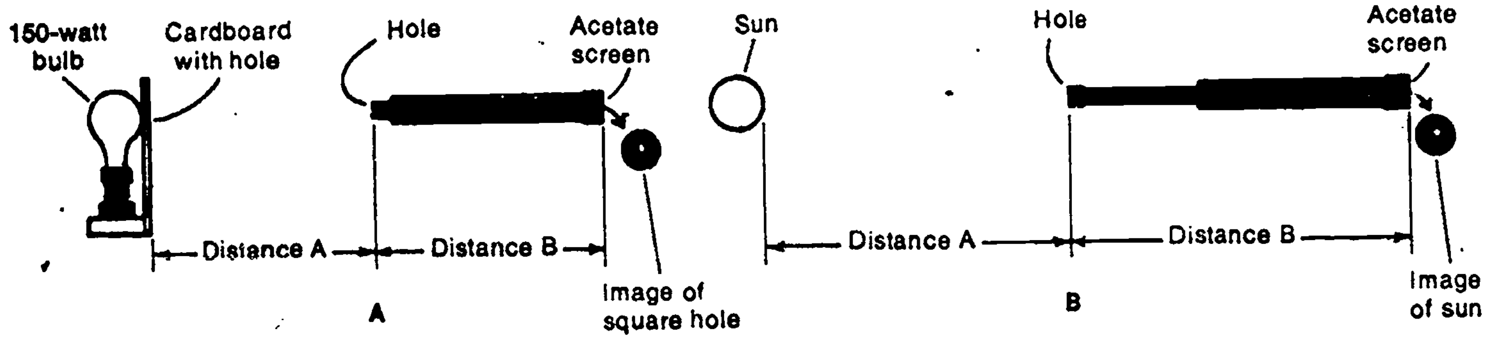


Figure 5-3

Even though there is a safety note for the students, it might be wise to remind them that, although they looked directly into the screen when getting the square image with the light bulb, they should not use the same technique with the sun. However, the sun's image is so much brighter that it can easily be seen without looking directly.

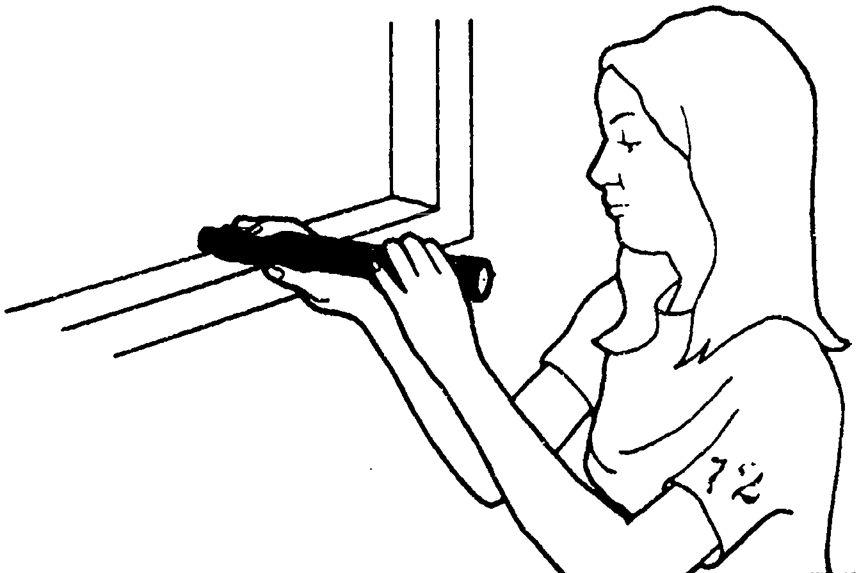
Safety Note *Remember, you should never look directly at the sun.*

Once you've formed an image of the sun, you can get everything needed to calculate the distance across the sun by using the relationship. You've already measured the distance from the sun to the pinhole—93 million miles. Thus:

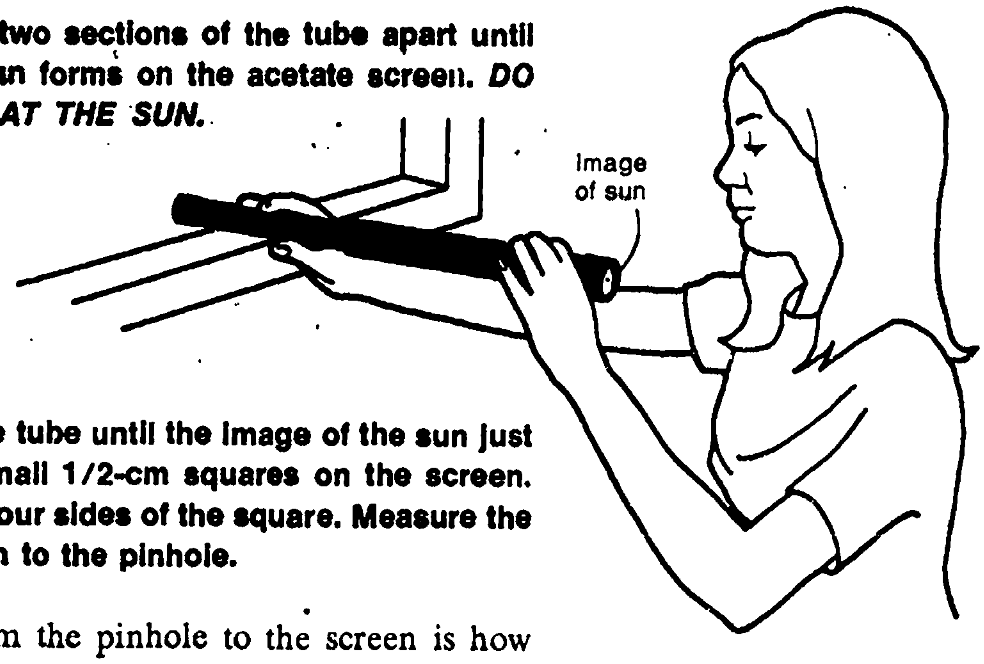
$$\text{Distance across the sun} = \frac{93{,}000{,}000 \text{ miles}}{\text{Distance from pinhole to screen}} \times \text{distance across the image}$$

Now you need to measure the width of the image on the screen.

ACTIVITY 5-7. Point the pinhole end of the tube directly at the sun as shown.



ACTIVITY 5-8. Pull the two sections of the tube apart until a *sharp* image of the sun forms on the acetate screen. *DO NOT LOOK DIRECTLY AT THE SUN.*



ACTIVITY 5-9. Adjust the tube until the image of the sun just fits inside one of the small 1/2-cm squares on the screen. It should just touch the four sides of the square. Measure the distance from the screen to the pinhole.

☐**5-5.** The distance from the pinhole to the screen is how many cm?

Now you have all the data that you need to calculate the distance across the sun by using the relationship.

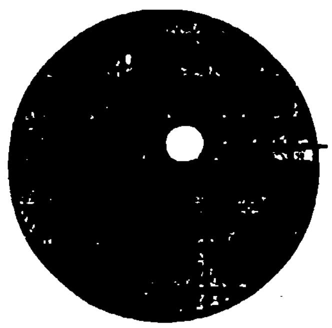
$$\text{Distance across the sun} = \frac{93{,}000{,}000 \text{ miles}}{\text{Distance from pinhole to screen in cm}} \times \tfrac{1}{2} \text{ cm}$$

☐**5-6.** What is the distance across the sun in miles? (If you make the calculation shown above, your answer will automatically come out in miles because the centimeters cancel out.)

You may have been surprised to learn how large the sun really is. Its diameter is greater in length than the diameter of the moon's orbit around the earth. More importantly, though, you should be beginning to realize that with careful thinking and a few measurements and calculations, astronomers can provide answers that at first seem almost impossible to get.

If you would like to make your own telescope and get a good look at the moon, do **Excursion 5-1.**

Before going on, do Self-Evaluation 5 in your Record Book.



If the student has made careful measurements, the distance from the pinhole to the screen should be about 54 cm (question 5-5). Anywhere in the 52-58 cm range should be considered adequate. The image of the sun, though distinct, is fuzzy enough on the screen to make it difficult to exactly fit it into one square. Using 54 cm, the distance across the sun (question 5-6) becomes 861,000 miles. The diameter generally used in astronomy is 865,000 miles. An answer anywhere between 800,000 miles and 900,000 miles should be acceptable.

Excursion 5-1, "Moon Gazing," is a fun exercise in which the student constructs a simple telescope not too unlike the one made by Galileo.

GET IT READY NOW FOR CHAPTER 6

Small pieces of cardboard and string will have to be supplied locally. Students will also need a sheet of white paper.

EQUIPMENT LIST

Per student-team

1 drawing compass
1 metric ruler
1 lead sinker
1 50-cm piece of string
1 protractor
1 sheet of white paper
Masking tape
Cardboard
Scissors

CHAPTER EMPHASIS

The relative motion between the sun and an observer is examined, and the effects of this motion are studied.

The Fiery Chariot

Chapter 6

Excursions 6-1 and 6-2 are keyed to the chapter, and Excursion 4-2 is rekeyed.

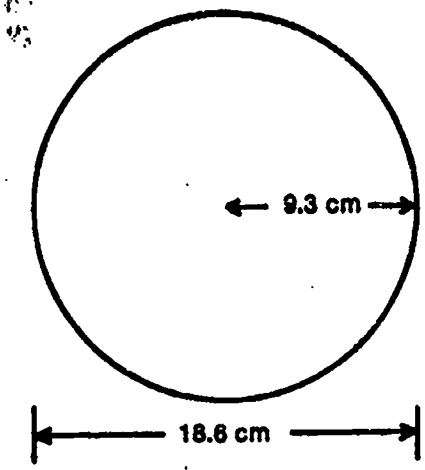
MAJOR POINTS

1. From observations of the apparent motion of the sun, it is impossible to tell whether the sun is moving and the earth is stationary or the earth is rotating and the sun is standing still.
2. The apparent motion of the sun is through 360° every 24 hours, or 15° per hour.
3. The time zones in use are based on this apparent motion of 15 degrees per hour.
4. The apparent path of the sun across the sky changes from day to day.
5. The apparent speed of the sun can be measured by the motion of the shadow that it casts.
6. The apparent speed of the sun is a very large number of miles per hour.
7. Because of this extremely high speed, the model that the sun moves around the earth each day is unlikely.

One of the myths told in ancient times described the sun as a flaming ball carried across the sky in a chariot drawn by four horses. Since you formed an image of the sun on a screen in Chapter 5, you know that part of the myth is in fact true—the sun is a flaming ball.

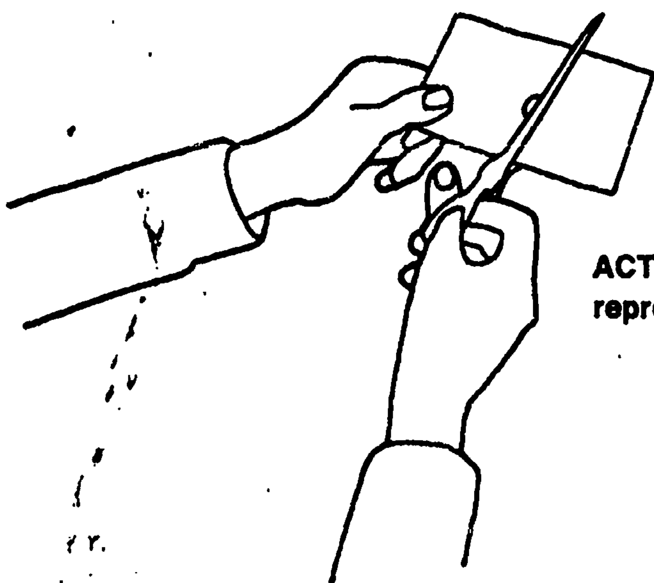
But does the sun move across the sky? To you, the answer is probably a solid No because you know that the earth's turning is what makes the sun appear to move. You may also know that proving this is not so easy. To someone standing on the earth, the sun moving around an unmoving earth would appear the same as the sun standing still with the earth turning. A simple model can show you why.

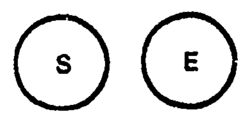
This circle is used and referred to in six different places in the chapter. Therefore, it should be drawn carefully and accurately. The measurement of the apparent speed of the sun is dependent on the circle's dimensions.



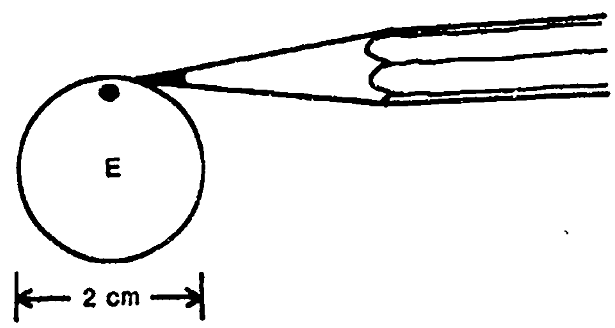
ACTIVITY 6-1. In the space provided in your Record Book, draw a circle 18.6 cm across. In other words, the circle has a radius of 9.3 cm, or 93 mm.

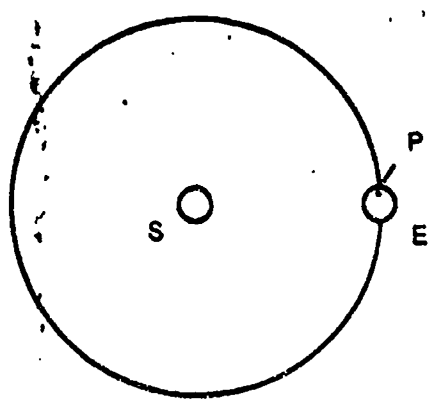
ACTIVITY 6-2. Cut out two cardboard circles about 2 cm across. Label one "S," for the sun, and the other "E," for the earth.





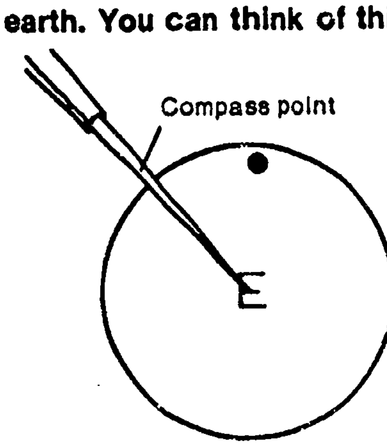
ACTIVITY 6-3. Make a small dot at the edge of the earth. This represents a person standing on the earth's surface.





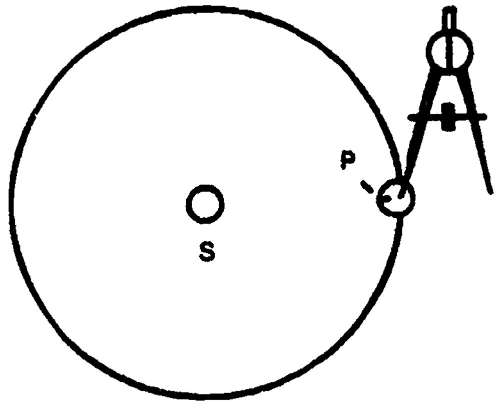
ACTIVITY 6-4. Place the sun in the center of the circle you drew in your Record Book. Then place the earth on the circle as shown. Be sure that the "person dot" is in the positio shown.

ACTIVITY 6-5. Stick the point of your compass through the center of the earth. You can think of this point as the North Pole.



☐**6-1.** If you were the person standing on the earth in Activity 6-4, would the sun appear to be overhead or on the horizon?

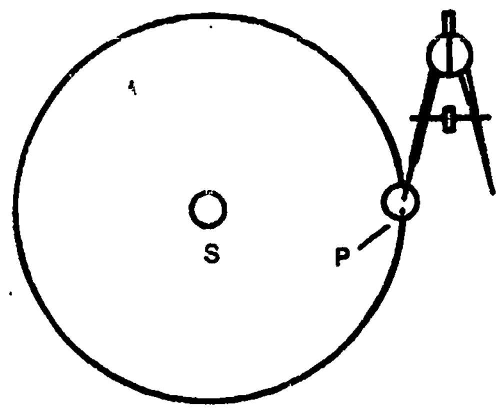
6-1. The sun would appear to be on the horizon (actually, on the eastern horizon)



ACTIVITY 6-6. Turn the earth around the compass point to the position shown.

☐**6-2.** Would the sun appear to be overhead to a person standing at the dot?

☐**6-3.** How many degrees did you have to turn the earth to get the sun overhead? (Hint: If you have trouble with this question, see **Excursion 4-2.**)



ACTIVITY 6-7. Keep turning the earth until it gets to the place where, to a person at the dot, the sun would again appear to be on the horizon.

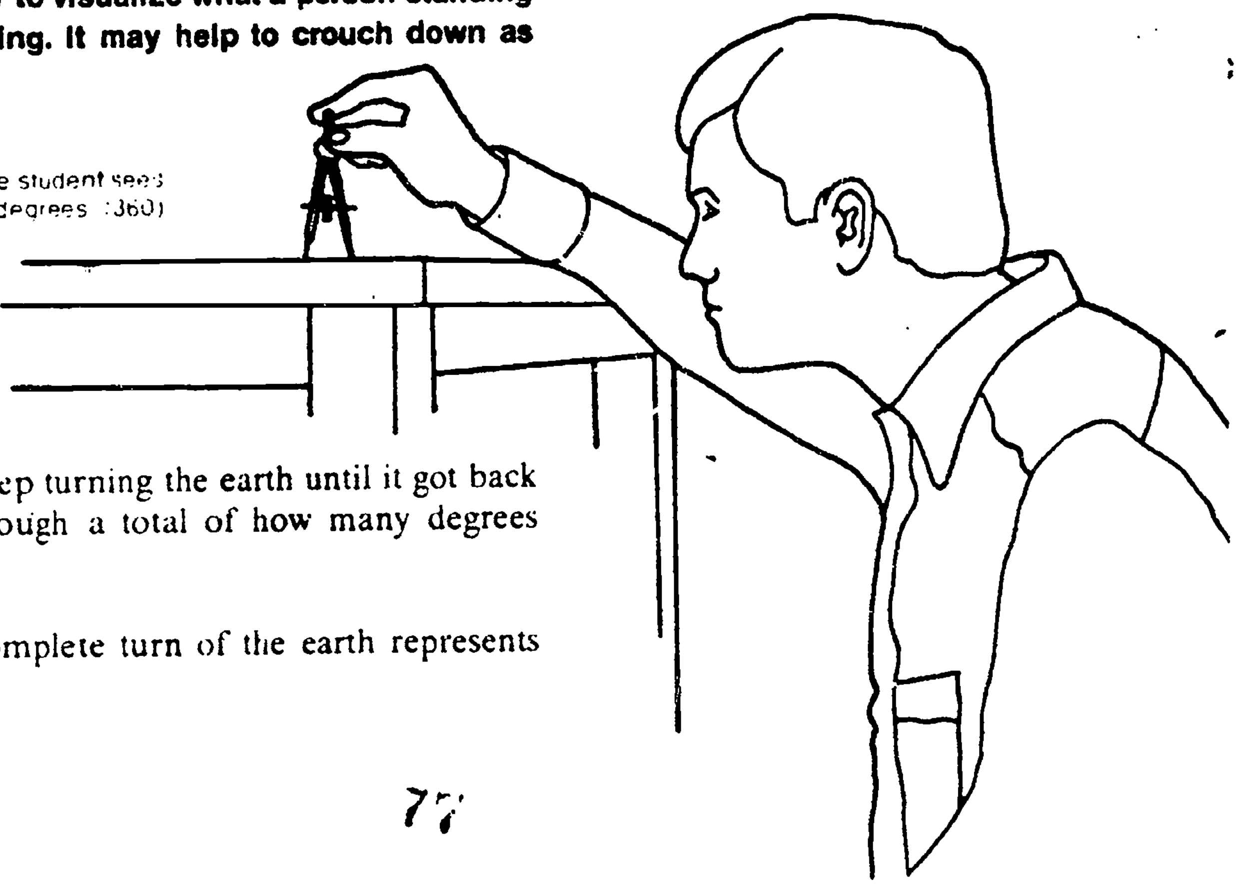
☐**6-4.** Now how many degrees have you turned the earth from where it started (in Activity 6-5)?

☐**6-5.** If you had been standing on the earth at the dot, would the sun seem to have traveled across the sky from one horizon to the other?

...te that Excursion 4-2, "Angles and Protractors," is rekeyed here for remedial purposes

ACTIVITY 6-8. Check your answer to question 6-5 by repeating Activities 6-6 and 6-7. Try to visualize what a person standing at the dot would be seeing. It may help to crouch down as shown.

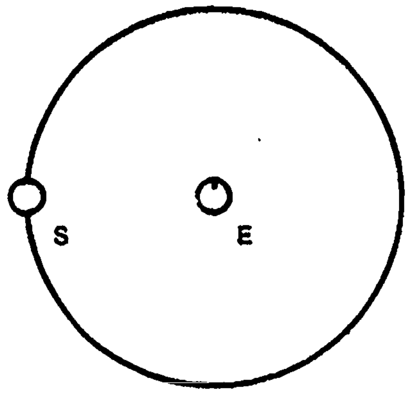
6-6. 360°. It is important that the student sees the connection between the degrees (360) and the hours (24)



☐**6-6.** If you were to keep turning the earth until it got back to where it started, through a total of how many degrees would it have turned?

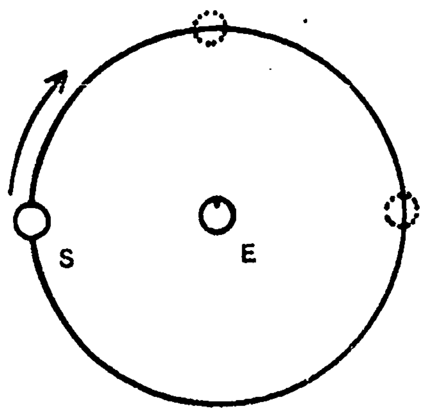
As you know, one complete turn of the earth represents one day, or 24 hours.

ACTIVITY 6-9. Now reverse the positions of the earth and the sun on the circle. Be sure that the "person dot" faces upward as shown.



☐**6-7.** With the earth and the sun in the position shown in Activity 6-9, would the person see the sun overhead, or on the horizon?

ACTIVITY 6-10. Move the sun along the circle to a point where it would appear to be overhead to the person. Then continue to move the sun to a point where it would appear to be on the horizon.



☐**6-8.** How many degrees did you move the sun to make it appear overhead to a person at the dot?

☐**6-9.** How many degrees did you have to move the sun to make it appear to move from one horizon to the other?

Now think about what a person at the dot would have seen in the case of the earth turning, and in the case of the sun moving around the earth. In both cases, the sun would appear to move around the earth. In both cases, the sun would appear to rise from one horizon and to set behind the other!

PROBLEM BREAK 6-1

How good an observer are you? You can tell by the answer you give to this question: Is the apparent path of the sun across the sky the same every day?

Of course, the sun doesn't leave a trail in the sky so that you can see any change in path. But there should be some way that you could observe a change if there is any. In your Record Book, describe an observation that you could make with simple apparatus that would show conclusively whether the apparent path of the sun across the sky is the same every day. If you decide that the path changes, give a short explanation of why this is so.

Problem Break 6-1 is difficult. Encourage students to really work on it. They should be able to suggest a variety of ways, with and without apparatus, that would show a changing path. One would be the change in the length of a shadow cast by a vertical object. Another would be the changing position on the horizon of a sunrise or sunset as seen from a fixed point. The greatest day-to-day change can be noted in the spring and fall; the least change occurs during the summer and winter.

The short explanation called for is the more difficult part. The apparent path of the sun across the sky is a little different each day because of the earth's rotation on its axis *and* its revolving around the sun in its orbit. With the axis of the earth tilted at $23\frac{1}{2}°$ from perpendicular, the sun seems to travel on a circle called the ecliptic. It changes its position on the ecliptic about 1° per day, thus passing through the 360° of the circle in 365 days.

Note that for a moving earth, the rotation is counterclockwise; but for a moving sun, the motion is clockwise.

As was said earlier, it isn't so easy to prove that the earth is turning rather than the sun moving around it. Suppose the sun actually does move around the earth while the earth stands still. Because it is far away, it would have to make a very long journey each day. It would have to travel very fast to make it in just 24 hours. You can get a good idea of the speed it must have to make the trip. You only need a few simple things. But you will have to have an hour of sunlight.

If you don't have a full hour ahead of you in this class, read ahead to see what has to be done. Then plan a time when you can do the activity. If you have some spare time now, this would be a good time to do **Excursion 6-1** and find out about "The Night That People Lost 10 Days." No equipment is needed.

Got a sunny day and a full hour? Then let's find out how fast the sun would have to be to go around the earth each day. Get the following items:

1 lead sinker
1 50-cm piece of string
1 protractor
1 2-inch piece of masking tape or cellophane tape
1 sheet of white paper

Tie the string to the lead sinker. Make an X with your pencil in the center of the paper. Take everything outdoors or to a windowsill where the sun will shine for at least an hour.

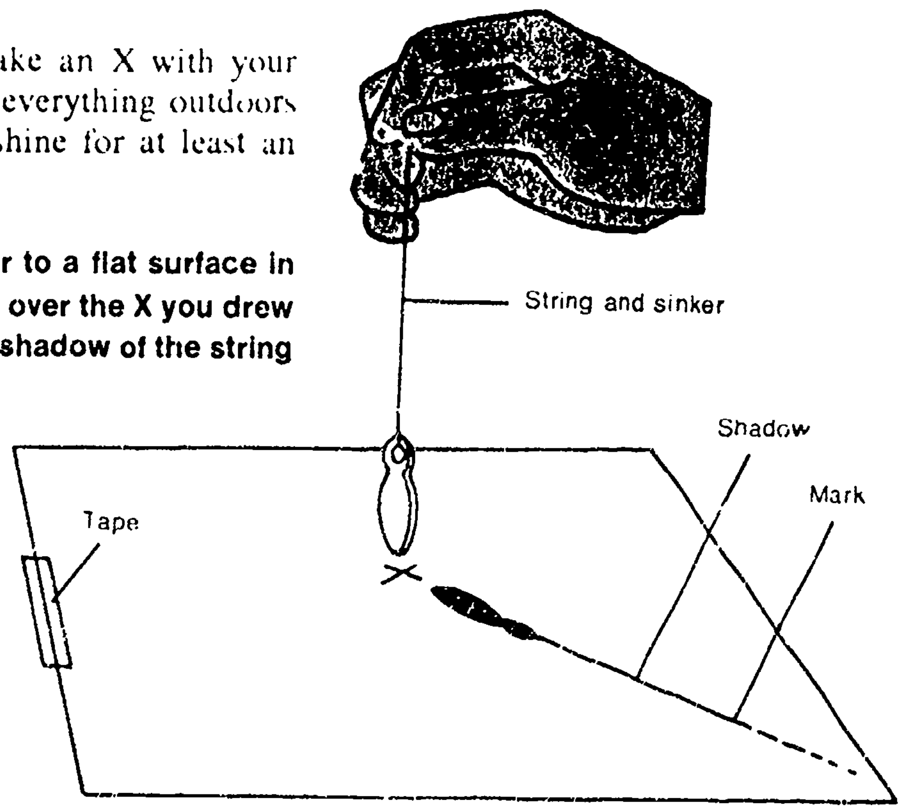
ACTIVITY 6-11. Tape your piece of paper to a flat surface in full sunlight. Then hold the sinker *exactly* over the X you drew on the paper. Draw a short line along the shadow of the string on the paper. Jot down the exact time.

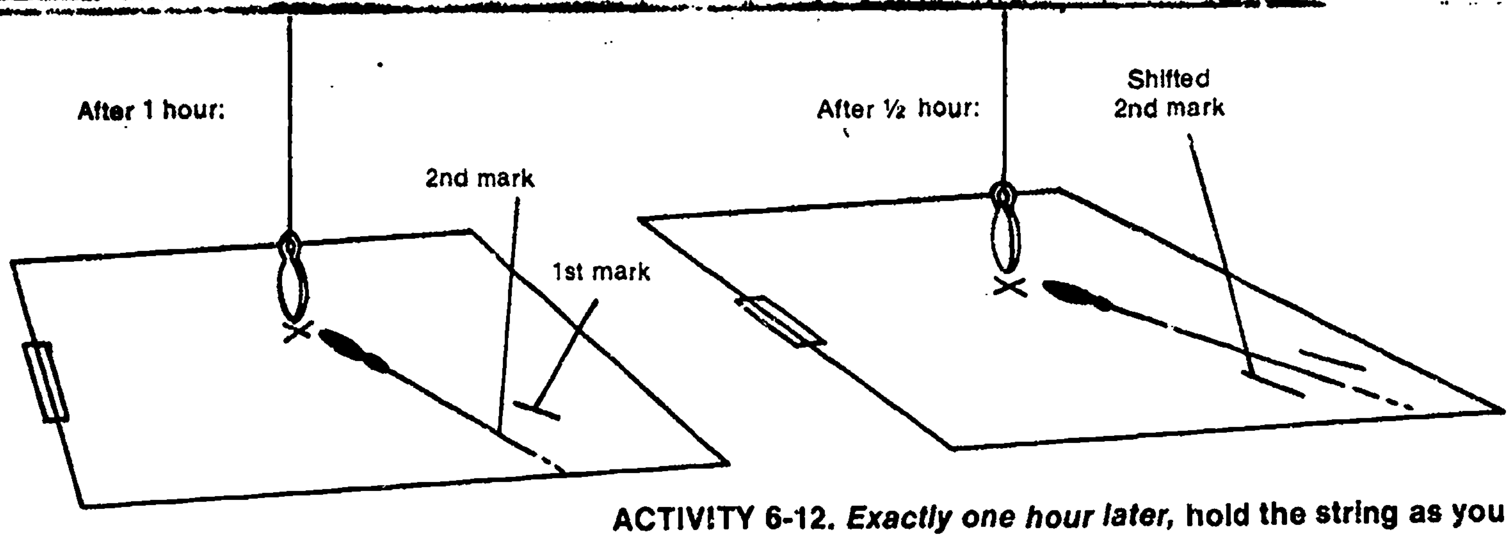
It may be possible for the student to use a ring stand or other vertical support from which to hang the sinker on the string. It could then remain motionless for the time period, and the beginning and ending positions could be marked.

The constraint for an hour of sunlight may not be realistic, considering the length of an average class period. Activity 6-12 on the next page modifies the instructions to allow the use of half an hour.

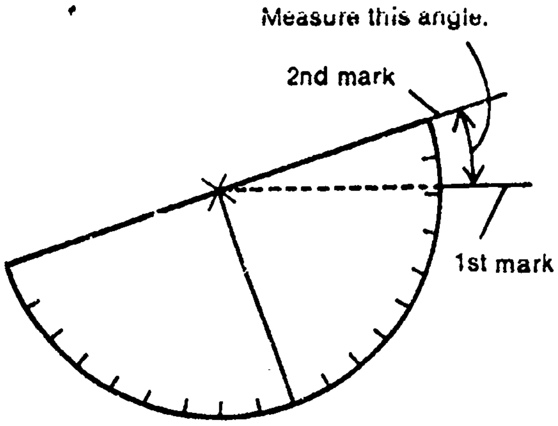
EXCURSION

Excursion 6-1 is a good one for general interest and extension, and it provides some background on the calendar.





ACTIVITY 6-12. ***Exactly one hour later,*** **hold the string as you did before, and once again mark the shadow. (Note: If you do not have a full hour available, use 1/2 hour and double the distance of the 2nd mark from the 1st mark.)**



ACTIVITY 6-13. Take your paper back to your desk. With a ruler, draw straight lines from the X along each of the shadow marks. Measure the angle between the lines with a protractor.

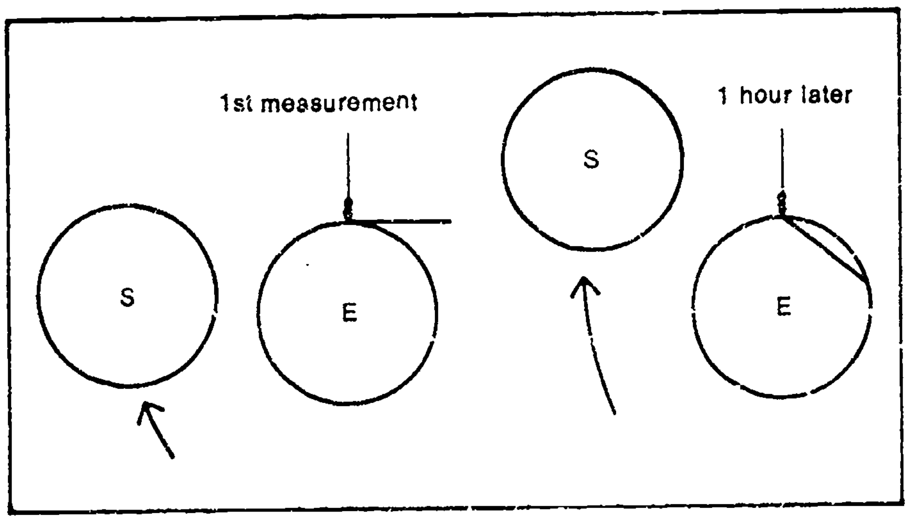
☐**6-10.** How many degrees are in the angle formed by the two shadow lines?

6-10. This answer (and some later ones that depend on it) may vary with geographic location, time of year, and time of day. An acceptable answer would be between 10° and 20°.

Now try to apply what you have just done to the model you built earlier. Figure 6-1 diagrams what would have happened if the person standing at the dot in Activity 6-10 had been holding a sinker as you did.

Notice in Figure 6-1 that as the sun moves, the shadow of the string moves too. This suggests that measuring the distance that the shadow moves in a given time could tell you how fast the sun would have to move. Let's find out if it will.

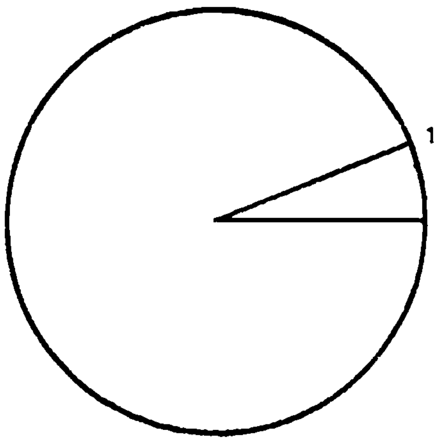
Figure 6-1



In Activity 6-1 you drew a circle with a radius of 93 mm. This size was chosen to make your next set of calculations easy. Think of a distance of 93 mm as representing the distance of 93 million miles from the earth to the sun.

☐**6-11.** How many miles does each mm represent?

ACTIVITY 6-14. On the circle you drew in your Record Book, draw an angle like the one you measured in Activity 6-13. Use your protractor and a sharp pencil. Label the angle as shown.



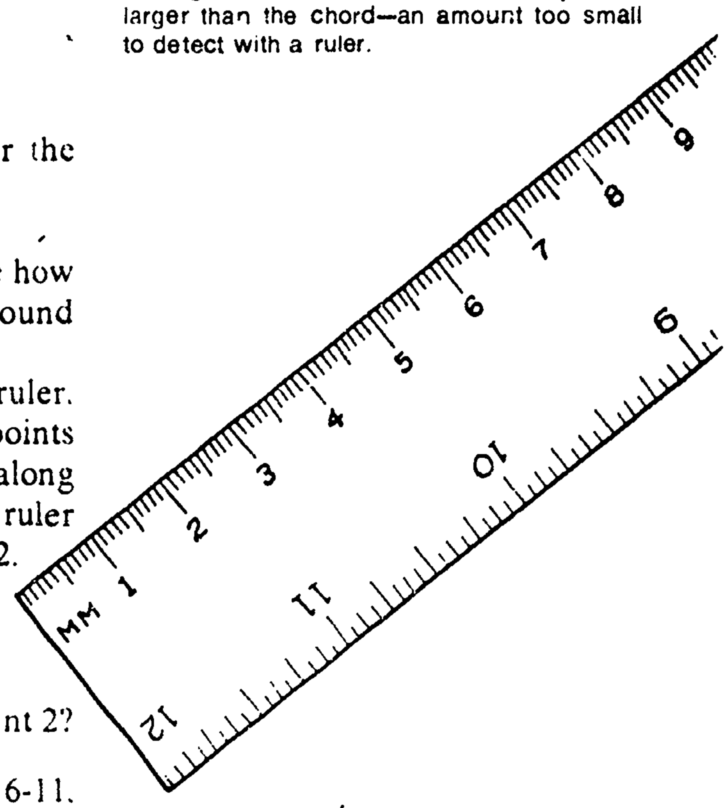
If the apparent path of the sun were on the celestial equator every day instead of continually on a different path in the sky, then the shadow motion in one hour would be 15°. With this changing path across the sky, the apparent speed of the sun also changes during the different hours of the day. Thus, the angle measured in Activity 6-13 will affect the answers for questions 6-13, 6-14, and 6-15 below.

The statement is made that when the angle is small, you can use a ruler to measure the distance from 1 to 2 (measure the chord instead of the arc). For your information, for an angle of 15°, the arc is less than $\frac{1}{4}$ of 1% larger than the chord—an amount too small to detect with a ruler.

☐**6-12.** The distance between 1 and 2 shows how far the sun appears to travel in how long?

Using the distance between 1 and 2, you can calculate how far the sun would have to travel in one hour if it goes around the earth in one day.

You can't measure a curved line accurately with your ruler. But when the angle is small, the distance between two points along a curve is not too different from the distance along a straight line. This means that you can use a millimeter ruler to get a good estimate of the distance between 1 and 2.



6-13. 16 mm to 32mm
6-14 16,000,000 mi to 32,000,000 mi
6-15. 16 million mph to 32 million mph

☐**6-13.** What is the distance in mm from point 1 to point 2?

☐**6-14.** Using the scale you determined in question 6-11, what is the distance in miles that the sun would have had to travel?

☐**6-15.** What would its speed in miles per hour have to be?

As a comparison, the orbital speed of Mercury, which is the fastest traveling planet, is about 106,000 miles per hour. Fastest orbital speed for a satellite in circular orbit around the earth is about 17,000 miles per hour. Both of these speeds are tiny compared to the calculated speed of the sun.

6-16. The speed of a point on the equator is about 25,000 miles in 24 hours, or slightly more than 1,000 miles per hour.

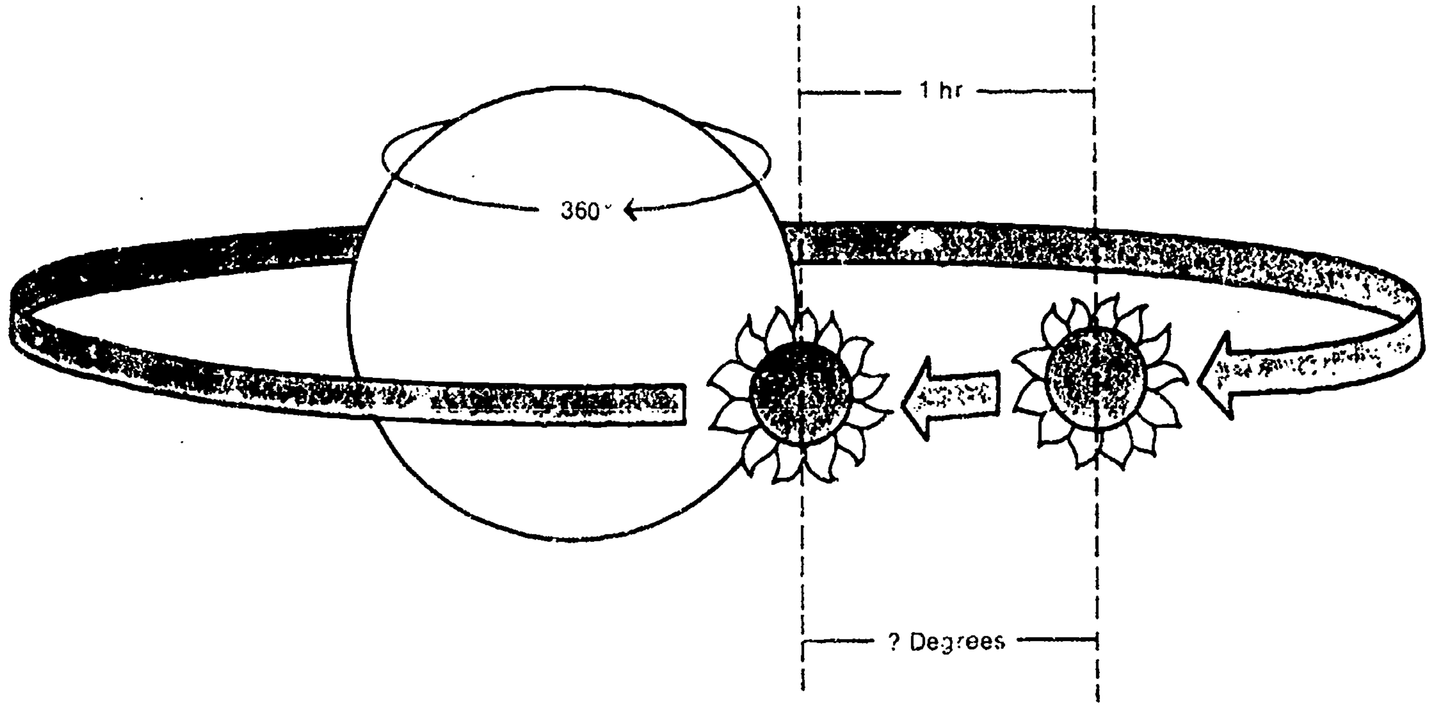
If the earth turns through 360° in 24 hours, then it turns 15° per hour. This is the average number of degrees the sun appears to travel in an hour. The students' answers should indicate that the time zones, one hour in difference, are roughtly 15° in width. The continental U. S. is about 60° across (67° W latitude to 125° W latitude) and there are 4 time zones: Eastern, Central, Mountain, and Pacific. Each is approximately 15° wide, although the width varies somewhat to accommodate state boundaries.

Your answer to question 6-15 should be a very large number. In fact, the speed is many, many times greater than that of any satellite ever put into orbit. And it is far greater than the calculated speed of other planets and most stars. Therefore, the model that the sun moves around the earth each day is very unlikely.

☐ **6-16.** Can you think of a way to calculate how fast the earth is turning? (Hint: The distance around the earth is 25,000 miles.)

PROBLEM BREAK 6-2

You know that the apparent rising and setting of the sun is caused by the earth's making one complete turn on its axis in 24 hours. You know that there are 360 degrees in a circle, or in one turn of the earth. Using this information, you can figure the number of degrees that the sun appears to travel in one hour.



What is the relationship between the number of degrees that the sun travels in one hour and the time zones that we use? For example, why is the time in New York different from the time in Chicago, and the time in Denver different from the time in Los Angeles? Write your explanation in your Record Book.

You have seen that your daily observations of the sun do not tell you whether it, or the earth, is moving. Because you've been told, you know that the earth is turning—the movement of the sun is just an illusion. Even so, it is more comfortable to say that the sun is "rising" or "setting" than to say the earth is turning. It feels quite natural and okay to say the sun moves across the sky.

Many scientists of old thought man lived in a sun-centered system. Others claimed that the universe was earth-centered. To find out how Galileo resolved this debate, do **Excursion 6-2.**

Before going on, do Self-Evaluation 6 in your Record Book.

Excursion 6-2 is for extension and general interest and lets the student follow Galileo's logic in solving the problem of the model of the solar system

EXCURSION

No advance preparations need be made for Chapter 7.

EQUIPMENT

None

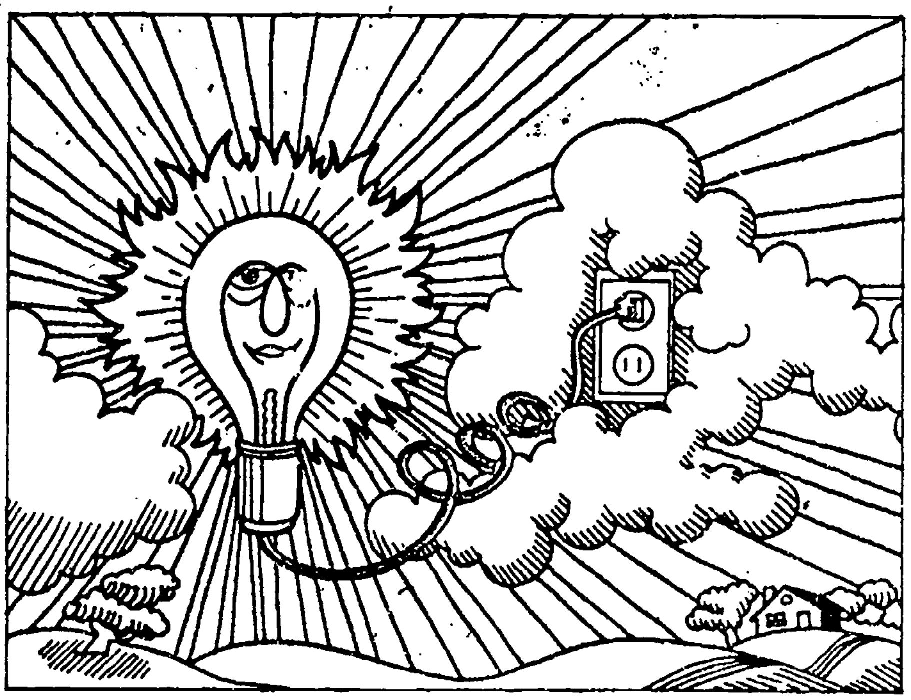
On Your Own

Excursions 7-1 and 7-2 are keyed to this chapter.

At the beginning of this unit, you set out to investigate the way astronomers get information about celestial objects. You now should have a pretty good idea of the way they work. By using sun-energy measurers (pyrheliometers) and photographs of spectra, and by calculating angles, astronomers can make quite remarkable measurements.

In this last chapter you will be given a chance to apply a few of the astronomers' techniques on your own. Your first investigation will help you wrap up your study of the sun.

Back in Chapter 2 you learned that the sun produces the same effect on your sun-energy measurer as does a 50-watt bulb held a few centimeters from it. However, you never really found out how many watts of power the sun has.



CHAPTER EMPHASIS

The student finally uses data he gathered in Chapter 2, with the distance to the sun in Chapter 4, to find the sun's power. He then uses techniques from other chapters to solve some individual problems in astronomy.

Chapter 7

MAJOR POINTS

1. The power of the sun at a distance of 93 million miles can be compared to the power of a light bulb at a short distance
2. The power required to produce a particular heating effect on an object must be four times as much when the distance from the power source to the object is doubled.
3. If power varies as the square of the distance, then the power of the sun can be computed in terms of a 50-watt bulb.
4. The power (wattage) of the sun is a huge number.
5. Using observed spectra and pyrheliometer readings, and given the distances to stars, a comparison can be made of their power and composition
6. The maximum sighting angle of Mercury can be used to find the shortest distance from the earth to the planet
7. The passage of a planet such as Mercury across the face of the sun, as viewed from the earth, is called a transit.
8. Data from a transit and from other known distances can be used to determine the diameter of the planet
9. Astronomers use other tools besides telescopes

This chapter calls for application by the student of the various concepts encountered during the unit. Due to the lack of equipment usage and experimental activities, there is a danger that the work will be taken too lightly, and rapidly passed over. Guard against this. The chapter can be the "frosting on the cake."

Excursion 7-1, "Power," is remedial-review. This is really the first place that the student is expected to understand the difference between energy and power. Encourage students to do the short excursion.

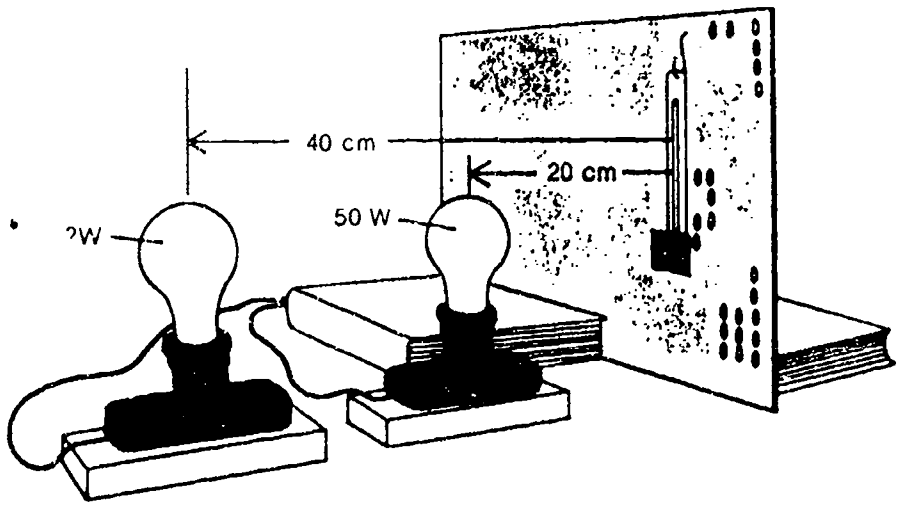
EXCURSION

To see how you can measure its power, you need to think of the sun as a great big light bulb 93,000,000 miles from the earth. To figure out how many watts that big sun bulb has, you need to know an important relationship. You need to know how distance affects the amount of light coming from a far object. You have a big clue to that relationship from Chapter 2. (Do you know what power is? Look over **Excursion 7-1.**)

In Activity 2-12, you found out the effect of a 50-watt bulb on your pyrheliometer. You placed the bulb 20 cm from the pyrheliometer and observed a certain temperature change. In Activity 2-13, you moved the light socket to a distance of 40 cm from the pyrheliometer. You then found out how many watts were needed to produce the same effect that had been caused by the 50-watt bulb at 20 cm.

Question 7-1 refers the student to question 2-21 for an answer. This is just one example of the need to use all the preceding chapters in working on this one. Of course, the previous answer may have been incorrect, and you may want to check for this. It should have been 200 watts. As the distance is doubled, (20 cm to 40 cm) the wattage increases as the square of the difference. $2^2 = 4$. 4×50 watts = 200 watts

7-1. How many watts at 40 cm produced the same effect on your sun-energy measurer as did a 50-watt bulb at 20 cm? (See your answer to question 2-21.)



7-2 As indicated above, you must multiply the wattage by four. If the student doesn't see this on the basis of previous work, this question, the following paragraph, and Figure 7-1, you may have to spend some time on the concept.

7-2. When you double the distance from the pyrheliometer to the light source, what must you do to the total wattage of the bulb to keep the sun-energy measurer reading the same?

If you did your arithmetic well, you now know how increasing distance affects the amount of light coming from a source. When the distance from an object to a light source is doubled, the power of the light source must be four times greater if the same amount of light is to reach the object. (See Figure 7-1.)

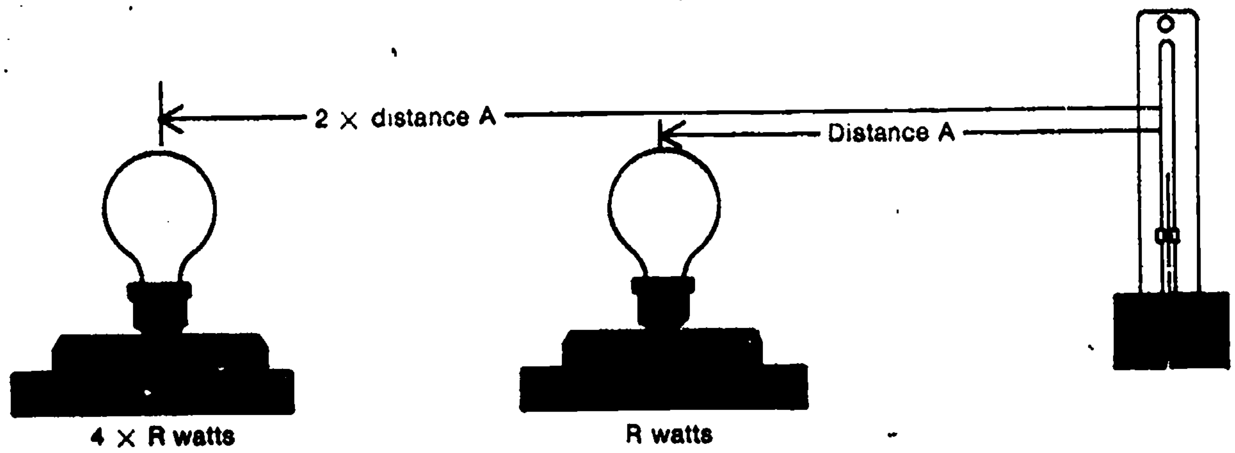


Figure 7-1

This relationship plus your earlier data is all that you need to know in order to measure the wattage of the sun. Table 7-1 suggests one way to do this.

Table 7-1

Measured Distance (Sample)	Wattage
10 cm	50
20 cm	200
40 cm	800
80 cm	3,200
160 cm	12,800
93 million miles	

The person who made Table 7-1 simply kept doubling the distance an imaginary bulb was from a sun-energy measurer. To keep the light received the same each time, he kept multiplying the wattage of the bulb by 4. If he were to keep doing this until the distance became 93 million miles (15,000,000,000,000 cm), he would have found the wattage of the sun.

There is nothing wrong with this method of doubling distance and quadrupling wattage as shown in the table. And actually the doubling gets to 15,000,000,000,000 cm quite rapidly. A total of 40 to 43 entries will do it—less than two sheets of paper. The checklist that is given will help. Be sure that the student starts with the actual distance (question 2-18), and *not* with the 10 cm as shown in the sample table.

If you have a lot of time to spare, you might like to try the approach taken in Table 7-1. Another way to do the same thing is described in **Excursion 7-2,** "Using Squares to Measure Distance." Although shorter, it involves slightly more-difficult mathematics. Use one of these two methods to calculate the sun's power in watts. If you decide to use the longer method described in Table 7-1, you may find the following check list helpful.

The more mathematically inclined students may want to use Excursion 7-2 for extension. It is definitely shorter than the 43-entry table, but requires an understanding of the law of squares.

1. Make two columns on a sheet of lined paper.
2. Label the left-hand column "Distance" and the right-hand column "Wattage."

As you can surmise, it is not likely that the student will reach *exactly* 15,000,000,000,000 cm as indicated in step 6. For example, the 40th entry may be some number like 11,446,337,208,320 cm for distance, and 16,914,575,040,808,832,043,827,200 for wattage. Another doubling of distance for the 41st entry will give 22,892,694,416,640 cm for distance and 67,658,300,163,[illegible],328,172 for wattage. The 40th entry was too low by 3,553,662,791,680 cm, and the 41st entry was too high. The student can (a) say that the wattage of the sun lies between the 40th and 41st entries, or (b) estimate how much greater the wattage is than the 40th entry and use that figure, or (c) interpolate by saying that the amount by which the 40th entry was too low represents [illegible] of the way toward the 41st entry and take that part of the wattage difference between the two entries.

7-3. The actual figure the student gets is not too important, but, for your information, the sun's power is about 370,000,000,000,000,000,000,000,000 watts (that's 3.7 × 10[illegible] W).

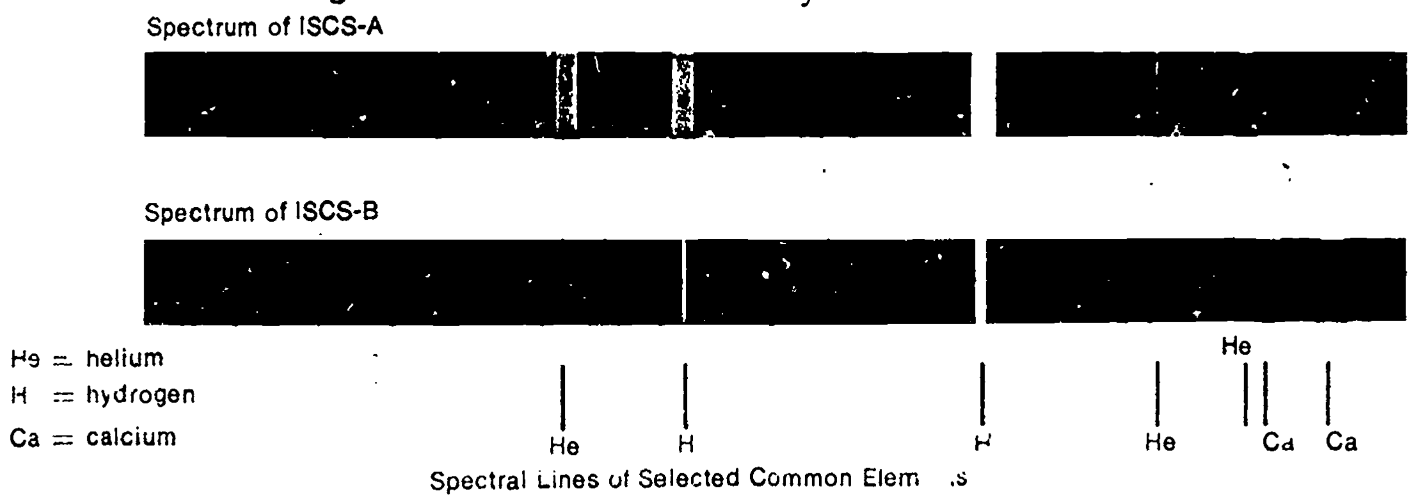
3. At the top of the left column, write in the distance in cm from question 2-18 of Chapter 2. Opposite this number, in the right-hand column, write in 50 Watts.
4. Double the distance in the left-hand column and write the new distance under the first. Multiply the 50 W in the right-hand column by 4, and write the new wattage (200) under the 50.
5. Keep doubling the distance number in the left-hand column. Each time, multiply the wattage number in the right-hand column by 4.
6. Continue doubling the left-hand numbers until you reach 15,000,000,000,000 cm. In each case, multiply the number in the right-hand column by 4.
7. The last number in the right-hand column, opposite 15,000,000,000,000 cm, is the estimated wattage of the sun.

☐ **7-3.** What is the wattage of the sun?

Now you should test your ability to use some of the other techniques you have learned. For the first exercise, you will be given spectroscope data for two stars, ISCS-A and ISCS-B. Your task is to interpret this information to find out as much as you can about the stars. From it, you should be able to say something of the way the two stars compare in composition, distance, and power.

Figure 7-2 shows the spectra observed when the light from ISCS-A and ISCS-B passed through a spectroscope. It also shows the spectral lines of some common elements. Look at the spectra carefully. They and Tables 7-2 and 7-3 contain all the information you need to finish this first exercise.

Figure 7-2



Distance from the Earth	
ISCS-A	50,000,000,000,000 miles, or 8,000,000,000,000,000,000 cm
ISCS-B	25,000,000,000,000 miles, or 4,000,000,000,000,000,000 cm

Energy Data	
	Sun-Energy Measurer Reading
ISCS-A	19.9° C
ISCS-B	34.6° C
Reading in shade	5.2° C

☐ **7-4.** In your Record Book, record your conclusions about the two stars. Then give a brief explanation of the way you reached the conclusions.

Your written discussion should include a comparison of the two stars in terms of their power and the elements they contain. Try to get other information about the two stars if you can. You will probably want to review Chapters 1, 2, and 7 as you do this activity.

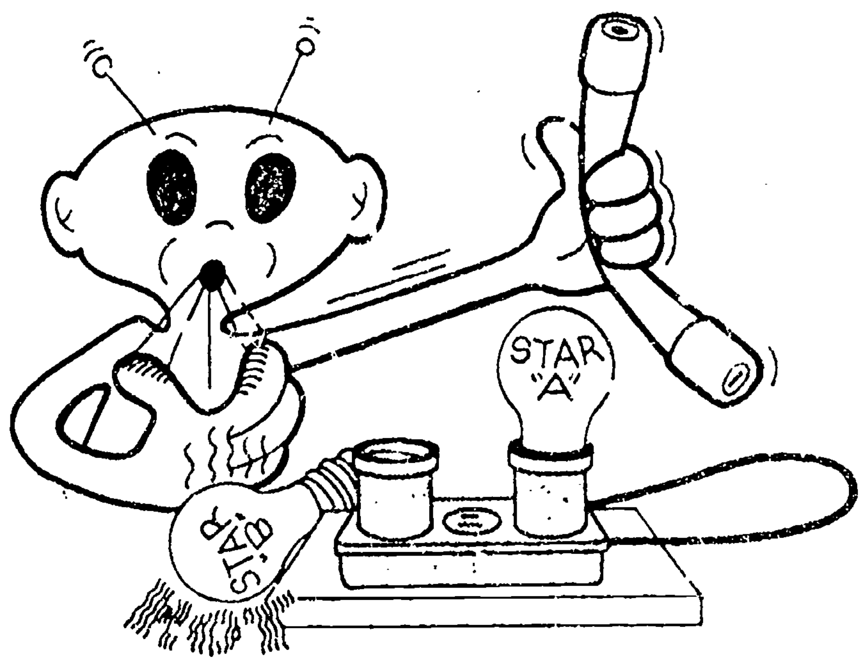


Table 7-2

The major star nearest to our solar system is about 25,000,000,000,000 miles away, which matches the distance to ISCS-B. It is the triple star Alpha Centauri. ISCS-A about matches in distance Sirius, the brightest star in the sky.

Table 7-3

The pyrheliometer would of course have to be mounted at the focus of a large telescope in order to get any energy readings.

From the spectra, the student should conclude that star A contains the elements helium and hydrogen, and star B contains hydrogen and calcium. From the distance and energy data, students should conclude that star A is twice as far away as star B, that the energy received from star B is about twice as much as that from star A, and that therefore the power of star A is greater than that of star B. If the two stars had the same power, star A would have produced only [illegible] as much temperature change as star B, since star A is twice as far away. Instead it produced [illegible] as much, so star A must be greater in power.

85

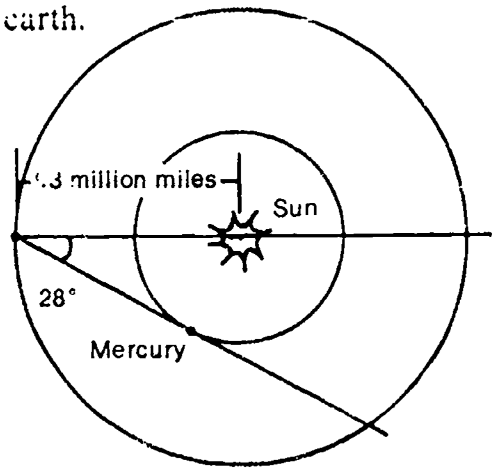
MEASURING THE DISTANCE TO MERCURY

Your next problem is to determine the shortest distance from the earth to the planet Mercury. You can use a procedure similar to that used in Chapter 4 to find the distance to the sun. You may assume that the earth and Mercury both move around the sun in circular orbits. You know that the earth is approximately 93 million miles from the sun, and that the maximum sun-earth-Mercury angle is 28°. Figure 7-3 illustrates this. With it and the data given, you should be able to solve the problem. Make your observations and record your findings in your Record Book.

Using the maximum angle of 28° and the method of Chapter 4, the sun-to-Mercury distance comes out about 42.8 million miles. Subtracting this from the Earth-sun distance, 93 million miles, gives about 50 million miles. (question 7-5) Actually, the orbit of Mercury is much more elliptical than that of Earth or Venus, and its distance from the sun varies from 28.5 million to 43.5 million miles.

☐ 7-5. Record your calculation of the shortest distance from Mercury to the earth.

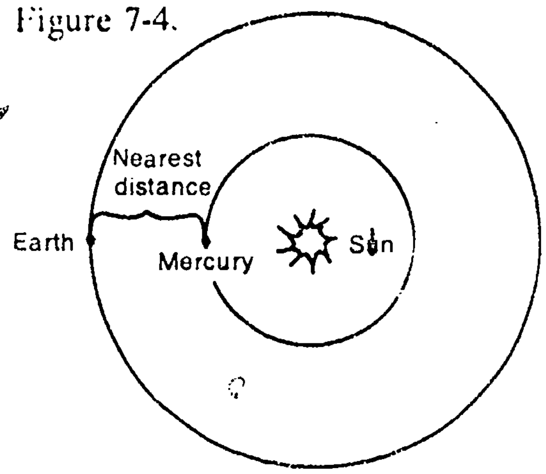
Figure 7-3



MEASURING THE SIZE OF MERCURY

Every few years the sun, the earth, and Mercury line up perfectly, with Mercury between the sun and the earth. This is shown in Figure 7-4.

Figure 7-4



A transit of Venus is a much finer sight because Venus is both closer and larger than Mercury. However, this event is rather rare, and the next transit of Venus will not occur until the year 2004.

When this happens, astronomers can photograph Mercury as it passes across the face of the sun. This is called a *transit*. Such a transit was observed in 1970, and there will be another in 1973, in 1986, and in 1993. Figure 7-5 shows Mercury crossing the sun.

Figure 7-5

Perhaps you see how this information can be used to determine the diameter of Mercury.

Suppose, during a transit of Mercury, the apparent size of the planet was measured to be $\frac{1}{200}$ as wide as the sun that it was crossing. Find the diameter of Mercury, using the following data you have already worked out:

1. The distance to the sun—from Chapter 4
2. The size of the sun—from Chapter 5
3. The nearest distance from the earth to Mercury—your answer to question 7-5

☐**7-6.** Record the diameter of Mercury in your notebook.

For lack of time and better equipment, you have not used to the fullest the measuring techniques you've learned. By looking at spectra, astronomers can determine such things as the speed of moving objects, as well as their temperature and composition. Mathematics can be used to produce many, many other kinds of distance measurements.

The diameter of Mercury can be found by proportion, using the data given below, as follows:

$$\frac{\text{Diam. of Mercury}}{\frac{1}{200}\text{ diam. of sun}} = \frac{\text{Distance to Mercury}}{\text{Distance to sun}}$$

$$\frac{\text{Diam. of Mercury}}{\frac{1}{200} \times 865{,}000\text{ mi}} = \frac{50{,}200{,}000\text{ mi}}{93{,}000{,}000\text{ mi}}$$

$$\text{Diam. of Mercury} = \frac{50{,}200{,}000 \times 4325\text{ mi}}{93{,}000{,}000}$$

$$\text{Diam. of Mercury} = 2{,}335\text{ mi}$$

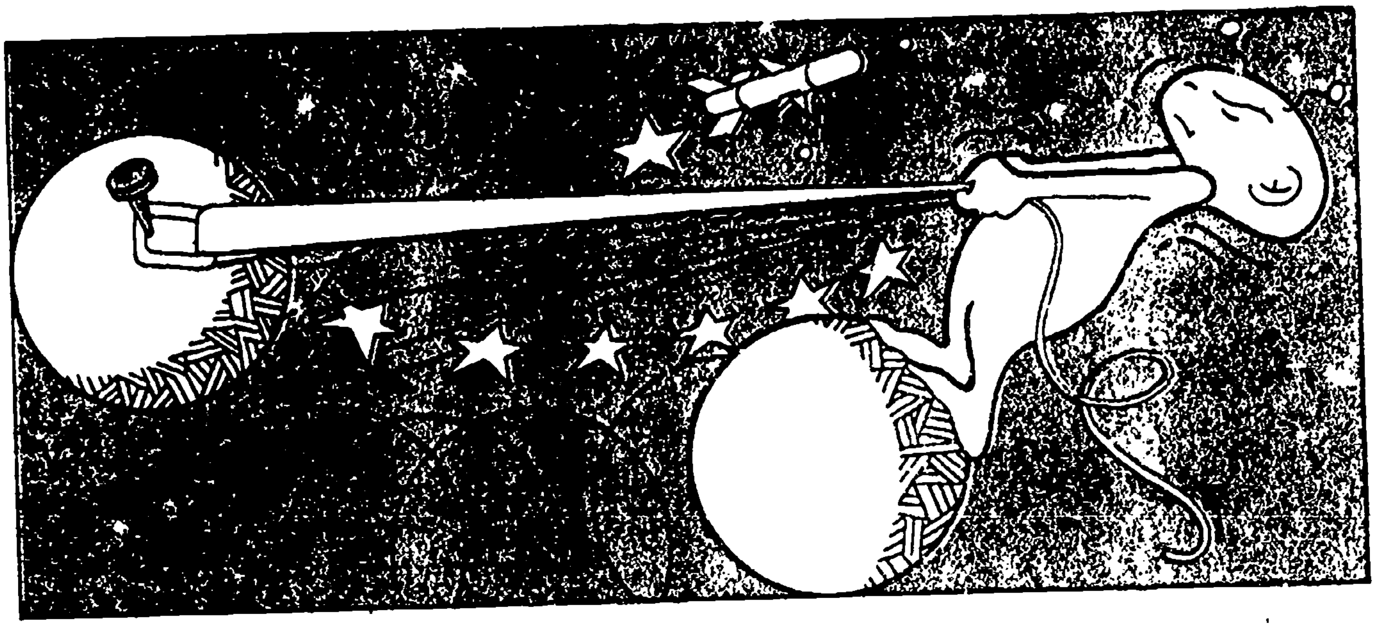
The accepted value for the diameter of Mercury is about 3,000 miles. The computed diameter compares favorably, and if the mean distance from Mercury to the sun of about 36 million miles had been used, it would have made the distance from the earth to Mercury about 57 million miles, and the diameter would have come even closer to the accepted figure

It will probably come as no surprise to you that there are very few astronomers who spend much time looking through big telescopes. Instrumentation and photographic techniques have made great changes in the art of astronomy.

Most people think of astronomers as constantly looking through big telescopes. Although the telescope is certainly important for gathering information about stars and planets, it is by no means the astronomer's only tool. In recent years, new ways of studying the heavens have been used. Not long ago, for example, it was discovered that some stars and groups of stars give off radio waves. By studying these waves, radio astronomers are locating objects that were unknown only a few years ago.

If you've done your work well, you now realize that a lot of work involves only a pencil, a piece of paper, and, most importantly, a lot of hard thinking. Of course, a computer comes in handy.

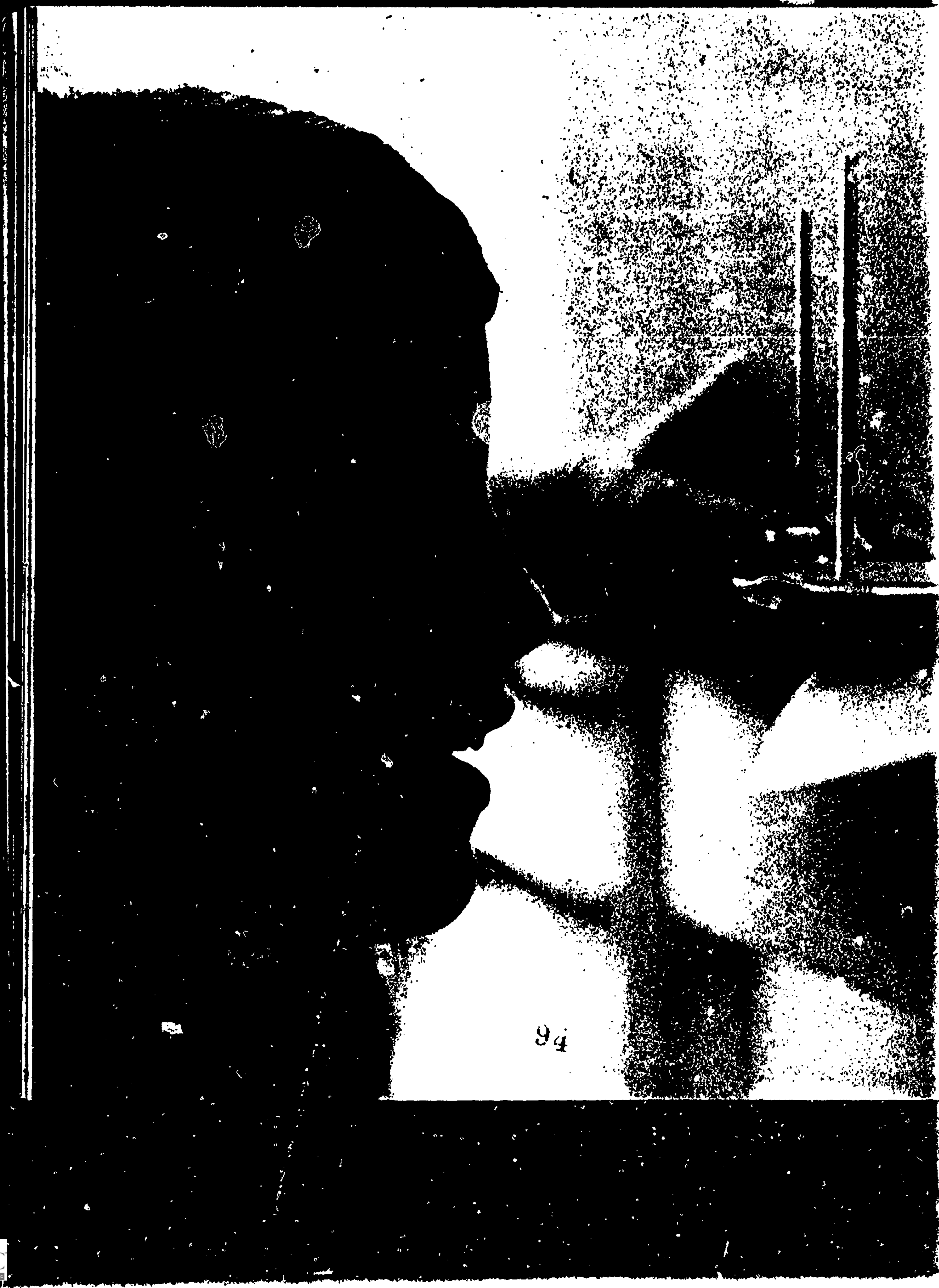
Before going on, do Self-Evaluation 7 in your Record Book.



Excursions

Do you like to take trips, to try something different, to see new things? Excursions can give you the chance. In many ways they resemble chapters. But chapters carry the main story line. Excursions are side trips. They may help you to go further, they may help you go into different material, or they may just be of interest to you. And some excursions are provided to help you understand difficult ideas.

Whatever way you get there, after you finish an excursion, you should return to your place in the text material and continue with your work. These short trips can be interesting and different.



EQUIPMENT LIST

3 pegboard backs
1 10-cm length of nichrome wire
1 petri dish or baby-food jar
1 alcohol burner
1 spectroscope
1 small container of water
1 150-watt bulb in receptacle
1 small pinch of NaCl

PURPOSE

To allow the student to observe the absorption, or dark-line, spectrum of sodium.

Those Strange Dark Lines

Excursion 1-1

MAJOR POINTS

1 The dark lines that cross the spectrum of the sun are in the same position as the bright lines in the spectra of certain elements.
2 Sodium vapor can subtract the yellow lines from the spectrum of a bulb.

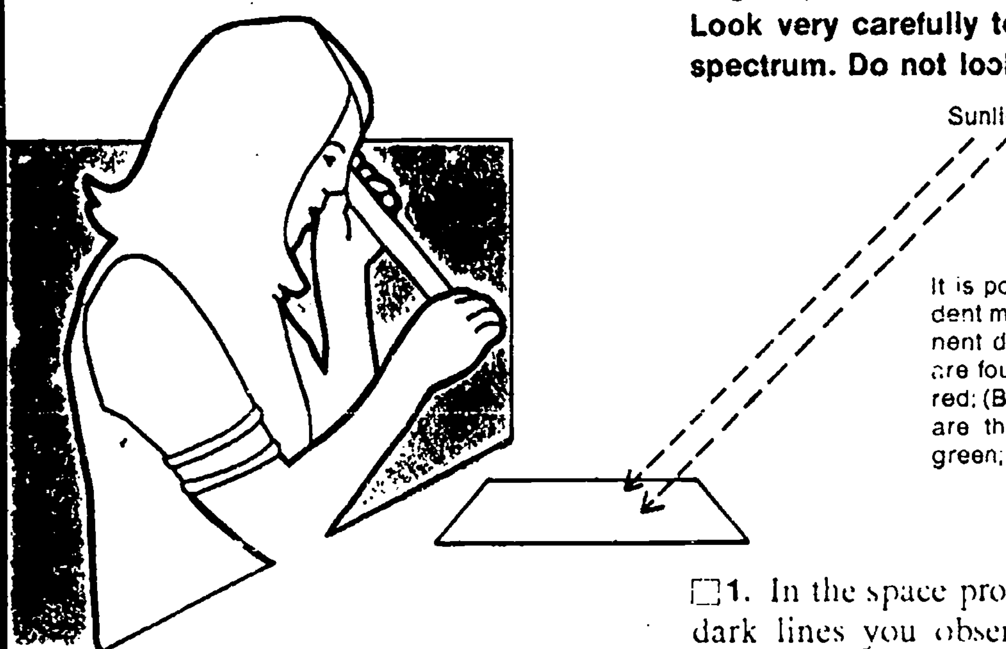
To keep from over frustrating a student, it would probably be wise to make it clear that the Fraunhofer lines are extremely difficult to observe, and there is a possibility that they will not be seen

This is an extension excursion requiring careful observation.

Your work in Chapter 1 introduced you to bright-line spectra. Now perhaps you'd like to meet the black sheep of the spectral family. If so, start right in.

Safety Note *Remember not to look directly at the sun as you do the activities that follow.*

ACTIVITY 1. Once again, use the spectroscope to study a bright spot of sunlight reflected from a piece of white paper. Look very carefully to try to locate a few dark lines in the spectrum. Do not look directly at the sun.



It is possible (but not probable) that the student may see most or all of the 8 most prominent dark lines in the solar spectrum. They are found in the following positions. (A) deep red; (B) red; (C) red-orange, (D) yellow—these are the sodium lines; (E) green; (F) blue-green; (G) blue-violet; (H) deep violet.

☐1. In the space provided in your Record Book, sketch any dark lines you observe. (If you don't see any lines after looking very closely, leave the space blank.)

Did you have difficulty seeing the dark lines in the spectrum of the sun? Don't feel too bad. Not only did some of the great scientists in the past not see the lines in the sun's spectrum, but some who did see the lines disregarded them. For example, one good scientist thought they were merely the boundaries between the various colors.

For your information, the good scientist mentioned here was William Hyde Wollaston, eminent English chemist and physicist. He first observed the lines in 1802.

Joseph von Fraunhofer

Joseph von Fraunhofer (1787–1826) was a German physicist and optical-instrument maker. He is credited with the invention of the diffraction grating that is used on the spectroscope.

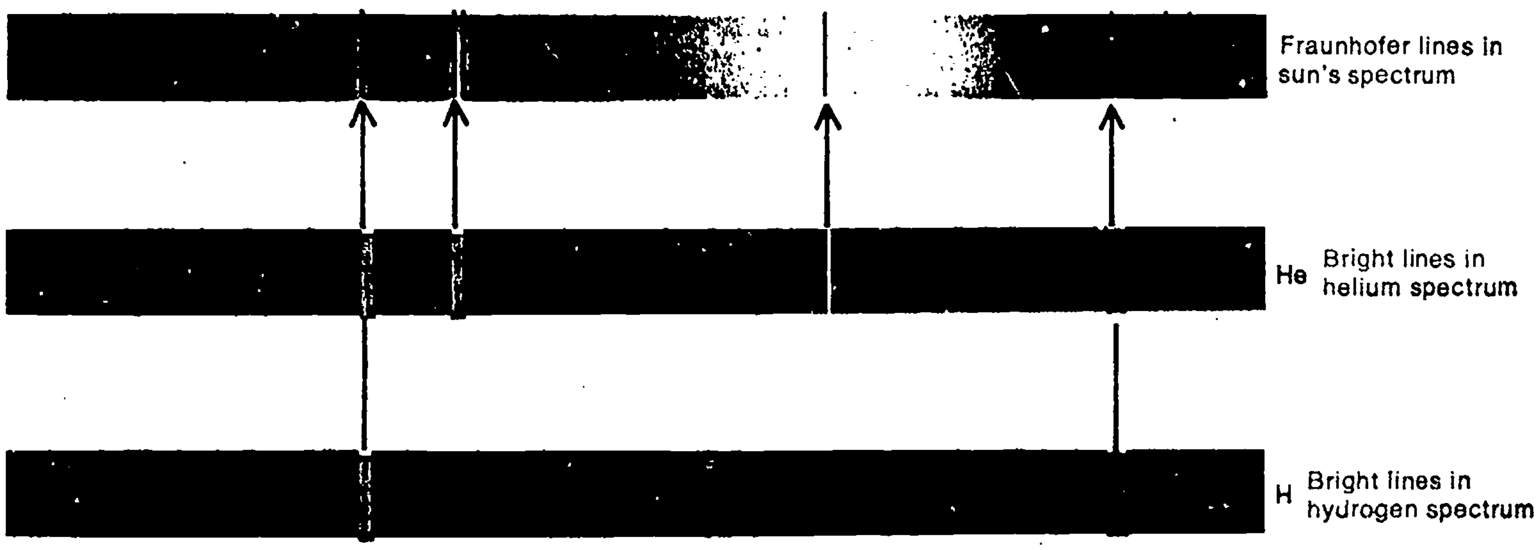
The dark lines that cross the spectrum of the sun were first investigated by Fraunhofer in 1814. He measured but couldn't explain the positions of a great many of them. The lines are now called *Fraunhofer lines* in Fraunhofer's honor, but their explanation was the product of another great scientist, Kirchhoff.

Gustav Robert Kirchhoff (1824–1887) also was a German physicist. He is perhaps best known for his Law of Thermal Radiation and his rules for calculating currents in electrical networks.

It was found that these dark lines on the spectrum were in exactly the same position as the lines in the bright-line spectra of certain elements. The dark lines are believed to be caused when light from the sun's surface passes through the gases in the atmospheres of the sun and the earth. Figure 1 shows a comparison between the two kinds of lines.

The spectrum of the light from the sun has been photographed, and the positions of the dark lines noted. These lines have been compared with known spectral lines. In this way the astronomer has been able to predict what elements the atmosphere of the sun contains.

Figure 1



You can do a simple experiment that will let you see the Fraunhofer lines of the element sodium. You will need the following equipment:

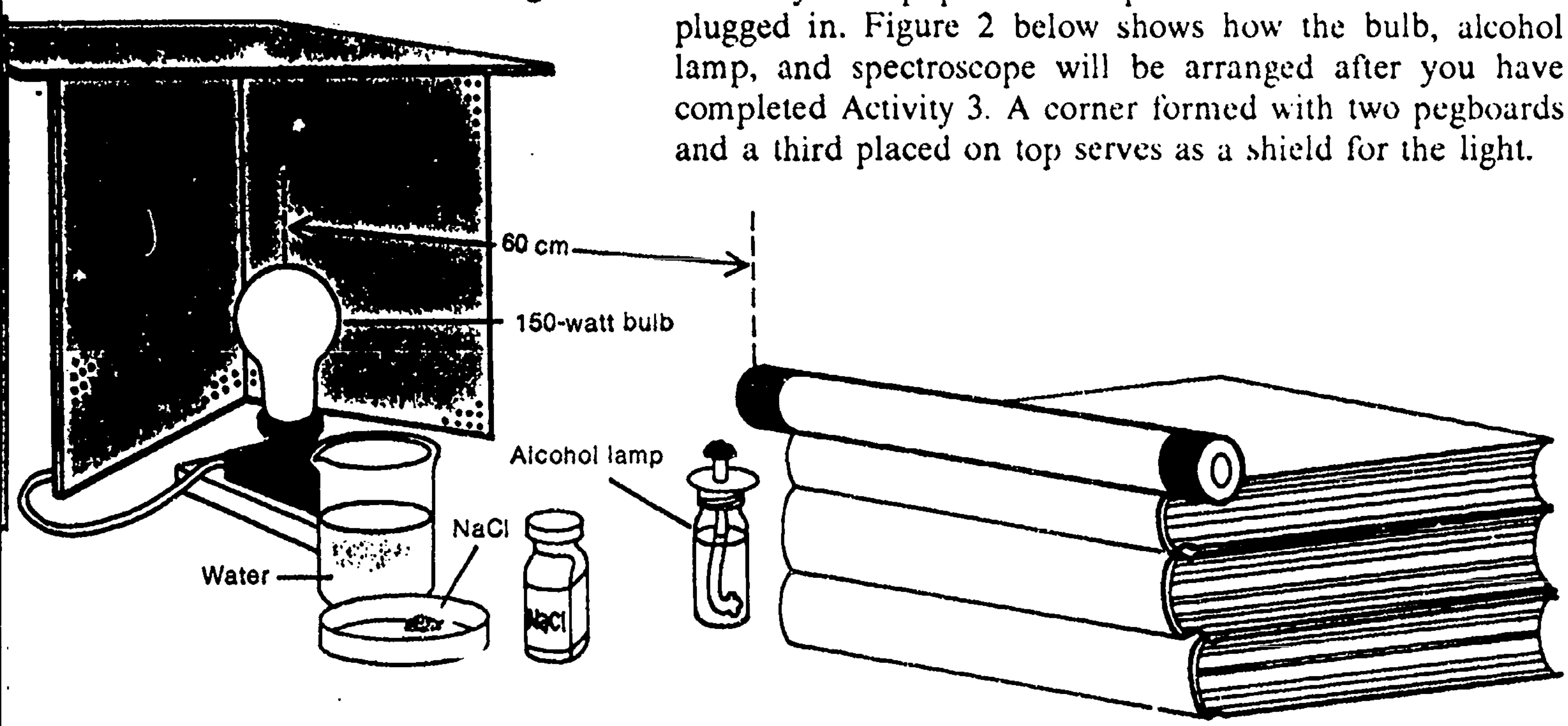
3 pegboard backs
1 nichrome wire, 10 cm long
1 petri dish
1 alcohol burner
1 spectroscope
1 small container of water
1 150-watt bulb in parallel-circuit receptacle
1 small pinch of NaCl

A container, such as a baby-food jar, may be used instead of the petri dish. Likewise, the nichrome wire that was used with the NaCl in Chapter 1 may be used here instead of making a new one.

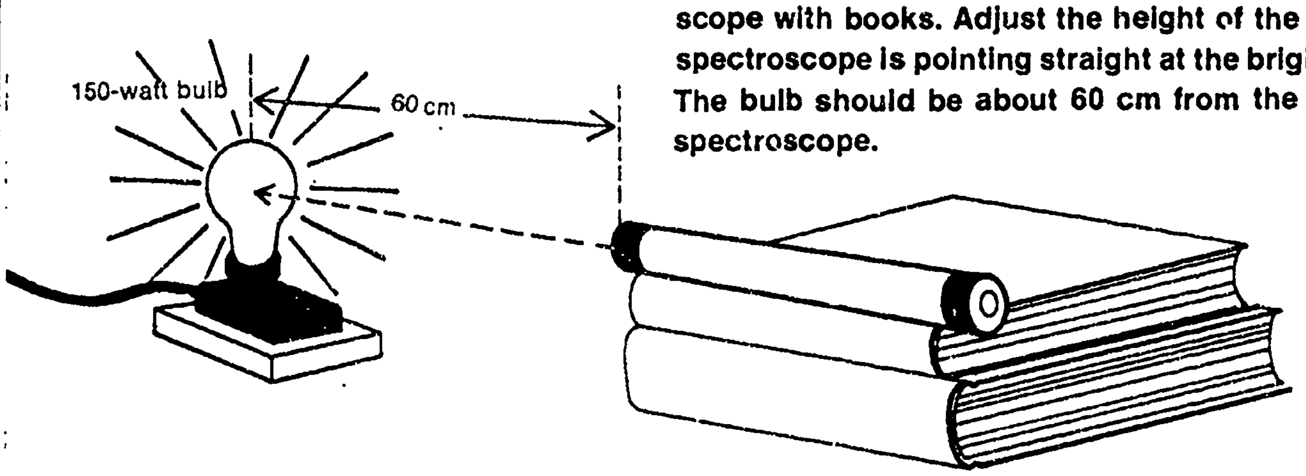
☐**2.** In the space provided, draw your predicted position of the dark lines of the Na spectrum. (Hint: What did you find for the bright-line spectrum?)

Figure 2

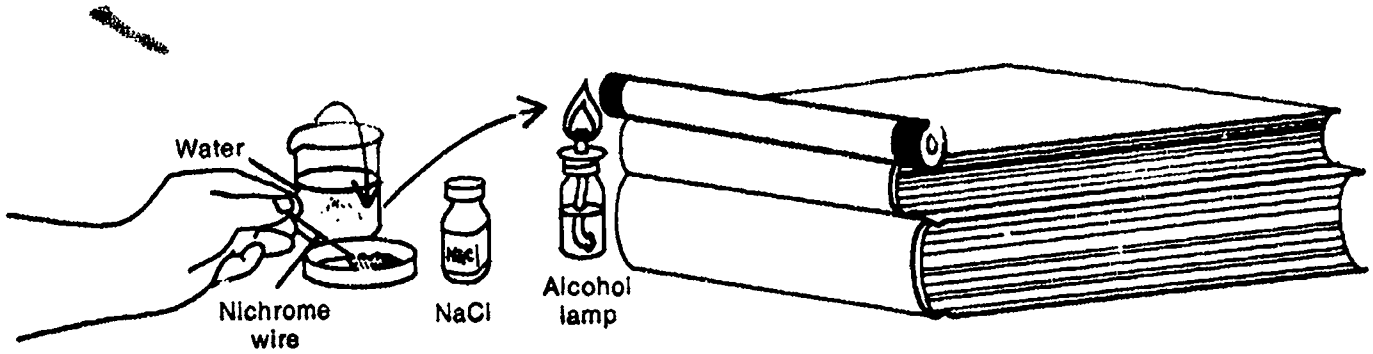
Take your equipment to a place where the bulb can be plugged in. Figure 2 below shows how the bulb, alcohol lamp, and spectroscope will be arranged after you have completed Activity 3. A corner formed with two pegboards and a third placed on top serves as a shield for the light.



ACTIVITY 2. Plug in the 150-watt bulb. Support the spectroscope with books. Adjust the height of the books so that the spectroscope is pointing straight at the bright part of the bulb. The bulb should be about 60 cm from the closer end of the spectroscope.

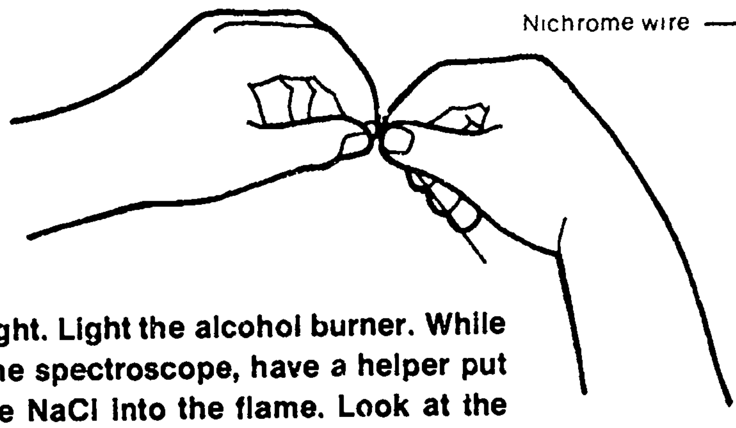


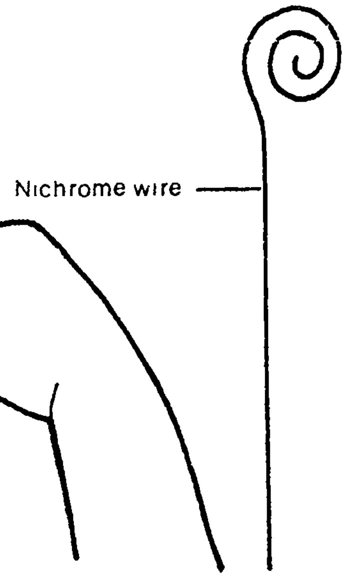
ACTIVITY 3. Turn off the 150-watt bulb. Place the alcohol burner close to the end of the spectroscope. Dip the nichrome wire into water and then into the NaCl. Then hold it in the flame, avoiding the wick. You should see the yellow sodium lines clearly through the scope. Adjust the height of the burner if necessary.



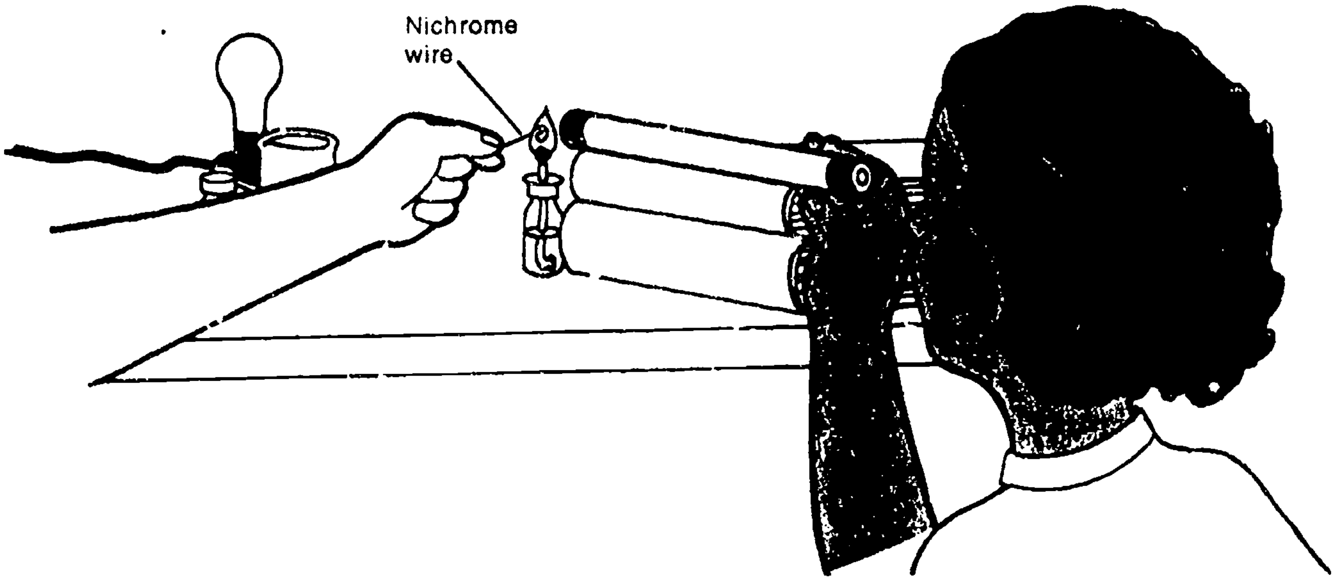
After you have completed Activity 3, you should be able to see the bright continuous spectrum from the bulb when it is turned on, and the bright yellow lines from the NaCl flame when the bulb is off, without having to move the spectroscope. Make the necessary adjustments until you can.

ACTIVITY 4. Twist the end of the nichrome wire so that it will hold more salt (NaCl) in the flame. Dip it into water to moisten it and then into the NaCl.





ACTIVITY 5. Turn on the light. Light the alcohol burner. While you are looking through the spectroscope, have a helper put the nichrome wire with the NaCl into the flame. Look at the spot where the bright yellow lines appeared before.

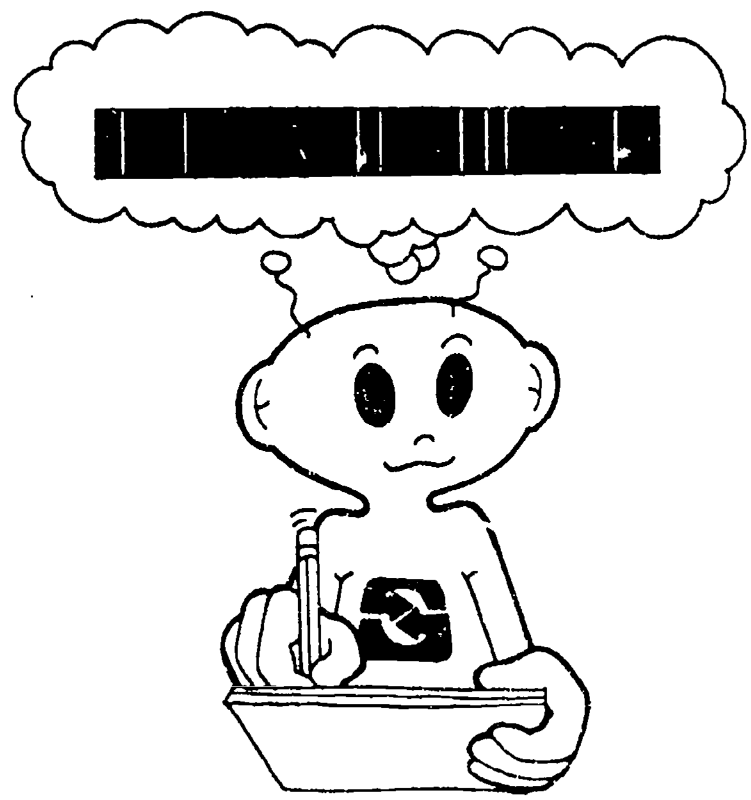


☐**3.** In the space provided in your Record Book, describe what you see.

If the observations are carefully made, and the lamp, flame, and spectroscope are lined up properly, the dark Fraunhofer lines should appear where the bright lines were before. The sodium (Na) vapor in the flame subtracts the yellow lines from the spectrum of the bulb. Fraunhofer noted that the measured positions of the dark lines were exactly the same as the bright lines of many of the elements in a flame.

With proper (and much more sophisticated) equipment, a dramatic demonstration of dark-line spectra can be done. Light from a carbon arc, after passing through a series of lenses and prisms, forms a continuous spectrum on a screen in a darkened room. A small amount of metallic sodium is inserted into a partially evacuated glass tube. When this tube is placed in the light path and gently heated, two dark lines appear in the yellow region of the spectrum.

☐**4.** How did your findings compare with your prediction in question 2?



EQUIPMENT

None

PURPOSE

To provide a review of the energy concept.

Energy at Work

Excursion 2-1

This is a remedial-review excursion. The student is led into it through the Checkup in Chapter 2.

MAJOR POINTS

1. Energy is equated to work.
2. Energy exists in different forms.
3. Energy can be transferred from one place to another.
4. Energy can be changed from one form to another.
5. Energy can cause a change in matter.
6. Energy is conserved. When it changes from one form to another, no energy is lost or destroyed.

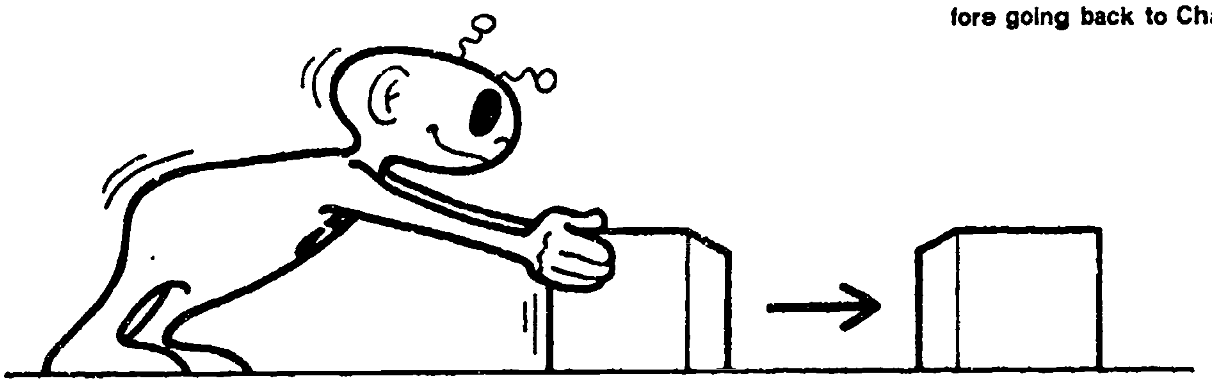
Answers to Checkup

The correct answers for the Checkup are 1 c; 2 b, d; 3 b, c, d; and 4 a, c. Notice that some questions had more than one correct answer. If you missed any of these, or if you checked any of the other choices, do this excursion before going back to Chapter 2.

Whenever possible, scientists use operational definitions in describing things they study. For example:

A scientific operational definition for work is

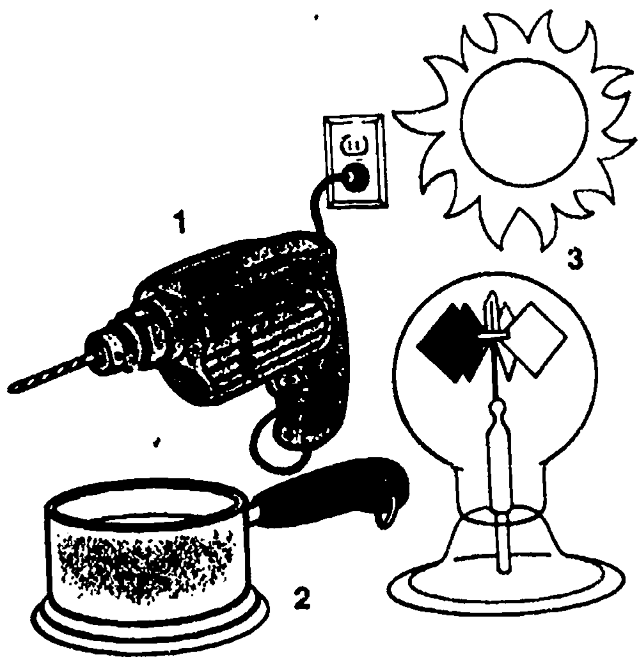
$$\text{WORK} = \text{FORCE} \times \text{DISTANCE}$$



According to this definition, Iggy (above) is doing work if he does two things:

1. Applies a force to the box, and
2. moves the box some distance.

Somehow, Iggy has the ability to do work. This ability can be thought of as something present in him. We'll call it energy. The scientist, being precise, wants a more accurate definition of energy. He says, "Energy can do work."



The scientist's definition of energy has an interesting result. There are different kinds of things that can do work. Therefore, energy must exist in different forms.

For example, electrical devices (1) can do work; therefore, electricity is one form of energy.

Heat (2) also can be used in doing work. It, too, must be energy.

Light (3) is considered as another form of energy because it can do work.

Still other forms of energy exist. Chemical energy is an example.

You know from your own experiences that energy can be transferred from one place to another. Light, for example, travels to the earth from the sun. A hot object next to a cold one loses heat to the cold object. Electricity can move from a power plant to the lamp on your table.

☐1. Give another example of the transfer of energy.

Remember, too, that energy can be changed from one form to another. For example:

Light can be changed to heat.

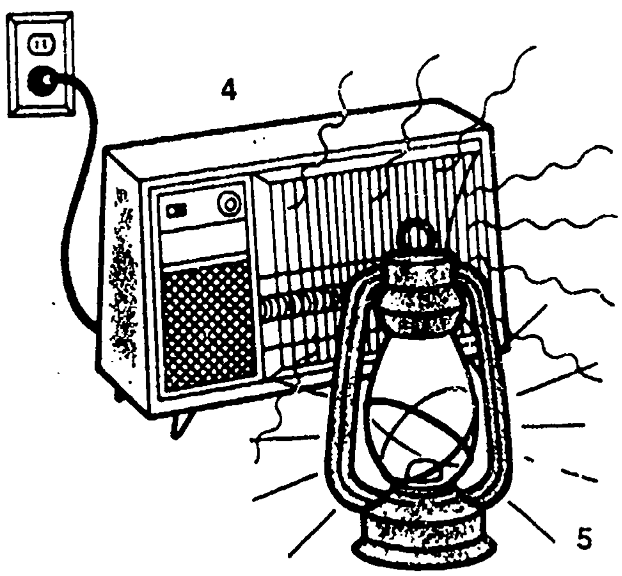
Electricity (4) can be changed to light and heat.

Heat (5) can be changed to light.

☐2. Can you give an example of heat being changed to electricity?

☐3. Can chemical energy be changed to electrical energy?

☐4. Give an example or two of how energy causes a change in matter.



When these changes in matter occur, and when one form of energy changes to another, no energy is lost or destroyed. Energy may be absorbed, released, changed in form, and spread around, but it is always somewhere—it is always conserved. Scientists refer to this fact as the conservation of energy.

Return now to Chapter 2.

EQUIPMENT LIST

Watch or timer with second hand.

PURPOSE

To show a simple method for measuring the diameter of the moon.

The Moon's Measurements

Excursion 3-1

This is a general-interest excursion that requires a short period of observation outside of school and a small amount of calculating.

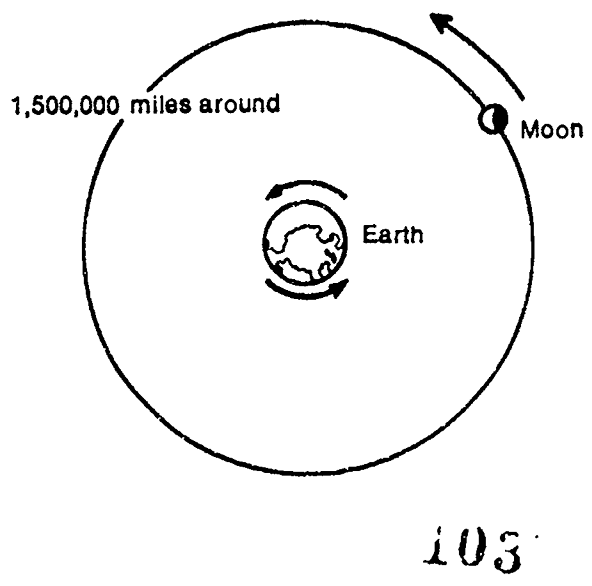
MAJOR POINTS

1. The distance around the moon's orbit, 1,500,000 miles, can be found by multiplying the distance to the moon, 240,000 miles by 2 × 3.14 (2 pi).
2. The apparent motion of the moon is influenced by the rotation of the earth and the movement of the moon in its orbit.
3. Most of the apparent motion of the moon is due to the earth's rotation.
4. The time that it takes for the moon to move one diameter in the sky, divided into the length of time for one day (24 hours), will give the number of moon diameters in one orbit.
5. Dividing the number of miles in the moon's orbit (1,500,000 miles) by the number of moon diameters in one orbit will give the diameter of the moon in miles.

During the 1968 Christmas holidays, the world was thrilled by the successful orbiting of the moon by three American astronauts. Of course, since then, several men have walked on the moon's surface. However, the first humans to get close to the moon's surface, astronauts Borman, Lovell, and Anders, were in an excellent position to measure the size of the moon.

Even though you are a long way from its surface, you too can measure the diameter of the moon. And you can do it almost as accurately as could the astronauts. All you need is a clock and the ability to visualize the motion of the moon with respect to the earth. Figure 1 will help you do this.

Figure 1



How do you calculate the distance around the moon's orbit? See the last part of this excursion.

Notice that the figure reminds you of two important assumptions. Keep these in mind as you proceed.

1. It is asumed that the moon's orbit is a circle. 1.500.000 miles around. The earth is placed at the center of that circle.
2. The earth turns at a constant speed.

As you may know, astronomers have shown that these assumptions are not completely accurate. They are close enough, however, to let you make the measurements you need.

On a night when the moon is full and the weather is clear, watch the moon for a few minutes. If you look carefully long enough, you will notice that the moon appears to move in the sky. If you know your directions, you may even notice that it moves from east to west. Look at Figure 2 and do some thinking.

The apparent motion of the moon is influenced by two things: (A) the turning of the earth, and (B) the moon's movement in its orbit.

Astronomers have found that most of what appears to be the motion of the moon is due to the turning of the earth. In fact, it is reasonable to assume that when you view the moon for only short periods of an hour or so, all the motion observed is due entirely to the earth's turning. You will assume this to be so as you make the observation called for in Activity 1.

Your first problem will be to find out how fast the moon appears to move. Since doing this may take an hour or so, you'd better start your work fairly early in the evening.

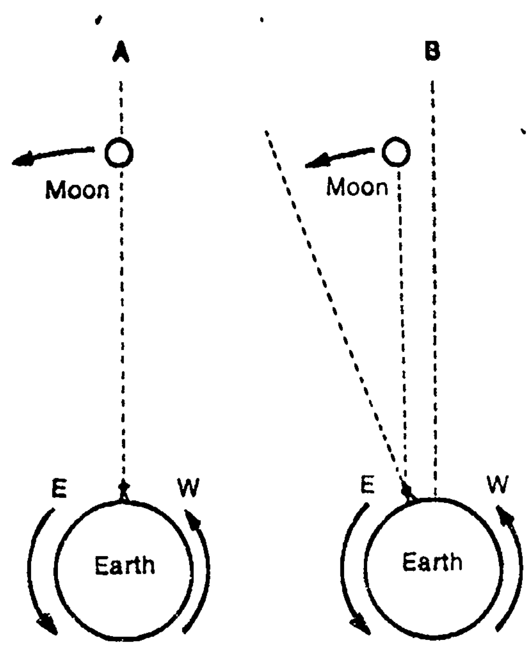
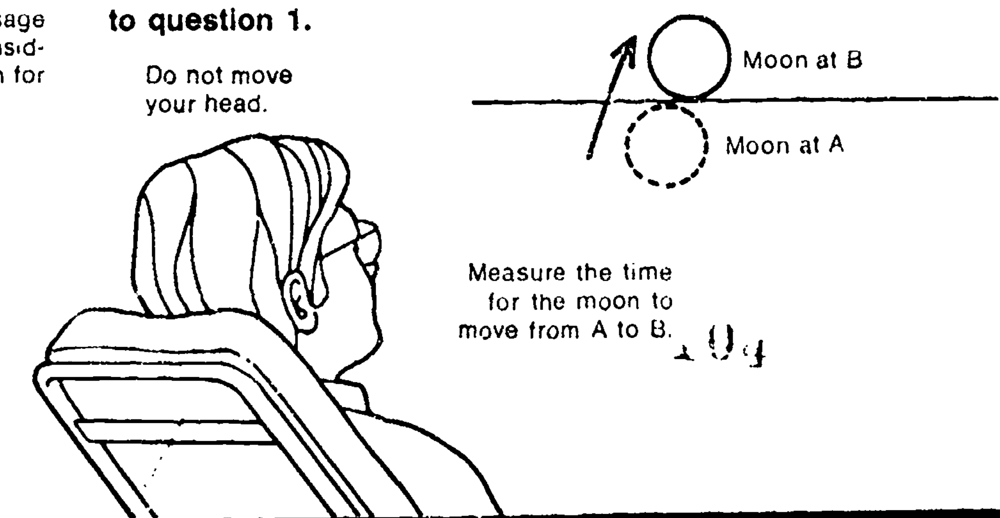


Figure 2

The correct timing of the passage of the moon across a wire is the crucial point. In order to get a reasonable measurement, the wire should be in such a position that it is at a right angle to the moon's orbit so that the moon will pass straight across the wire and not laterally along it. The actual time of passage will [illegible] relatively short, but it may take considerably longer to get in the proper position for the sighting.

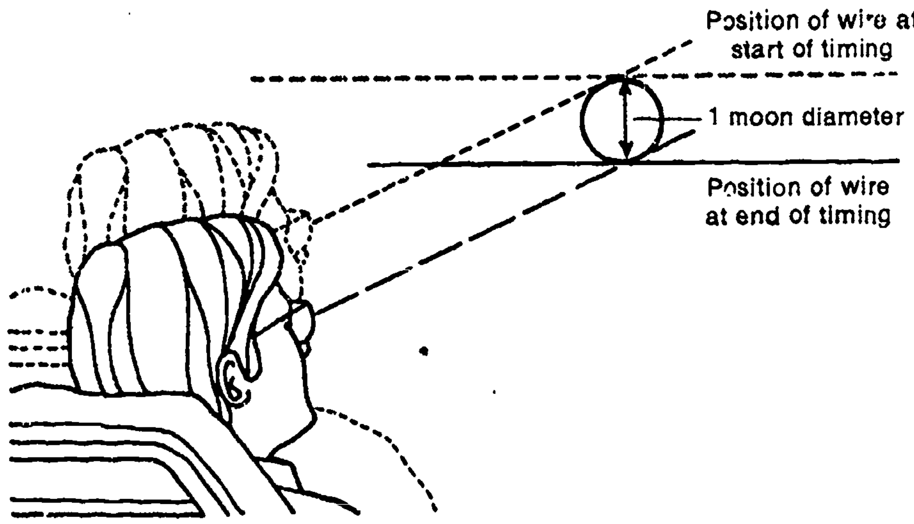
ACTIVITY 1. Line up the top of the moon with a power line or telephone wire. With your head resting against some object to keep your eye steady, time the movement of the moon across the wire. Record the time in minutes as your answer to question 1.



□**1.** How many minutes did it take the moon to pass across the wire?

Your answer to question 1 is a very interesting measurement. Figure 3 may help you figure out what it means. The drawing is based upon the assumption that the earth's motion makes the moon appear to move.

Figure 3



1. The time should be about 2 minutes. For simplicity in the calculations, you may want the students to round off the reading to the nearest minute, and not use a fraction or a decimal of a minute above or below the two minutes. Question 2 is just a reaffirmation of this same reading of 2 minutes. Question 3 is 24 hours per rotation multiplied by 60 minutes per hour, or 1,440 minutes per rotation. In question 4, 1,440 minutes per rotation divided by 2 minutes per diameter gives 720 diameters per rotation.

The rotation of the earth moves the wire and observer to a new position with respect to the moon. Since the observer thinks he is motionless, he naturally believes the moon has moved.

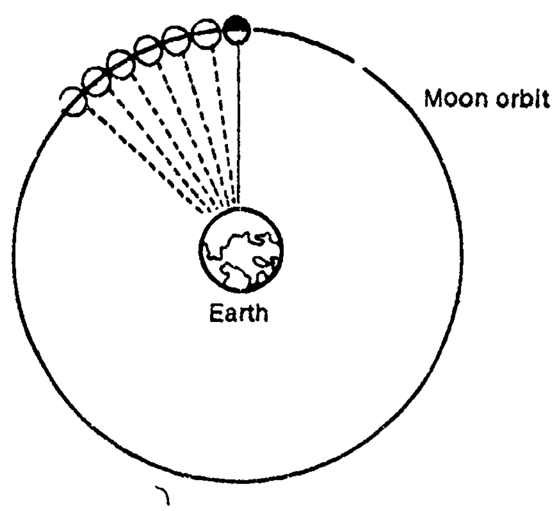
□**2.** In question 1, you recorded the minutes it takes for the wire to sweep across one moon diameter. How many minutes did this sweep take?

□**3.** How many minutes does it take the earth to make one complete rotation?

□**4.** How many moon diameters would a telephone wire sweep across in one full day? (Hint: You know the time needed to sweep across one moon diameter. You also know how many minutes there are in one full day.)

You now have enough information to calculate the moon's diameter. Your answer to question 4 tells you how many moon diameters there are in one moon orbit. Figure 4 illustrates this.

Figure 4



You also know the length in miles of the moon's orbit (1,500,000). The following relationship allows you to make the final calculation.

$$\text{Diameter of moon (in miles)} = \frac{\text{Length of moon's orbit (in miles)}}{\text{Number of moon diameters in one orbit}}$$

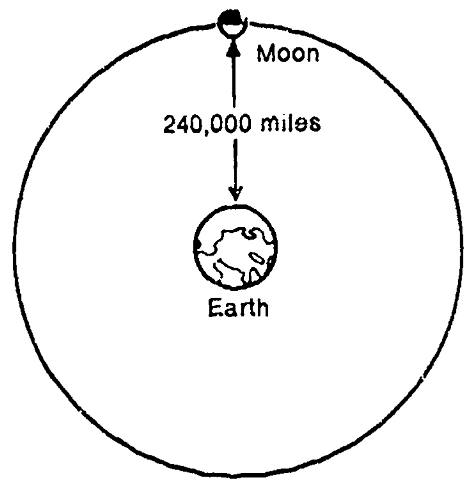
☐ **5.** What is the diameter of the moon?

5. The calculation should show 1,500,000 miles per rotation divided by 720 diameters per rotation, or about 2,080 miles for the diameter. The accepted astronomical figure is 2,160 miles, which means that the student measurement is smaller by less than 4%. This could be considered a remarkably accurate accomplishment.

Special note to students on calculating the length of the moon's orbit

Are you wondering how the moon's orbit was measured? In Chapter 3 you learned that the moon is about 240,000 miles from the earth (Figure 5).

Figure 5



An astronomical oddity is the fact that, seen from the earth, both the moon and the sun measure about $\frac{1}{2}°$ in the sky. This is about the width of a pencil held at arm's length. It is because of this odd fact that the moon can exactly eclipse the sun at times when they line up in the heavens. This also gives an alternative method for doing the problem. If the earth rotates on its axis through 360° in 24 hours, then it rotates 15° per hour. That is 15 divided by 60, or $\frac{1}{4}°$ per minute. To go $\frac{1}{2}°$, then, would require 2 minutes, which is the time the student should have observed. Dividing $\frac{1}{2}°$ per 2 minutes by 360° per rotation gives $\frac{1}{720}$ of a rotation in 2 minutes. $\frac{1}{720}$ of the orbital distance of 1,500,000 miles is the same 2,080 miles.

You may know that the distance around any circle (circumference) may be found by multiplying the distance across the circle through its center (diameter) by a constant called π (pronounced "pie"). The value of π is approximately $\frac{22}{7}$, or 3.14. With this in mind:

$$\begin{aligned}\text{Distance around} &= \pi \times \text{distance across}\\ &= \pi \times 2 \times \text{half the distance across}\\ &= 3.14 \times 2 \times \text{half the distance across}\\ &= 6.28 \times \text{half the distance across}\end{aligned}$$

In Figure 5, "half the distance across" the circle is the distance from the earth to the moon. Thus we write:

$$\begin{aligned}\text{Length of the moon's orbit}&\\ &= 6.28 \times \text{distance from the earth to the moon}\\ &= 6.28 \times 240{,}000 \text{ miles}\\ &= 1{,}500{,}000 \text{ miles}\end{aligned}$$

EQUIPMENT

None

PURPOSE

To explain how radar is used for the measurement of astronomical distances

What's Radar?

Excursion 4-1

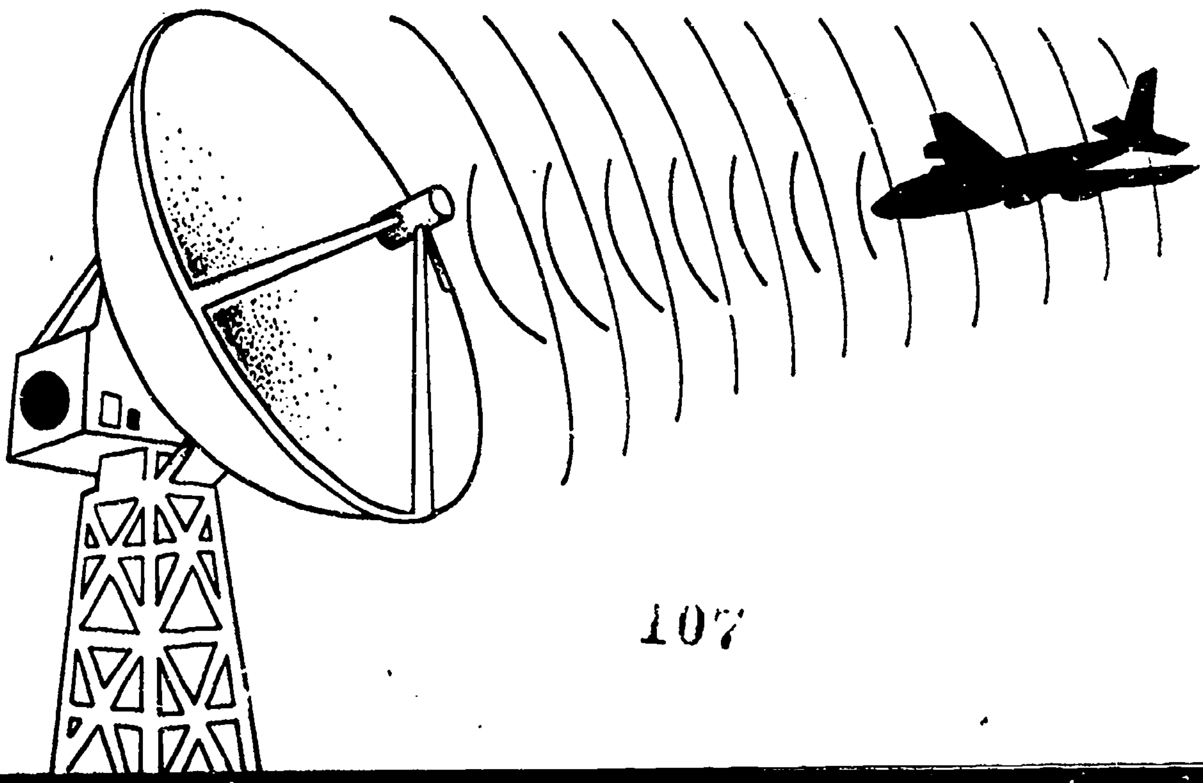
This is a general-interest excursion, with practice in using distance calculations.

MAJOR POINTS

1. Radar uses radio pulses to detect the location of an object
2. Radio pulses travel at a speed of 186,000 miles per second.
3. The distance to an object can be computed by taking half of the round-trip time for a pulse to travel to the object and back.
4. Many different objects can be located by radar
5. Radar is ineffective in accurately measuring the distance to the sun.

What is radar? The name *radar* was coined from the words *RA*dio *D*etection *A*nd *R*anging by two United States naval officers, F. R. Furth and S. M. Tucker. Radar is the process of using radio pulses to detect the location of an object. In the process, very short powerful pulses of radio energy are transmitted. They bounce off the object and return to the sending station a bit weaker.

Radar technicians measure how long it takes for a pulse to travel to an object and back. The longer it takes the pulse to return from an object, the farther away the object must be. Thus, by measuring time of travel of the pulse, it is possible to determine the distance a target is from the radar set.



The student may recognize the speed of 186,000 miles per second as that of light and, in fact, of all electromagnetic radiation. Note that the 280-second round-trip time is for the situation when Venus is closest to Earth, and when Earth, Venus, and the sun are in a straight line.

This is precisely how radar was used to measure the distance to Venus. Radio pulses travel at 186,000 miles/sec. A pulse of energy was beamed at Venus. Then the radar operator waited until his antenna received the reflected signal. Since the round-trip time was about 280 seconds, the one-way trip took half this time; that is, the pulse required 140 seconds, or $2\frac{1}{3}$ minutes, to travel from Earth to Venus (Figure 1).

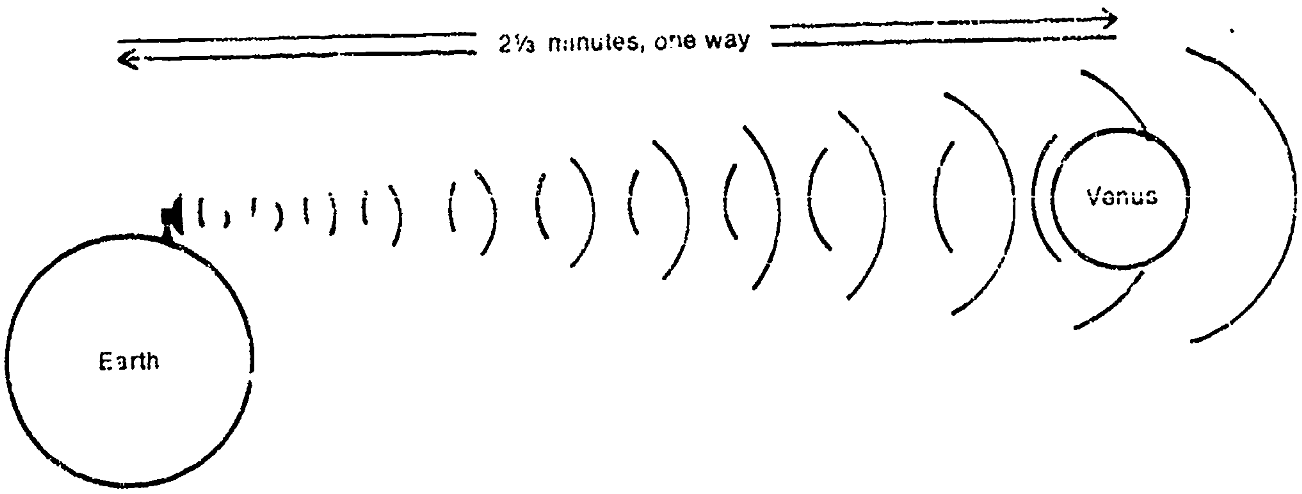


Figure 1

The student may not know how to use speed and time to find distance, and may need help. Speed × time = distance. The answers to the three questions are as follows:

1. 186,000 mi/sec × 60 sec/min = 11,160,000 mi/min
2. 11,160,000 mi/min × 2.33 min = 26,002,800 mi
3. Same as 2 (26 million miles)

You probably know how to use speed and time measurements to find the distance traveled.

☐ **1.** How far will a radio pulse travel in 1 minute if it moves 186,000 miles/sec?

☐ **2.** If the pulse takes 2.33 minutes to travel from Venus to Earth, how far has the pulse traveled?

☐ **3.** How far is Venus from Earth?

Using the methods discussed above, radar locates airplanes and ships, birds and thunderstorms, man-made satellites and planets. The same principle has also been used to measure the distance to Mars, Mercury, and of course to our moon.

So far, scientists have not been able to use radar to accurately measure the distance to the sun. Being a body composed mainly of hot gases, the sun is what scientists call a "soft" target rather than a hard target such as a planet. Therefore, although radar can give the distance to Venus to use as a base line in measuring the distance to the sun, it cannot accurately give the distance to the sun.

EQUIPMENT LIST

Protractor
Ruler

PURPOSE

To acquaint the student with the proper us of a protractor to measure and constru angles.

Angles and Protractors Excursion 4-2

This is a remedial excursion

MAJOR POINTS

1. An angle is formed when two lines meet.
2. The meeting point of the lines is called the vertex of the angle.
3. When two lines meet to form a square corner, they form a right angle, which contains 90°.
4. The angle that you are interested in is indicated by a curved line near the vertex.
5. There are different kinds of protractor
6. To measure an angle, a protractor mu cover the angle, with the center point on th vertex and the 0° mark touching one sid
7. To draw an angle of a particular size, dra a line; place protractor on line with center a one end and 0° point on the line; mark a poi at the desired angle; connect this point wi the end of the line on which the center of th protractor was placed.

As you open a pair of scissors, the angle (opening) formed by the blades changes.

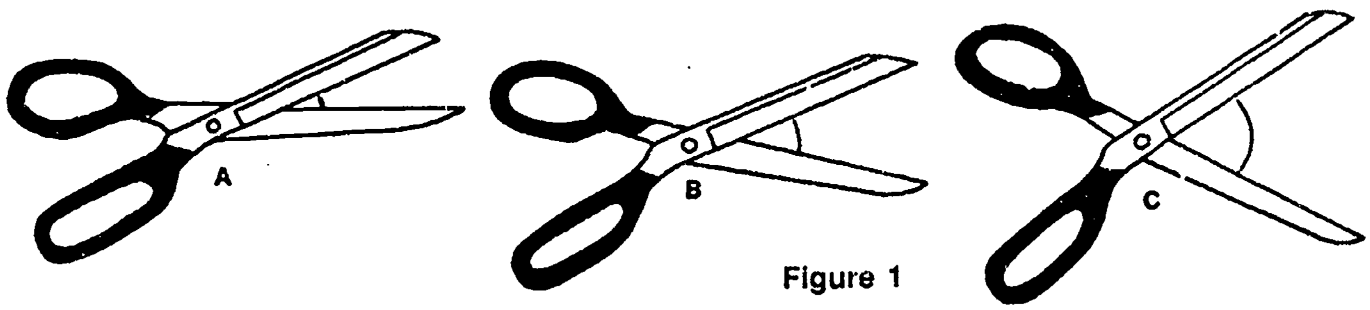


Figure 1

☐**1.** Which angle formed by the blades in Figure 1 is the largest?

Whenever two lines meet, an angle is formed. The meeting point of the lines is the *vertex* of the angle (Figure 2).

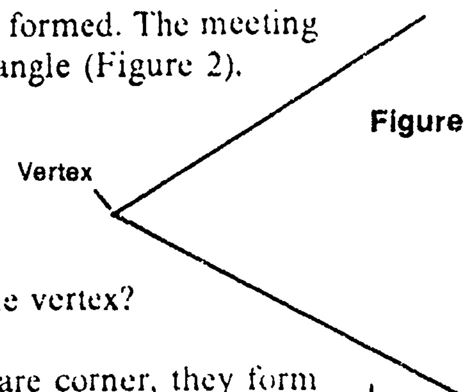


Figure 2

☐**2.** Can an angle have more than one vertex?

When two lines meet to form a square corner, they form a *right angle* (see Figure 3).

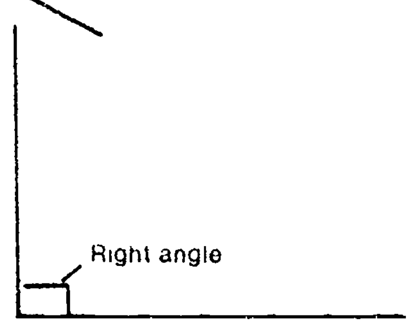


Figure 3

□**3.** List some examples of right angles formed by objects in your classroom.

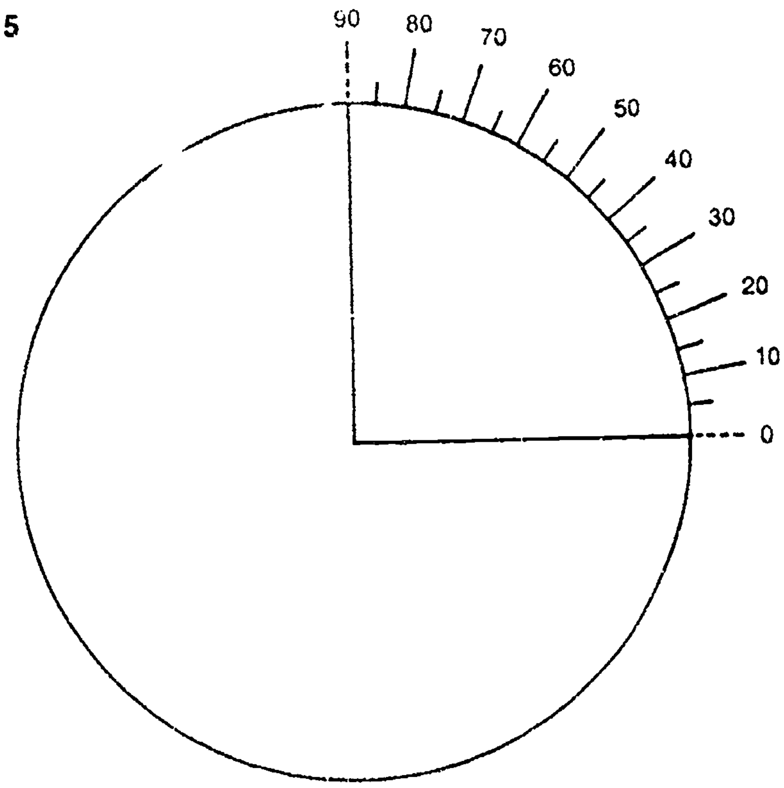
Notice the curved lines used to indicate angles in Figure 4. Such a line can indicate any angle you are interested in. Right angles are usually represented by a square, as in Figure 3.

Figure 4

Circles are measured by dividing them into equal parts called degrees. These are not the same kind of degrees you remember from your earlier work with temperature. However, the same symbol is used for angle degrees.

Thus a right angle contains 90° (Figure 5).

Figure 5

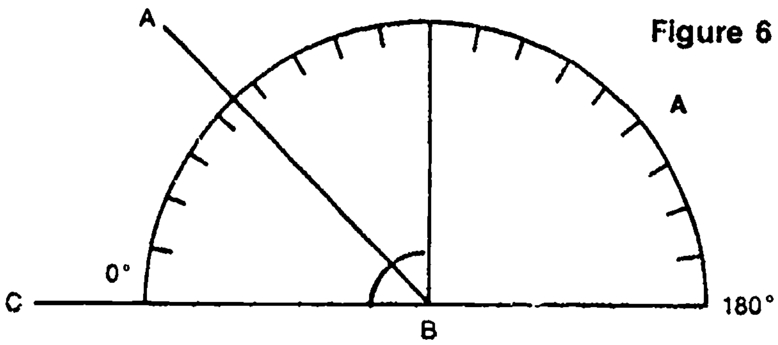


□**4.** What portion of a circle is a right angle (90°)?

□**5.** If a right angle contains 90°, how many degrees are in a complete circle?

If your supply of protractors or the ones the students have are different from the one illustrated, you may have to adapt the activities to teach them to use the other kind.

Look at your protractor. It should be positioned with its center point on the vertex B of angle ABC, and its zero point on line BC. This is shown in Figures 6A and 6B.



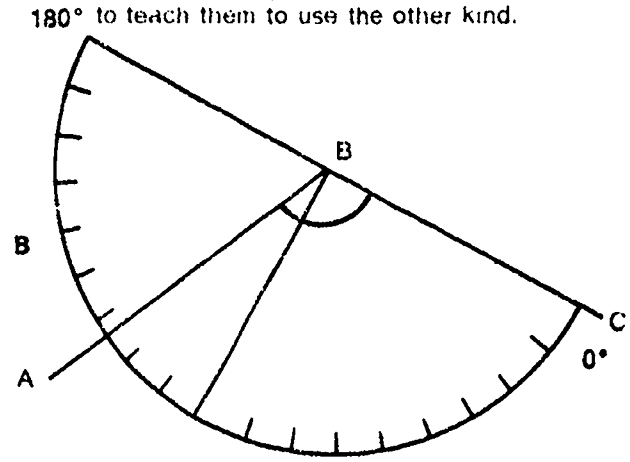
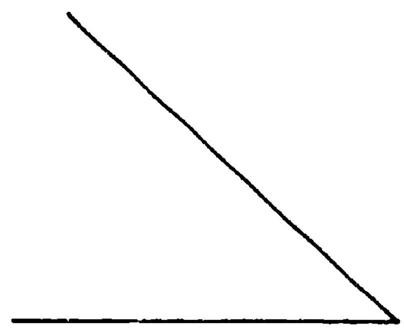


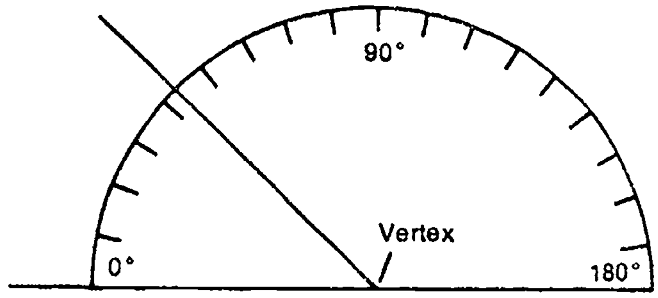
Figure 6

Some protractors have two scales. You then use whichever one is easier in reading the desired angle. In the following illustrations, a protractor with only one scale is shown. Figure 7 provides an angle for you to measure for practice. Activities 1 and 2 show you how to do it if you need additional help.

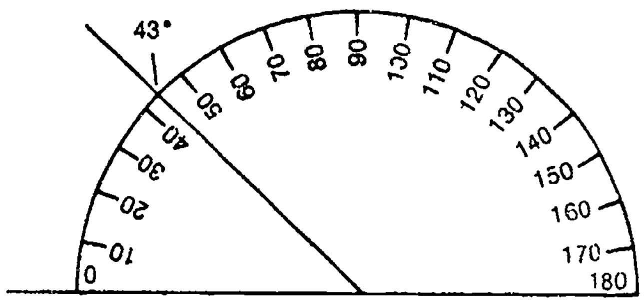
Figure 7



ACTIVITY 1. Set the protractor on the angle with the center point on the vertex and the curved part of the protractor covering the angle. The 0° mark must touch one side of the angle. Notice that the protractor forms a curved line like the ones you've seen in the drawings so far.



ACTIVITY 2. Read the number on the scale that the other side of the angle passes through.



Measure the angles in Figure 8 to the nearest whole degree. Record your measurements in Table 1. Have your teacher check your figures to be sure that you understand how to use the protractor.

Figure 8

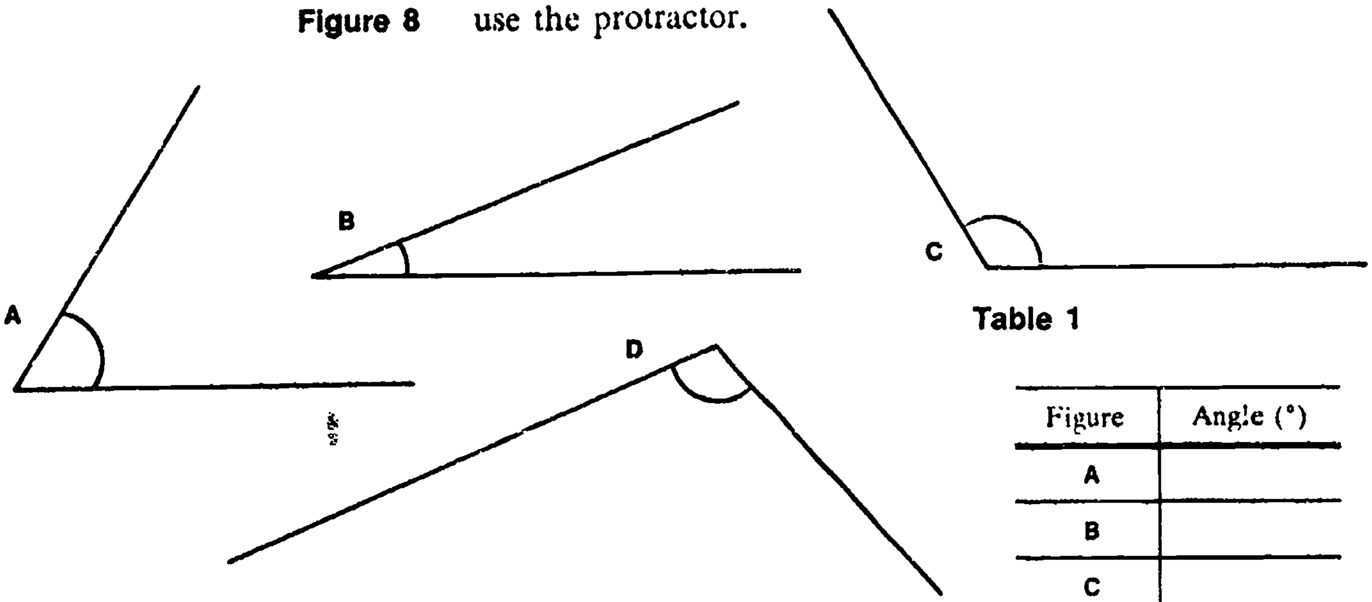


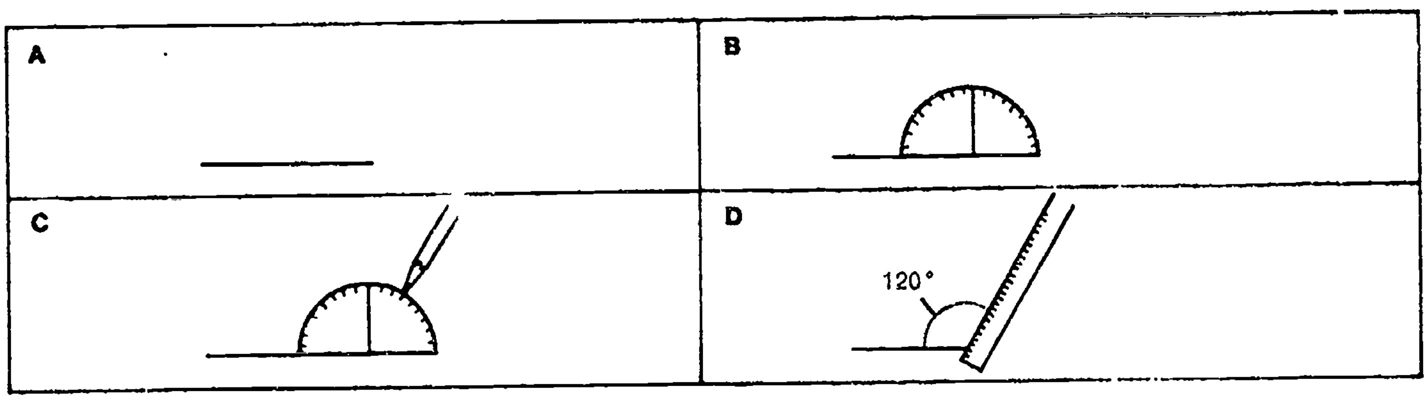
Table 1

Figure	Angle (°)
A	
B	
C	
D	

You should check the angles yourself. Angles should be as follows. A—57°; B—21°; C—121°; D—109°.

Now that you have measured some angles, try to draw some angles of certain sizes. Activity 3 shows you how.

ACTIVITY 3. A. Draw a line. B. Place protractor with center on one end of the line. C. Mark a point by the desired angle. D. Connect this point with the line's endpoint.



☐**6.** In the space provided in your Record Book, draw the following angles: 72°, 30°, 115°.

Have your teacher check your drawings. When he approves, you are ready to return to your work in Chapter 4.

EQUIPMENT LIST

Metric ruler

Scale Drawings

PURPOSE

To acquaint the student with the use of scale drawings

Excursion 4-3

MAJOR POINTS

1. If you know the scale of a drawing, you can determine the size of the object drawn.
2. The actual size of an object is equal to the measurement on the drawing, multiplied by the scale used.
3. Actual distances can be found from a map by using the scale in the same way.

This is a remedial excursion that the student should do if he does poorly on the Checkup.

Answers to Checkup

1. 16 feet (Consider 15 or 17 to be close enough.)
2. 14 feet (Consider 13 or 15 to be close enough.)

If you missed either of these questions, do this excursion before returning to Chapter 4.

If you know the scale used in a drawing, you can determine the actual size of the object drawn. Look at Figure 1. It is a simple plan for a new building.

☐**1.** What scale did the architect use?

☐**2.** How many centimeters wide is the storage area as shown in the drawing?

☐**3.** When the warehouse is actually built, how wide will the storage area be?

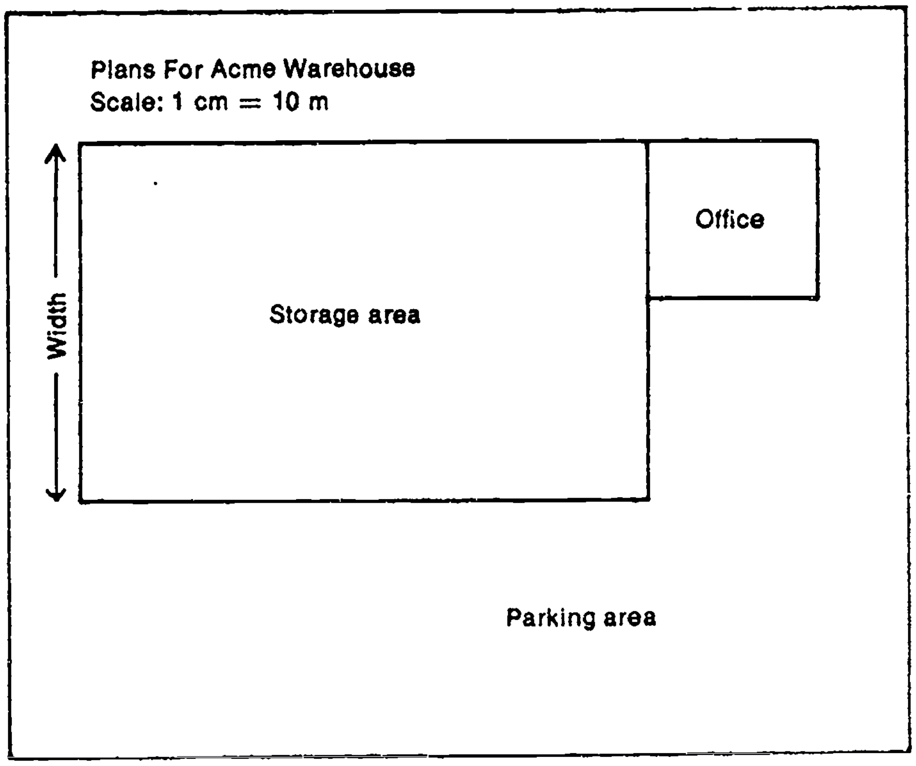
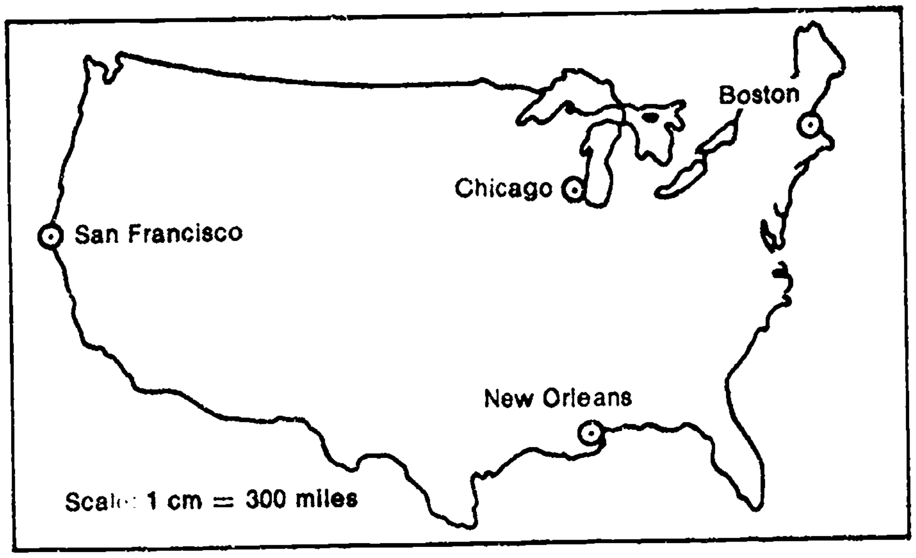


Figure 1

Your answer to question 2 should be 4 cm. The answer to 3 should be 40 m (This results from multiplying 4 × 10. Remember that 1 cm on the drawing represents 10 m in the finished building.)

☐**4.** Use the information in Figure 2 to answer these questions:

Figure 2



What is the actual distance

A. from Boston to Chicago?
B. from Chicago to San Francisco?
C. from Chicago to New Orleans?

Answers given are in round numbers. If you are consulted about any missed parts to the question, you will have to use your judgment concerning further action. It may only require a moment of time to straighten out the difficulty, or it may indicate that the student should repeat the excursion. You might even want to devise another simple exercise on scale drawings for additional practice.

If your answers to question 4 were A. 840 miles, B. 1,800 miles, and C. 840 miles, you are ready to continue with Chapter 4. If you missed any of the parts to question 4, consult with your teacher before going ahead.

EQUIPMENT LIST

Metric ruler

Practice in Using Scale Drawings

This is a remedial excursion that is designed to help those who are having difficulty finding the required distances at the end of Chapter 4.

PURPOSE

To give additional practice in measuring on a scale drawing and using the measurements to find actual distances.

Excursion 4-4

MAJOR POINT

Actual distances can be found by multiplying the distances measured on a drawing by the scale of the drawing.

How can you find the distances from Earth to the sun and Venus to the sun by using a scale drawing? The sketch in Figure 1 is a scale drawing. Measure the distances shown on the drawing: VS, ES, and EV. Try it.

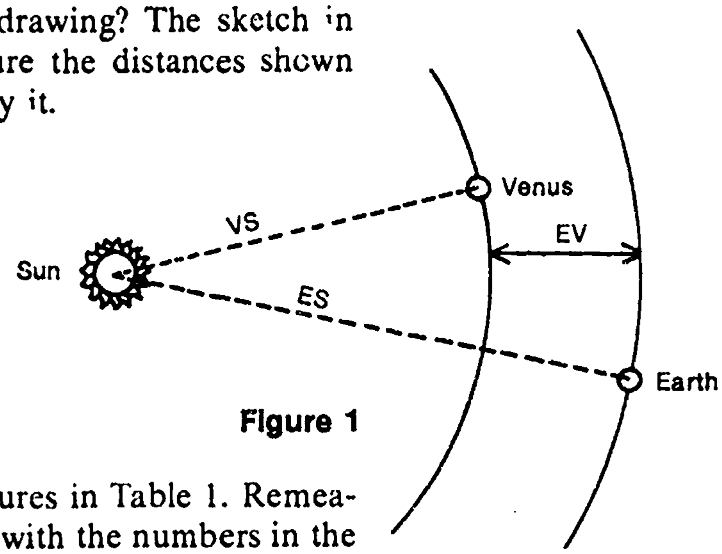


Figure 1

Compare your results with the figures in Table 1. Remeasure any distances that do not agree with the numbers in the table.

Table 1

	Scale Drawing (Distance in mm)	Actual Distance (in miles)
Venus to Sun (**VS**)	43	?
Earth to Sun (**ES**)	60	?
Earth to Venus (**EV**)	17	26,000,000

□**1.** From Table 1 you see that 17 mm on the drawing represent 26,000,000 actual miles. How many actual miles would be represented by 1 mm? Of course, $\frac{1}{17}$ as many miles, or 1 mm on the drawing, represents $\frac{1}{17} \times 26{,}000{,}000$ actual miles = how many miles?

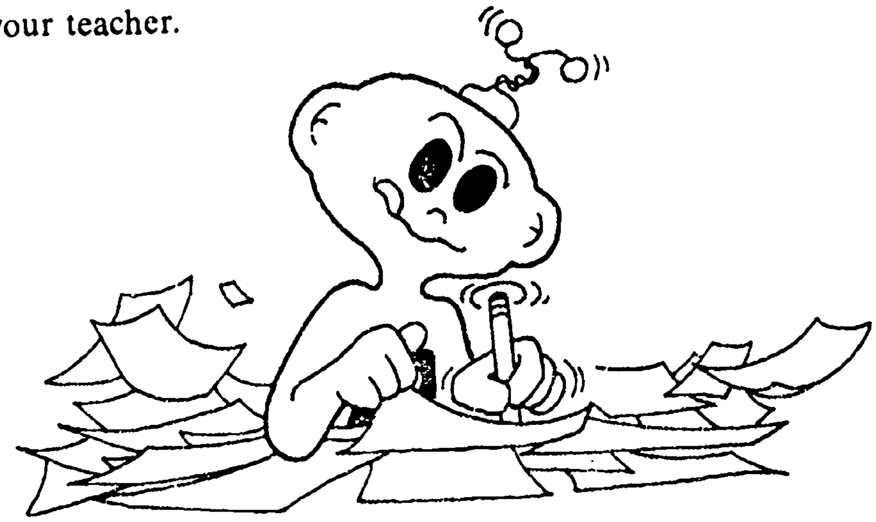
□**2.** How many actual miles would be represented by 2 mm on the drawing?

□**3.** Now figure out the Venus–sun distance for Table 1. How many actual miles are represented by 43 mm? 43 mm in the drawing represent $\frac{43}{17} \times 26{,}000{,}000$ actual miles = how many miles?

□**4.** Using the same method, you can find the Earth–sun distance. The Earth–sun distance on your drawing is 60 mm. How many actual miles are represented by 60 mm?

You should have gotten about 66,000,000 actual miles as an answer for question 3. About 92,000,000 actual miles should be your answer for 4. Record these results in Table 1 in your Record Book. Now return to Chapter 4 and complete Table 4-2. If you continue to have difficulty, consult your teacher.

If the student is still having difficulty at this point, and consults you, it may help to break the "system" into its components to try to locate the trouble. The system of getting actual distances from a scale drawing involves two subsystems:
1. Making the measurement.
2. Converting the measurement to distance.
Under "making the measurement" could be the components of (a) using the proper scale (if there is more than one) on the ruler, (b) placing the ruler on the proper line, (c) having the zero of the ruler on one end of the line, (d) reading the ruler correctly.
Under "converting the measurement to actual distance" could be the components of (a) using the proper mathematical operation (multiplication), (b) multiplying correctly, and (c) copying the result correctly.



EQUIPMENT LIST

1 telescoping tube with caps
1 object lens, 34 mm in diameter
1 eyepiece lens, 25 mm in diameter
1 piece white cardboard
1 meterstick
Masking tape

PURPOSE

To construct a simple astronomical telescope and study the principles of its operation.

Moon Gazing

Excursion 5-1

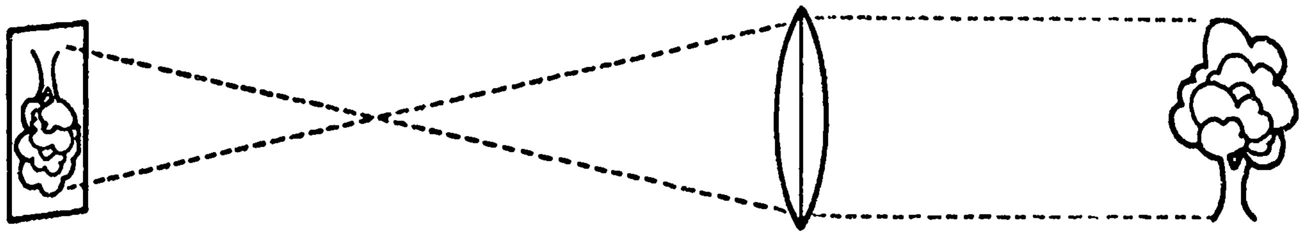
This is a general-interest and extension excursion.

MAJOR POINTS

1. A lens can focus light rays from an object to form an inverted image.
2. A lens can be used to magnify an image.
3. The distance from the lens to its focus is called the focal length of the lens.
4. The power of a telescope is equal to the focal length of the object lens divided by the focal length of the eyepiece.
5. An astronomical telescope forms an inverted image.
6. The diameter of the object lens is a measure of the light-gathering ability of the lens.

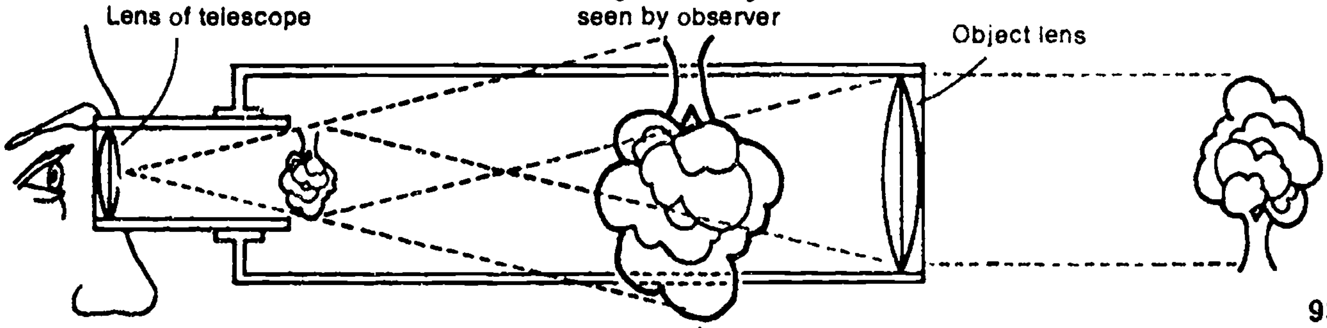
A Dutch eyeglass maker, Hans Lippershey, discovered the principle of the telescope. He found that an eyeglass lens can focus light coming from a distant object. As light passes through the lens, the light rays are brought closer together. They eventually cross and can form an image on a flat surface. The crossing of the light rays produces an upside-down image of the object. Figure 1 illustrates this.

Figure 1



Lippershey found that such a lens could be placed in one end of a cylinder. A smaller lens, placed at the other end, could be used to magnify the image. (See Figure 2.)

Figure 2



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Lippershey probably didn't think of using his telescope to look at the stars or moon. But others who heard of the new gadget did. Soon instruments were being made just for that purpose. One person who made his own telescope and used it for sky gazing was the scientist Galileo. Perhaps you've heard of him. He's the same fellow who tested the idea that objects with different masses fall at the same rate.

People who use telescopes don't just want to see distant objects. They want to see as much detail as possible. To understand how this is achieved, you need to know a bit more about the lenses in the telescope.

The distance from the object lens to its focus is called the *focal length of the object lens.* Likewise, the distance from the eyepiece lens to its focus is the *focal length of the eyepiece.*

The power or magnification of a telescope is calculated by using the following equation.

$$\text{Power} = \frac{\text{Focal length of object lens}}{\text{Focal length of eyepiece}}$$

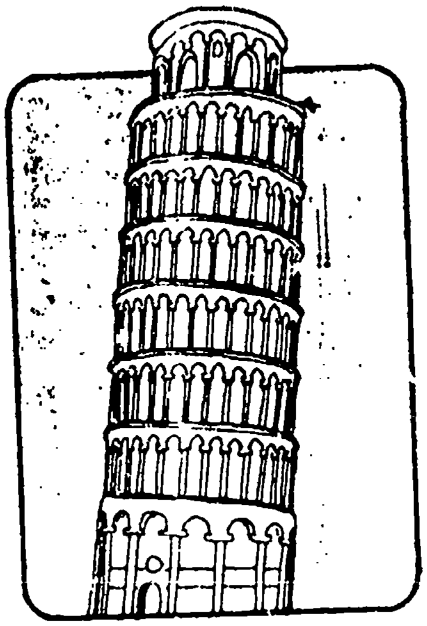
☐**1.** Suppose a telescope has an object lens with 30-cm focal length and an eyepiece lens with 5-cm focal length. Determine the power of the telescope.

The greater the focal length of the object lens as compared with the focal length of the eyepiece, the greater the magnification. However, when you magnify size, you also magnify motion. So the greater power the telescope has, the steadier you must hold it. Even the slightest motion may make the image seem to float, bobbing up and down and sideways like a cork on a windswept pond.

☐**2.** Why must giant telescopes at observatories rest on massive concrete foundations?

Perhaps you'd like to construct an instrument similar to the one Galileo made, and use it as he did—to observe the surface of the moon, its craters, flat plains (called seas), and mountains. If so, you will need the following equipment:

1 cardboard tube, 40 cm long, with inside tube and end caps
1 object lens, 34 mm in diameter
1 eyepiece lens, 25 mm in diameter



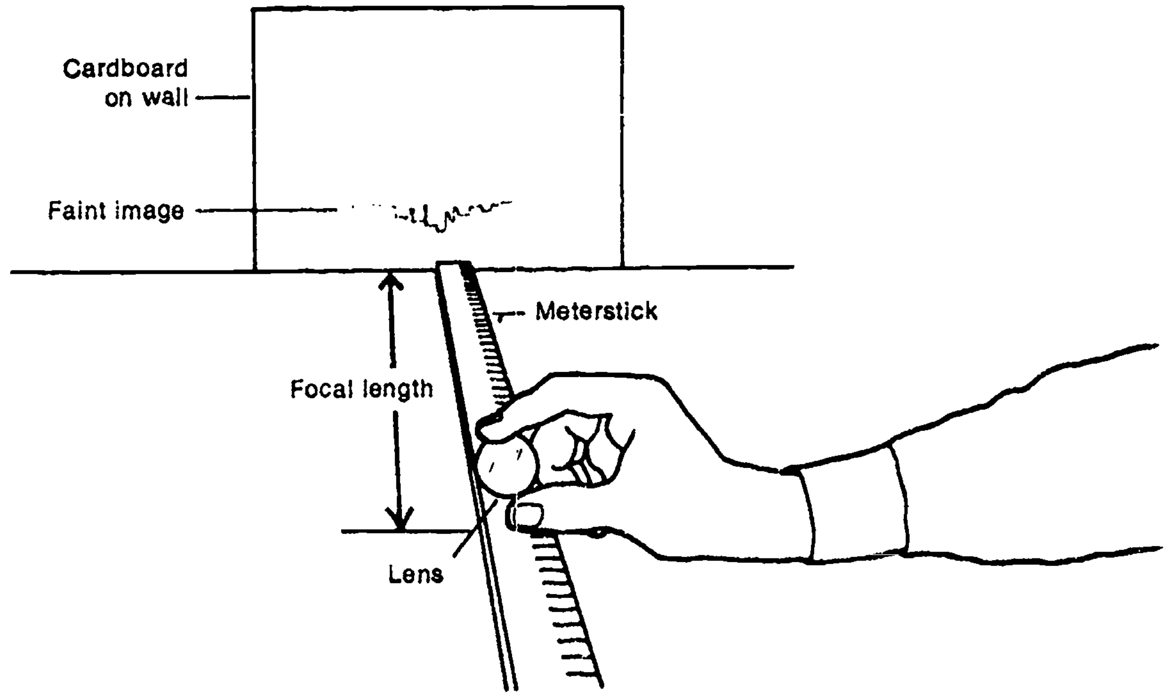
The study of lenses and their uses in telescopes can be a complete subject in itself, and is far beyond the capabilities of the student at this point. For your information, the type of telescope discussed in this excursion is called a refractor, because it focuses light by refraction, or bending. The largest refracting telescope of this kind is the 40-inch instrument at Yerkes Observatory. This is about thirty times the diameter of the 34-mm lens used here. The light-gathering ability is proportional to the square of the diameter, so the Yerkes instrument collects 30 squared, or 900, times as much light. Instruments larger than this have been found to be impractical because of the tendency of the huge lens to sag, distorting the image. Thus, all the larger telescopes today are reflectors, which form an image by the reflection of light. The mirror can be adequately supported from the rear, so there is little distortion. The largest of these in use at present is the 200-inch Hale reflector, which gathers over 22,000 times as much light as your little lens. With this amount of light to work with, eyepieces can be used that give tremendous magnifications.

1 cardboard, 15 cm square, with white surface
Meterstick
Masking tape

In order to know the power that your telescope will have, you need to find the focal lengths of the two lenses. Be careful in handling them. Do not drop them, as they break easily. When you are ready to start, go to the darkest part of the room and prop the cardboard flat against the wall.

Finding the focal lengths of the two lenses can be tricky. With the method illustrated, it is imperative to have a darkened area where the image can be formed. You might have greater success with the following alternative method.
Plug in a 150-watt bulb and socket. Have the student set up the white card, meterstick, and lens about 10 feet away from the bulb. Focus the light onto the card by moving the lens until the smallest sharp spot of light is formed. The distance from the lens to the card will be close enough to the actual focal length for student use. This method may be used with the room lighted.

ACTIVITY 1. Hold the object lens (the larger lens) by the edge, in front of the cardboard. Move the lens toward or away from the cardboard until a faint image of a distant object appears on the cardboard. The distance from the lens to the cardboard will then be its focal length. Use the meterstick to measure this distance.



☐**3.** What is the focal length, in cm of the object lens?

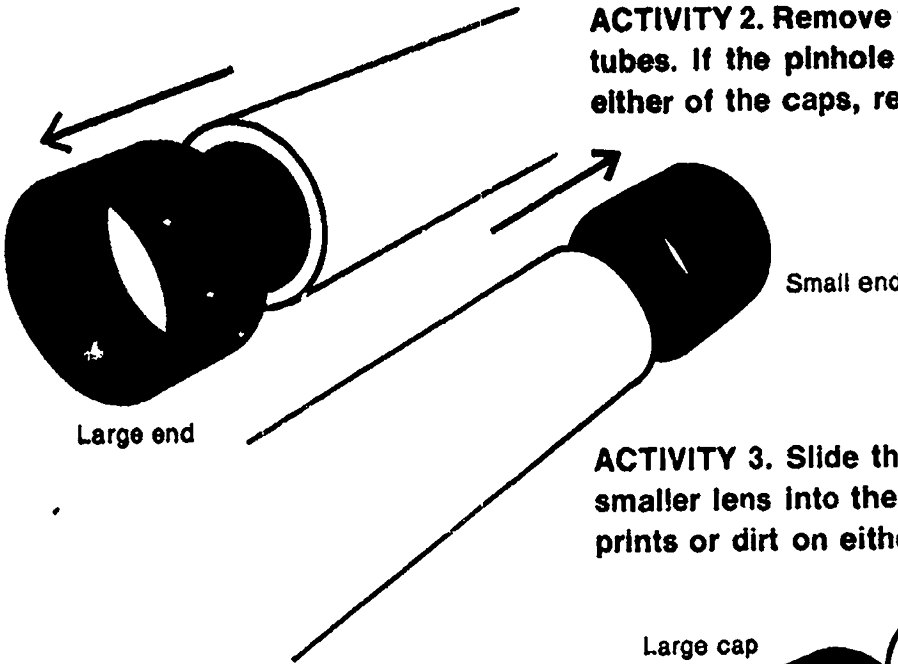
Repeat Activity 1 with the eyepiece lens. This time the focal length should be much shorter.

☐**4.** What is the focal length of the eyepiece lens, in cm?

☐**5.** Using the equation given earlier, calculate the power of your telescope.

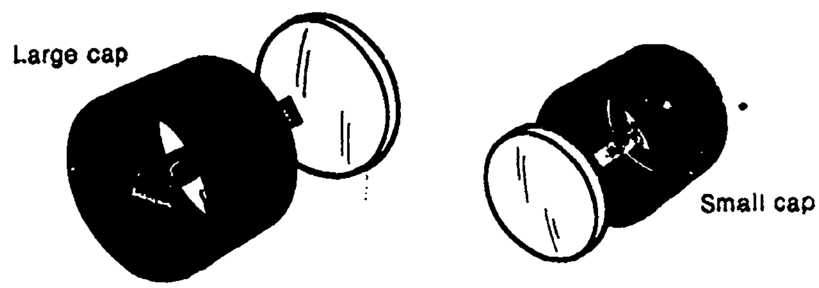
Now continue with the telescope construction.

The lenses supplied are supposed to have focal lengths of [illegible].2 cm and 4 cm respectively (questions 3 and 4). This means that the power in question 5 will be a little over 11. You may want to check the lenses that are supplied. However, Activity 5 will give you an approximate measure of the sum of the focal lengths.



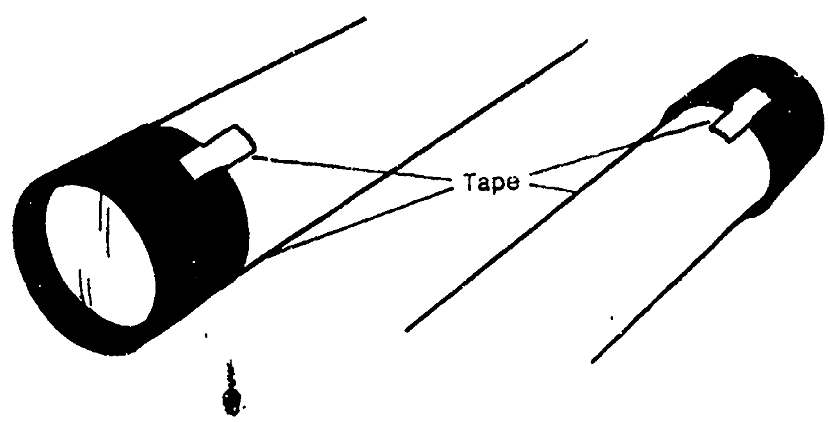
ACTIVITY 2. Remove the two caps from the ends of the sliding tubes. If the pinhole disk or the acetate grid disk is still in either of the caps, remove it and return it to your teacher.

ACTIVITY 3. Slide the larger lens into the large cap and the smaller lens into the small cap. Be careful not to get fingerprints or dirt on either lens.



An 11-power telescope is comparable to the ones Galileo constructed. At a magnification of 11 diameters, tiny motions are magnified the same amount. The scope must be steadied in order to see anything clearly.

ACTIVITY 4. Replace the caps on the tubes. Secure them with small pieces of tape.



Take your telescope to the window. Rest it on the ledge or against the window and point it toward a distant object other than the sun. Hold the eyepiece close to your eye. Slide the outer tube out or in until you can see a sharp image.

Safety Note *Remember, do not look at the sun.*

☐**6.** Describe anything different about the image that you observe (different from what you would see with the naked eye).

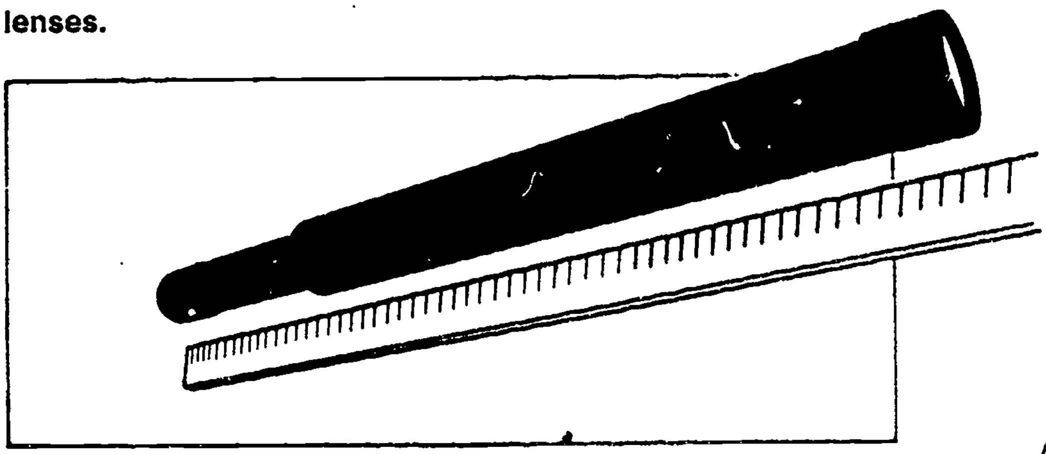
Besides magnifying, your telescope did something else that was unusual. You should have described it above. This is a common trait of astronomical telescopes. However, it is not bothersome.

☐**7.** Why is the unusual trait not bothersome to astronomers?

Your telescope will give maximum magnification when the distance between the lenses is about equal to the sum of their focal lengths.

☐**8.** How far apart should the lenses be in your telescope to give it the maximum magnification?

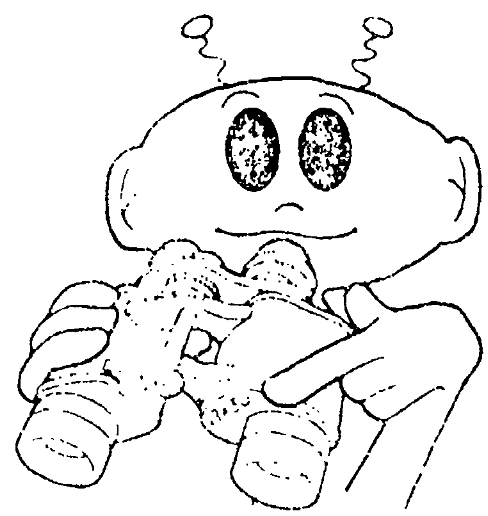
ACTIVITY 5. Sight a far object to adjust your telescope for maximum magnification. Then measure along the outside of the case to get the approximate distance between the two lenses.



Any difference between what you measured in Activity 5 and what you predicted in question 8 will be due in part to individual eye differences (assuming that you answered question 8 correctly).

Incidentally, if you were to buy a telescope, field glasses, or binoculars, you might see two numbers listed in the descriptive literature. You might, for example, see "8 × 30" (read "eight by thirty"). The first number is the power—in this case, a magnification of 8 times. The second number

6. The [illegible] That is not bothersome to astronomers (question 7) [illegible] difference to them whether a celestial object is viewed inverted or [illegible]. In addition, most modern astronomy [illegible] photographic [illegible] because long exposures can give much greater sensitivity. The picture need only be turned to give an [illegible] image. [illegible] glasses, etc.) [illegible] inverted, [illegible] is usually inserted between [illegible] and the eyepiece so that the [illegible]



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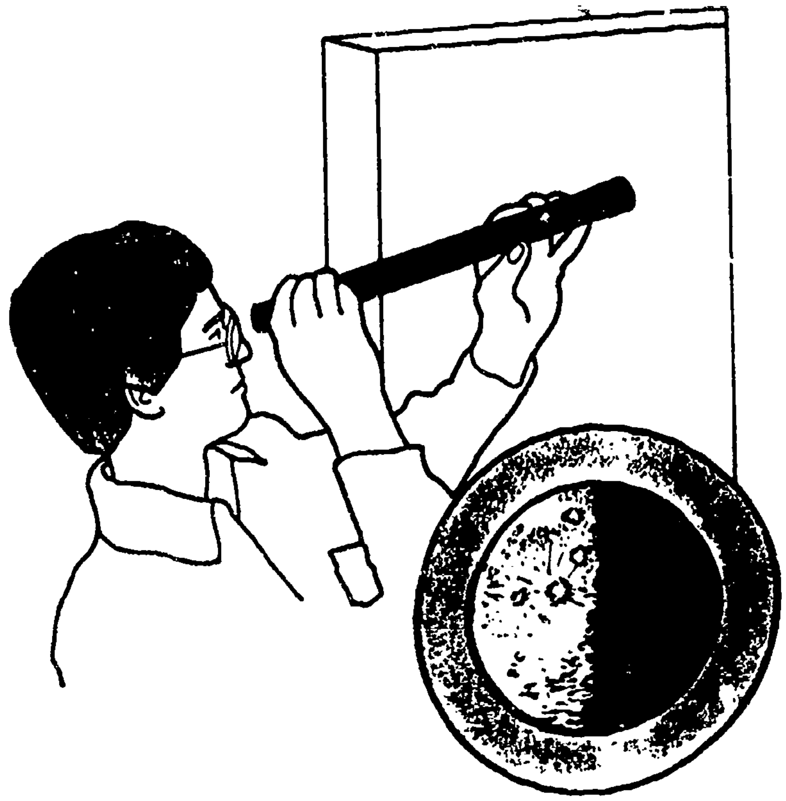
gives the diameter of the object lens in millimeters—in this case 30 mm. The latter figure is important. It tells you the light-gathering ability of the instrument. The higher this number is, the more light it allows to enter the instrument. Instruments with greater light-gathering ability work better at night.

9. At face value, the descriptive numbers would be 11.3 × 34. Actually, the power would probably be given to the nearest whole number—11. Examination of the telescope shows that, although the lens is 34 mm in diameter, the inside diameter of the larger tube limits the effective size of the lens to 25 mm. Thus, the numbers could better be stated as 11 × 25. But even with only 25 mm usable, the little telescope has remarkable light-gathering ability. It has a diameter about 5 times as great as the pupil of an eye, so it would gather 25 times as much light.

☐**9.** Give the descriptive numbers for the power and light-gathering ability of your telescope.

Now that you have made a telescope, ask your teacher if you may use it at night to observe the moon. You should be able to identify some of the moon's features.

You will have to be the judge on the use of the instrument outside of school. Actually it can be a stimulating experience for the student. With a similar instrument, Galileo mapped the surface of the moon, described the appearance of mountains on the terminator, discovered 4 moons of Jupiter, and observed the phases of Venus.



EQUIPMENT

None

PURPOSE

To explain how the present calendar came into being and to tell some of the changes that had to be made in order to use it.

The Night That People Lost 10 Days

Excursion 6-1

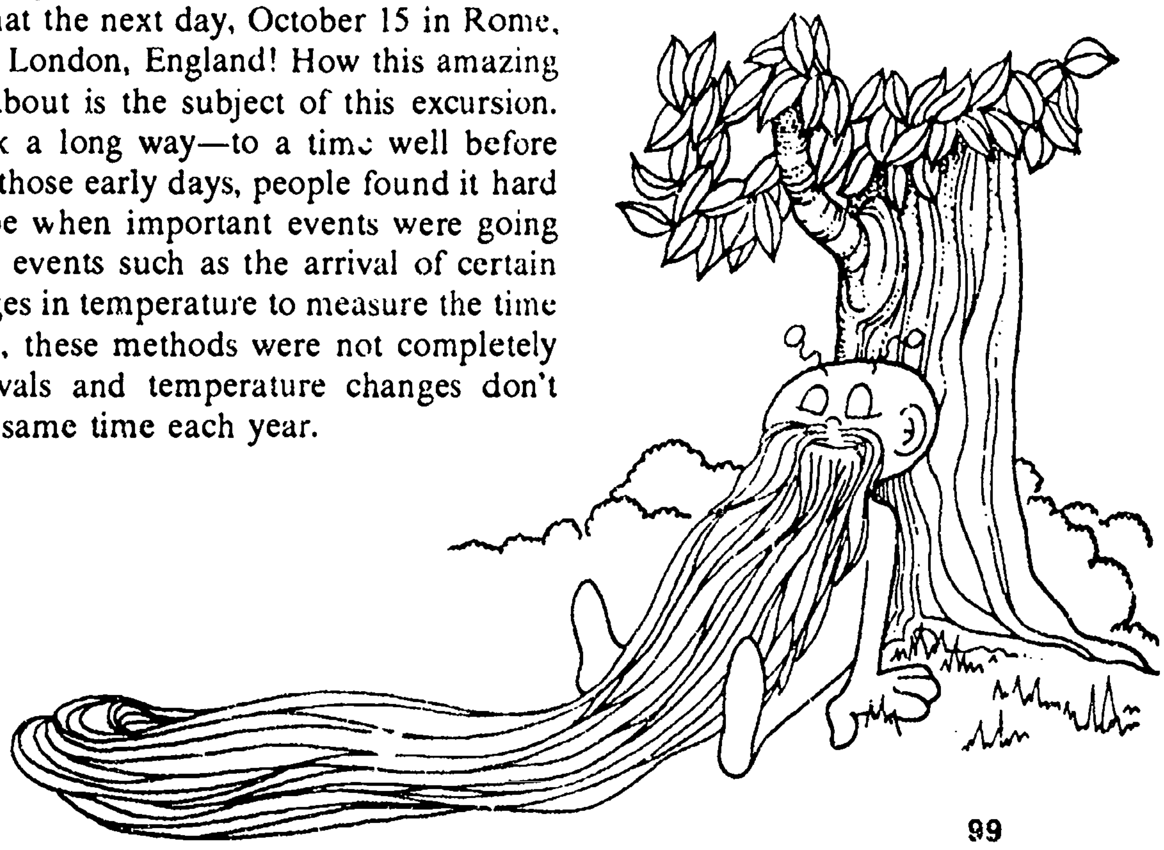
MAJOR POINTS

1 A calendar is a system of timekeeping based on some regular event.
2 Three possible regular events are the appearance of a full moon, a sunrise or the coming of spring
3 Probably the first calendar was made more than 4,000 years ago
4 The Romans made significant changes in the calendar
5 A church decree setting the time for the celebration of Easter as the first Sunday on or after the first full moon after the first day of spring necessitated further changes in the calendar
6 When the new Gregorian calendar was adopted, it became necessary to adjust the date accordingly
7 The changing of dates and dropping of days caused many difficulties

This is an excursion for general interest and extension.

You've probably heard the story of Rip Van Winkle, who slept for 20 years, but have you heard about the night the people of Rome, Italy, actually slept away 10 days? It seems incredible, but in 1582 everybody in Rome went to bed on October 4 and woke up on October 15. Even more remarkable is the fact that the next day, October 15 in Rome, was only October 5 in London, England! How this amazing turn of events came about is the subject of this excursion.

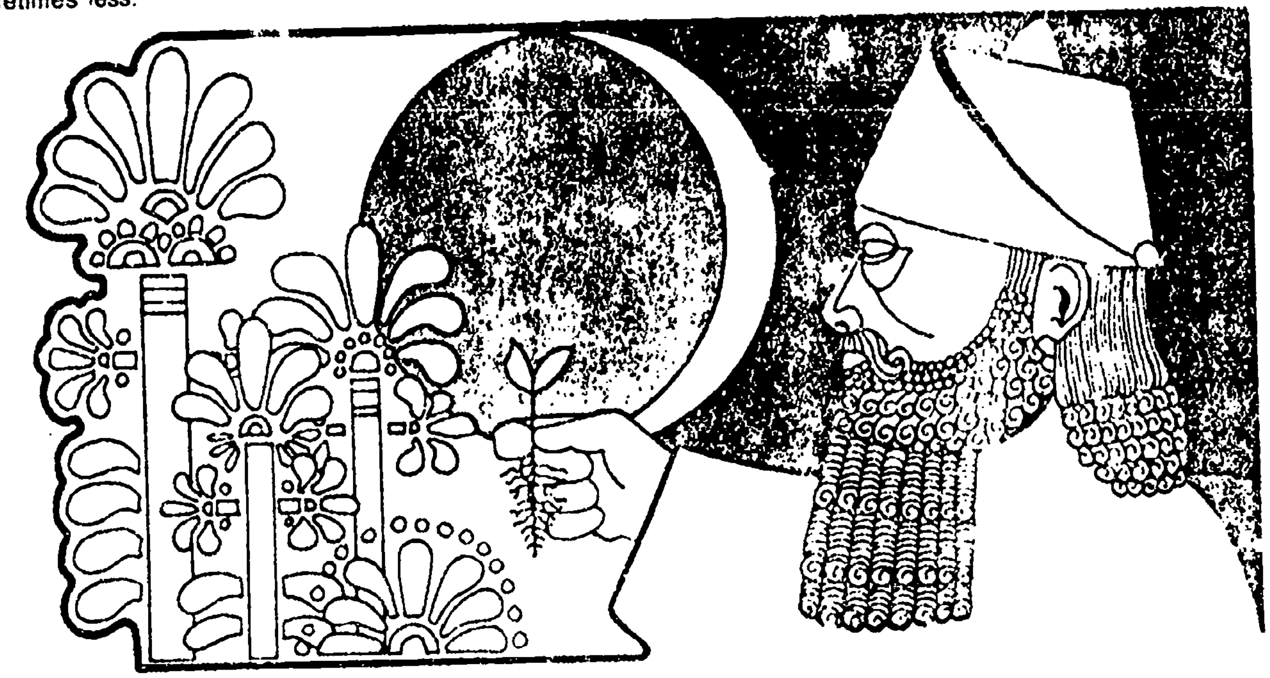
The story goes back a long way—to a time well before the birth of Christ. In those early days, people found it hard to predict and describe when important events were going to happen. They used events such as the arrival of certain kinds of birds or changes in temperature to measure the time of the year. Of course, these methods were not completely satisfactory. Bird arrivals and temperature changes don't happen at exactly the same time each year.



Although the three regularly occurring events listed here can be used as a basis for a calendar, you cannot assume that they are not subject to variation. Because of friction of the tidal forces on the earth's rotation, the earth is slowing down a very tiny amount. Thus the rotating earth is not a perfect clock, or timekeeping device. In addition, because of the slightly elliptical orbit, the speed of the earth in its path around the sun is not uniform. It speeds up in the winter, when it is closer to the sun, and slows down in the summer, when it is farther away. The effect of this change in speed (and of the obliquity of the ecliptic, or sun's path) is to make the time between successive sunrises different in the different seasons of the year—sometimes greater than 24 hours, and sometimes less.

To solve the problem of knowing the time of the year, people had to develop a calendar—a system of timekeeping based on some regularly occurring event. They found that at least three such events could be used.

1. The time from one full moon to the next
2. The time from one sunrise to the next
3. The time from one spring to the next (Astronomers determined the first day of spring by observing the exact time the sun passed a particular point in the sky on its north-south journey.)



EARLY CALENDARS

The particular point in the sky that is used to determine the first day of spring changes also. The earth, spinning on its axis as it revolves around the sun, wobbles somewhat like a spinning top. This means that the North Pole points at a different spot in the heavens, and the place where the apparent path of the sun crosses the celestial equator, called the equinox, moves a little also. During a lifetime the change is extremely small, but in the 2,000 years since man began using a reference point in the sky, it has shifted about 30°. In the time of Hipparchus (130 B.C.) the point locating the first day of spring was in the constellation of Aries, the Ram. Now it is located a whole constellation away, in Pisces, the Fishes. But astronomers can still locate its exact position each year.

The Sumerians lived more than 4,000 years ago in what is now Iraq. They were probably the first people to make a calendar. They used the phases of the moon to determine how long a month was (about 30 days). In the Sumerian calendar, twelve lunar months (360 days) made a year.

☐**1.** How many days shorter than our year was the Sumerian year?

The Sumerians tried to make up the difference between their year and the amount of time that passed between springs by adding an extra month about every fourth year.

☐**2.** About how often should the Sumerians have added a 30-day month to get a year as big as ours?

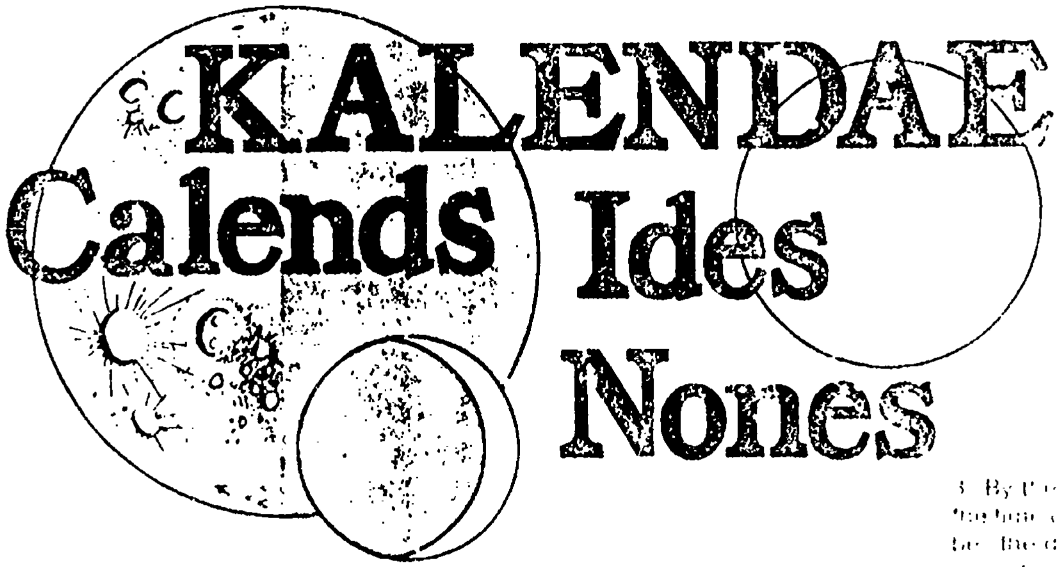
As you can probably see, there were problems with this calendar. The Sumerians were never able to adjust their calendar so that the seasons arrived in exactly the same month each year. Although the Greeks, the Hebrews, and the Egyptians made improvements in the Sumerian calendar, the problem continued.

The [illegible] month, from full moon to full moon, is a little [illegible] 29 days long. The Islamic calendar, still in use in Moslem countries, is based on the lunar cycle, and the first day of [illegible] from year to year.

The calendar of the early Romans was also based on the phases of the moon. The Roman year was 355 days long. The months that corresponded to our March, May, July, and October were 31 days long. February had 28 days, and each of the other seven months had 29 days. The Romans, like the Sumerians, added an extra month every fourth year.

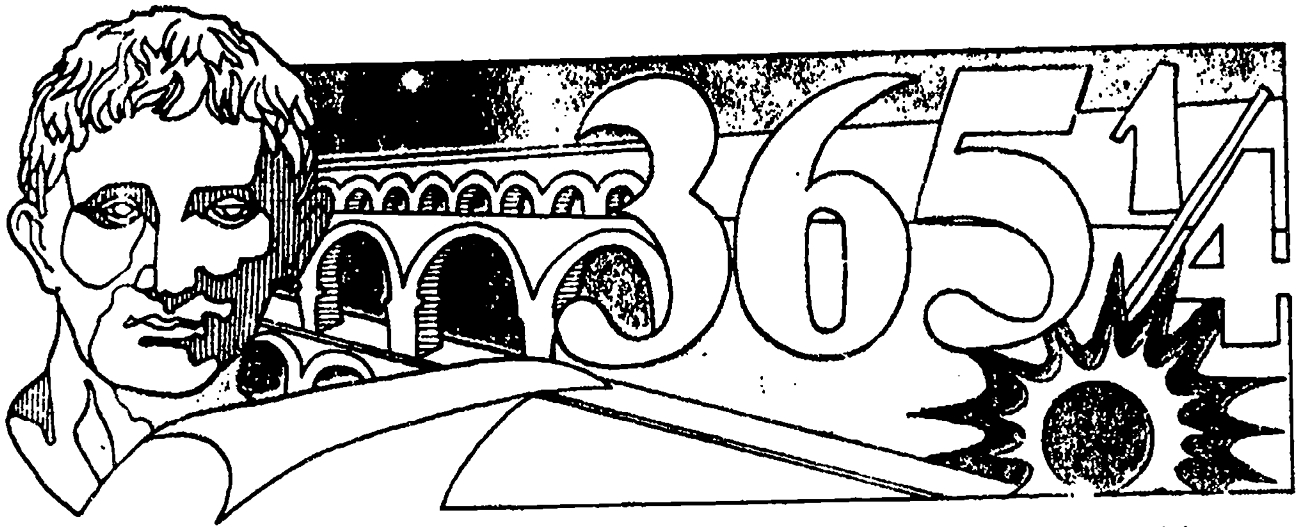
The word *calendar* comes from the Latin word *kalendae* the first of the Roman month. This was the day that accounts were entered in an account book (*kalendarium*) and paid. You can see that the custom of paying bills on the first of the month goes back a long way.

The Roman high priest kept track of the calendar. On each calends, or day of the new moon, the priest announced the phases of the moon for that month. The first quarter phase was called the nones. The full moon was the ides.



3. By the information given here, the ides are the time of the full moon, so the answer would be the date of the full moon in March. However, it is [illegible] accepted that in the [illegible] calendar, the ides of March, May, July, and October were on the 15th of those months. In other months, the date was the 13th. However, the nones were the 9th day before the ides.

3. You may have heard the famous quote from Shakespeare's *Julius Caesar:* "Beware the ides of March." What is meant by the ides of March?



JULIUS CAESAR'S CALENDAR

By 46 B.C., the Roman Emperor Julius Caesar had become quite unhappy with the Roman calendar. Because the high priests had done a poor job of keeping track of the calendar, the summer months were now coming in the spring. To solve the problem, Caesar introduced what became known as the Julian calendar.

The Julian calendar was devised by the Egyptian astronomer Sosigenes. It had a 365-day year (10 days longer than the Roman calendar). The extra 10 days were added to the months with 29 days, making them identical with the months on today's calendar.

The unique feature of the Julian calendar was the extra day added to every fourth (or leap) year. This produced the same result that adding a quarter of a day to each year would produce. In effect, this meant that the Julian year was 365¼ days long. This is almost, but not exactly, as long as the earth takes to make a complete turn around the sun. Because the Julian year was only a few minutes per year longer than the earth year, the change of seasons occurred on almost the same date every year.

We would probably be using the Julian calendar today if it were not for something that happened A.D. 325. That year there was an important meeting of church officials in Nicaea (in what is now Turkey). At the Council of Nicaea, the bishops decided that Easter would be celebrated on the first Sunday after the first full moon that occurs on or after the first day of spring. A.D. 325 the first day of spring occurred on March 21; this meant that Easter could not occur before March 22 or after April 25.

☐4. See if you can explain why Easter would have to occur within these dates in order to meet the council requirements.

Without leap years, after 750 years January would be the middle of summer in the Northern Hemisphere, and July would be a cold month.

The rule for the determination of the date for Easter is still the same. Thus, between A.D. 1800 and A.D. 2000 the celebration falls on all the dates from March 22 to April 25.

4. If the student has difficulty with this question, encourage him to concentrate on the extremes—that is, on March 22 and April [illegible] If March 21 came on Saturday and there was a full moon that day, then the first Sunday after the first full moon on or after March 21 would be March 22. If March 21 came on Sunday and there was a full moon the day before, March 20, then the next full moon would be a lunar month later, (29½ days) on [illegible], April 18, and the first Sunday after that is April 25.

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Over the years the few minutes' difference between the time it takes the earth to go around the sun and the 365¼ days in the Julian calendar began to add up. In fact, by the year 1562 it added up to 10 full days. That year the first day of spring came on March 11 instead of March 21! This meant that Easter would be celebrated at a time before March 22. This violated the rules of the Church.

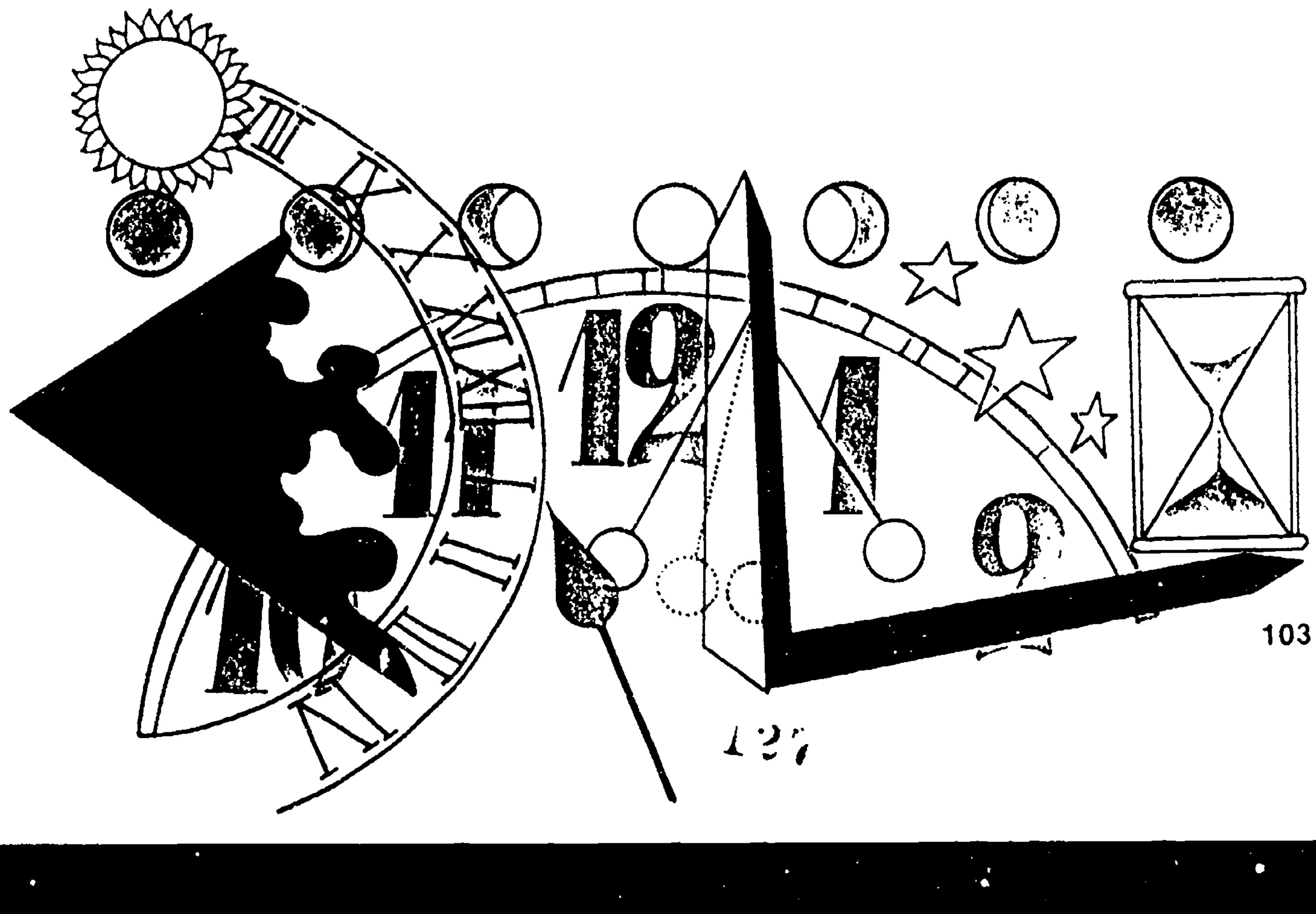
The difference in time mentioned here was about 11 [illegible] per year. That amounts to 8 days in 1,[illegible] years. From A.D. 325 to A.D. 1562 ([illegible] years) it came to 10 days.

Pope Gregory decided to find some way to change the calendar to make sure that Easter would be celebrated at the proper time. This decision led to the 10-day sleep mentioned at the beginning of this excursion. The pope decreed that the day following October 4, 1582, would be October 15. He also directed that, in the future, leap year would be omitted about once every 128 years. (This made the calendar year almost exactly the same length as the earth year.) The dropping of the specified leap years was designed to keep the first day of spring on the same date so that Easter would always be celebrated at the proper time.

Actually, the Gregorian rule states that only the century-ending years that are divisible by 400 should be leap years. Thus the years 1800, 1900, and 2100 have no February 29, but the year 2000 does have the extra day. This puts the calendar remarkably close to the ordinary year. The difference is less than half a minute and the calendar will get out of step only one day every 3,000 years.

THE GREGORIAN CALENDAR

The new calendar proclaimed by Pope Gregory became known as the Gregorian calendar. The Gregorian calendar set January 1 as the beginning of the year. Until then, the year had begun in some countries on December 25, in others on January 1, and in still others on March 25.



The Gregorian calendar was adopted immediately by countries with large Catholic populations. Protestant countries, and some countries in the Middle East, continued to use the Julian calendar. For example, the new calendar was not adopted in England until 1752. By this time, the English had to drop 11 days, not 10. Many Englishmen resented the change and held protest marches, crying "Give us back our 11 days." Most Middle Eastern countries didn't adopt the Gregorian calendar until 1923. These countries had to drop 13 days. The Chinese adopted the new calendar in 1912.

☐**5.** Can you explain why it was October 15 in Rome and only October 5 in London following Pope Gregory's decree?

The argument over which calendar to use has caused all sorts of trouble for people who study history. Historical dates depend upon what book you read. For example, George Washington was born either on February 22, 1732, or on February 11, 1731. The difference depends upon whether or not the writer dropped the 11 days and whether he considered the year as starting on January 1 or on March 1. In fact, some books list Washington's birthday as February $\frac{11}{22}$, $173\frac{1}{2}$.

The Pilgrims landed at Plymouth, Massachusetts, on December $\frac{11}{21}$, 1620. According to Governor William Bradford, they began building their first house on December 25, 1620. By the Gregorian calendar, however, this was January 4, 1621.

Changing the calendar has caused legal problems, too. Some landowners in England tried to collect rent on their property for the 11 days that were dropped from the calendar during 1752. The British Parliament had to pass a special act declaring that salaries, rents, and interest would not be collectable for the 11 lost days.

EQUIPMENT

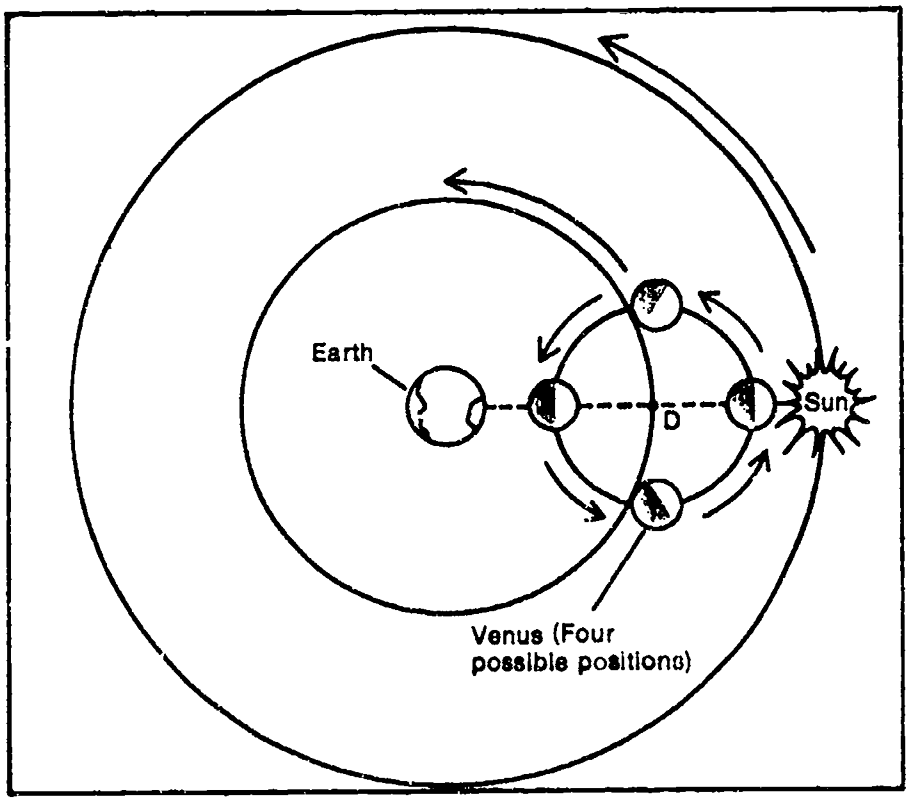
None

Matching Wits with Galileo

This is a general-interest and extension excursion.

According to the theory of Ptolemy, an ancient Greek astronomer, the earth is at the center of the solar system. In other words, the planets and the sun move around the earth (see Figure 1). Ptolemy's theory holds that Venus is closer to the earth than is the sun. Further, the theory holds that as Venus travels around the earth, it also moves in another circular path. Figure 1 shows this as a motion around point D.

Ptolemy also believed Venus and the sun move in such a way that at any time a straight line can be drawn joining the earth, the sun, and point D.



PURPOSE

To examine the logic used in deciding between the Ptolemaic and Copernican models of the solar system.

Excursion 6-2

MAJOR POINTS

1. In the model of the solar system propounded by Ptolemy, the earth was at the center of the system
2. Ptolemy believed Venus and the sun moved so that a straight line could always connect the earth, the sun, and the center of Venus' epicycle.
3. Copernicus proposed a model with the sun at the center of the system, and the planets revolving around it
4. As observed with a telescope, Venus passes through phases much as our moon does. However, it also changes in size, more than the moon does
5. The change in shape and size of Venus supports the Copernican model of the solar system

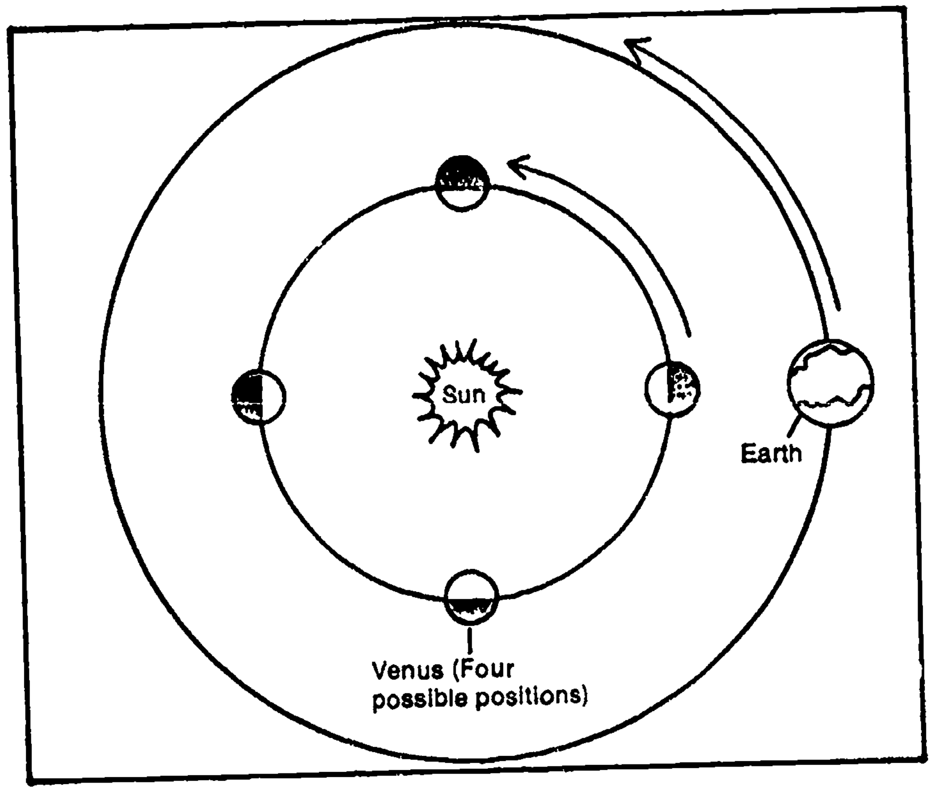
Figure 1

For your information, but not important for the student, is the fact that in the Ptolemaic system, point D in its successive positions is called a deferent. As you can see from Figure 1, a view of Venus from the earth, with the sun always farther away, could never show anything more than a thin crescent.

Copernicus believed the sun is at the center of the solar system. He believed Venus and the earth (and the other planets as well) move around the sun (see Figure 2).

Figure 2

A view of Venus from the earth in the Copernican model (Figure 2) should show phases of the planet, all the way from no light (a "new Venus") to a full orb of light (a "full Venus"). Moreover, because of the large change in distance between the earth and Venus in this model, there should be a distinct change in the size of the planet's image.



Galileo tried to decide which of the two theories was correct. With a telescope that he made, he observed Venus for two years. He observed some interesting changes in the appearance of the planet. What he saw is shown in Figure 3. He found that the shape of Venus changed, very much as the shape of our moon seems to change. Galileo realized that he had all the information he needed to decide definitely whether Ptolemy or Copernicus was right. You have all the information that you need, too. Match wits with Galileo. On the basis of the telescope evidence and Figures 1 and 2, tell which theory you support and why.

☐ **1.** Which theory do you support?

☐ **2.** What are your reasons for supporting the theory?

Hopefully, the student will choose the Copernican model. The change in shape will be the more likely reason for support, but the change in size is of equal importance. Together they form a strong case.

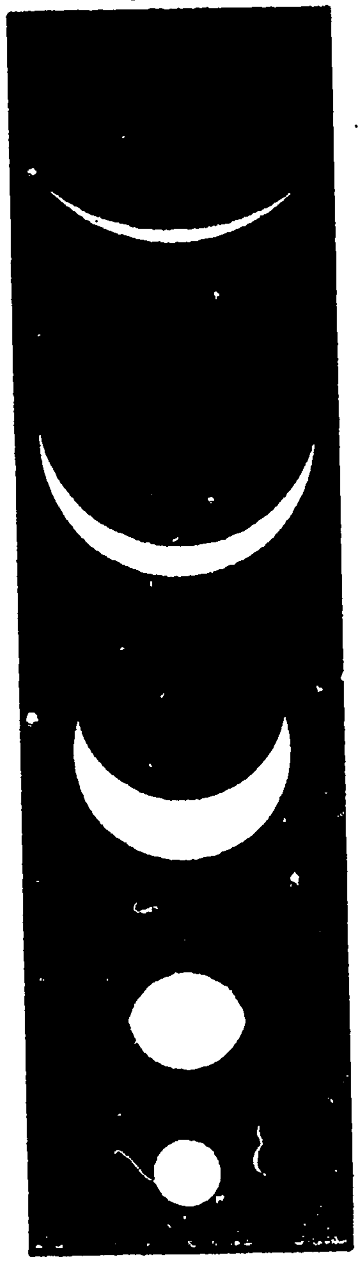


Figure 3

EQUIPMENT

None

PURPOSE

To explain the difference between energy and power.

Power

Excursion 7-1

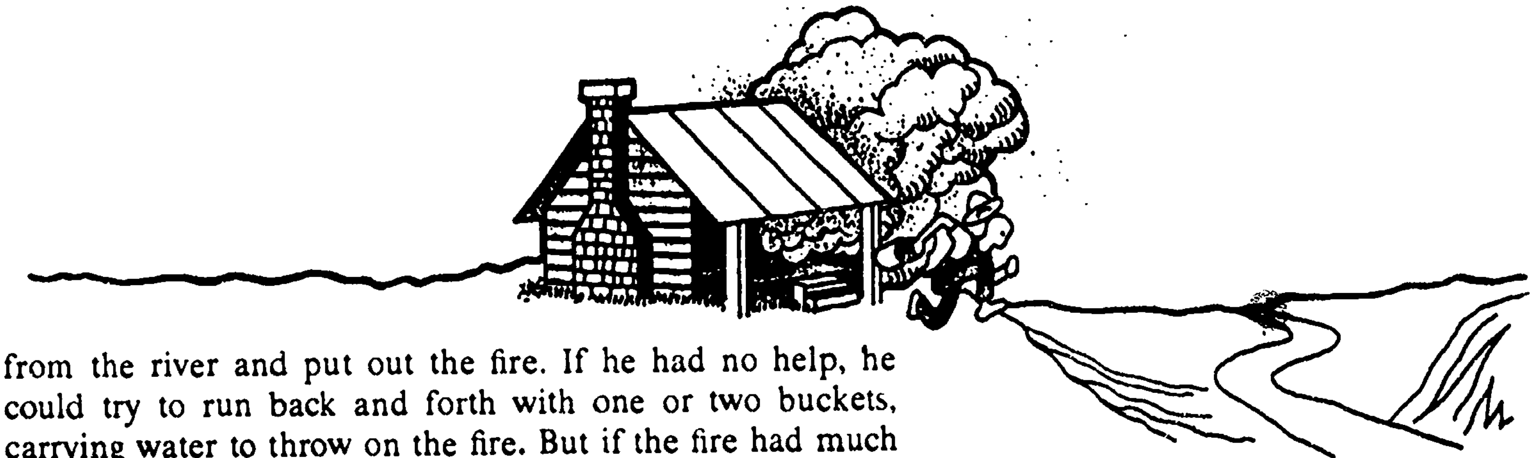
This is a remedial-review excursion.

MAJOR POINTS

1. The time it takes to do a given amount of work is important.
2. The rate at which work can be done, or the rate at which energy can be transferred, is called power.
3. A watt of power is equal to one newton-meter per second.

Suppose a house stands on a hill beside a river. The house catches on fire. Naturally, the owner would like to get water

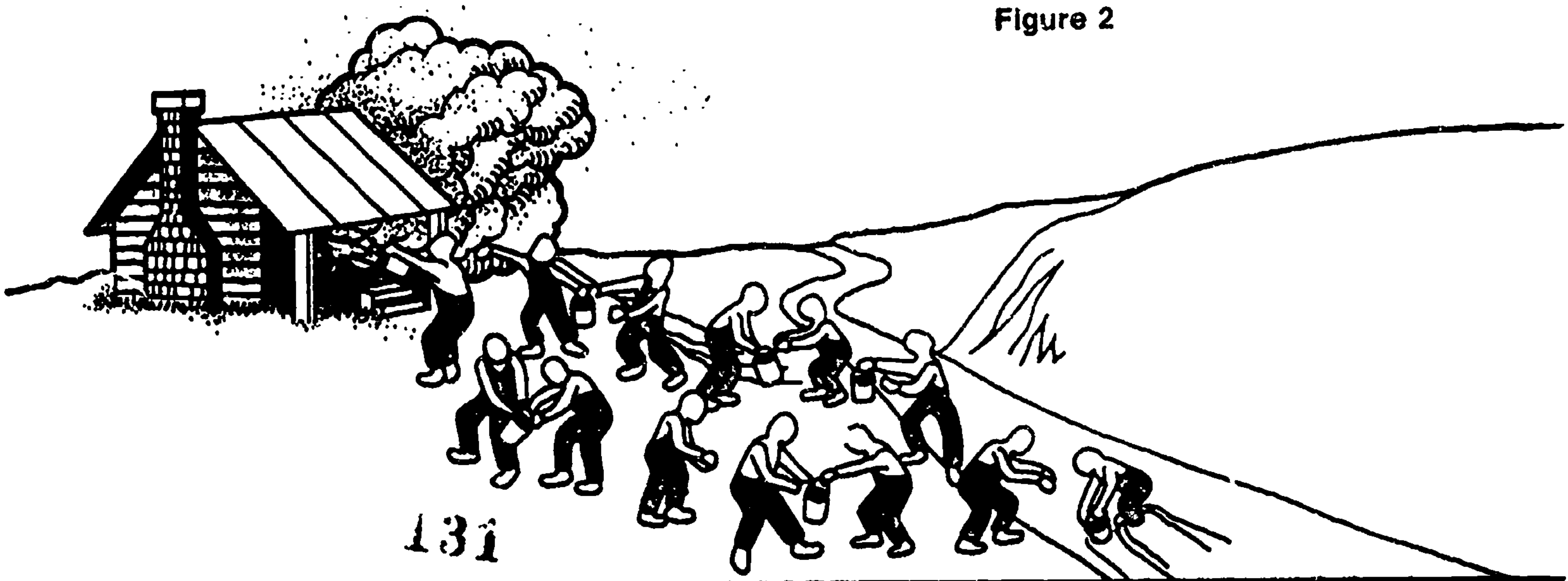
Figure 1

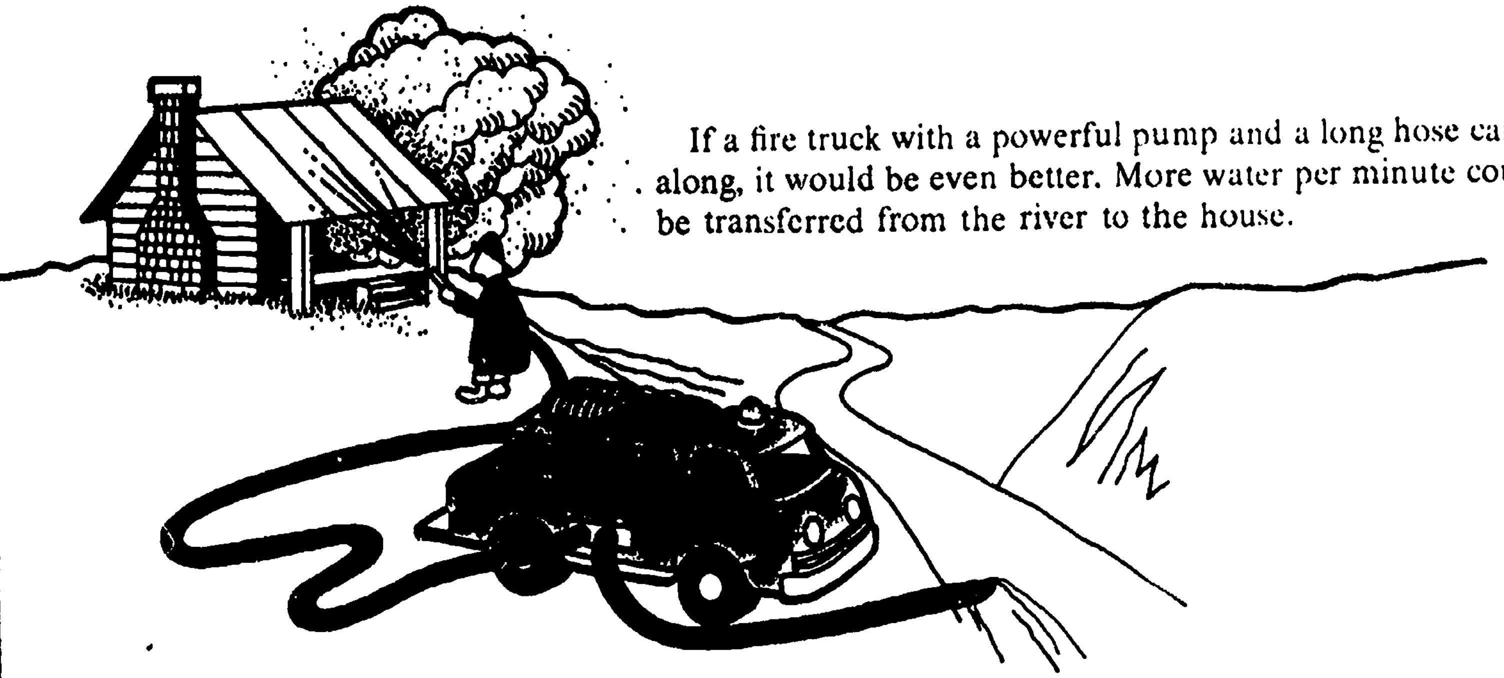


from the river and put out the fire. If he had no help, he could try to run back and forth with one or two buckets, carrying water to throw on the fire. But if the fire had much of a head start, he would lose his house.

If the owner had enough neighbors with buckets, they could form a double line, handing full buckets up and empty buckets down. Certainly more water could be carried to the house each minute this way. The chance of saving the house would be a great deal better.

Figure 2





If a fire truck with a powerful pump and a long hose came along, it would be even better. More water per minute could be transferred from the river to the house.

Figure 3

What is the point of the story? Just this Almost always, the time it takes to do a given amount of work is quite important. Given a long enough time, the owner by himself could have carried any amount of water from the river to the house. But after the house has burned down, the water does no good.

In the language of science, the *rate at which work can be done*, or the *rate at which energy can be transferred*, is almost always very important. The real difference between a man with a bucket and a fire truck with a pump is the rate at which each can do work.

If the student still has trouble understanding the concept of power, it is conceivable that the difficulty lies in an inadequate knowledge of energy You may want to suggest repeating Excursion 2-1.

Science has given a name to the rate of doing work, or the rate of energy transfer. The name is *power*.

The power of the sun is the amount of energy per second it sends out into space. This power can be measured in units called watts. If you had Level I of ISCS, you may recall the definition of a watt.

$$1 \text{ watt} = \frac{1 \text{ newton} \cdot \text{meter}}{\text{second}}$$

Remember, calculating the wattage of the sun means calculating the energy it produces per second.

EQUIPMENT

None

PURPOSE

To provide an alternative shortcut method for calculating the sun's power

Using Squares to Measure Distance

Excursion 7-2

MAJOR POINTS

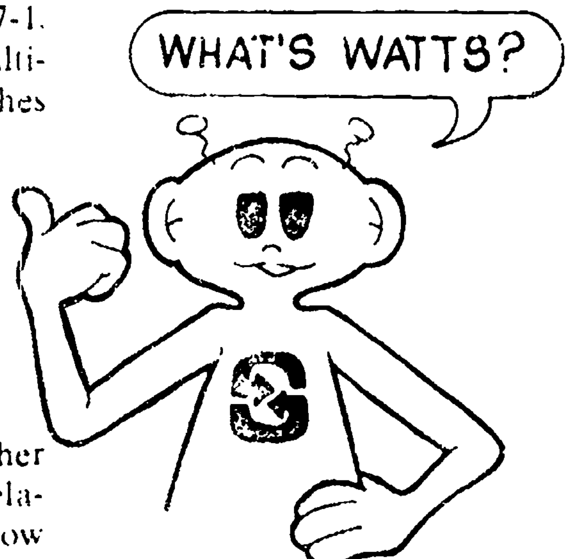
1 When the distance from the source to the object is multiplied by some factor, the power of the source must be multiplied by the square of that same factor

2 To square a number, you multiply it by itself

3 To find the power of the sun, you divide the distance to the sun by the distance that a 50-watt bulb must be from the pyrheliometer to produce the same temperature change as the sun, you square this result and then multiply the number you got by 50 watts

This is a mathematical extension excursion

In Chapter 7 you set out to measure the wattage of the sun. One way to do this is to use the process shown in Table 7-1. All that table calls for is doubling the distance and multiplying the wattage by four until the distance reaches 15,000,000,000,000 cm. But this is a rather slow process!



This problem could be solved more easily by using another approach. The key to the solution can be found in the relationship between the numbers in Table 1. These data show how the power of a light source must be increased to give the same amount of light as its distance from the object increases.

Table 1

Distance to Light Source	Power of Source (watts)
10 cm	50
20 cm	200
40 cm	800
80 cm	3200
93 million miles	?

Take a close look at the next table of data. It points out some important facts about the distance-power relationship.

Table 2

Distance to Source	Amount of Increase in Distance	Power of Source (watts)	Amount Power Source Must Increase to Give Same Light as a 50-watt Bulb at 50 cm
10 cm	2 times	50	4 times
20 cm	4 times	200	16 times
40 cm	8 times	800	64 times; ? times
80 cm	? times	3200	
93 mil. miles		?	

In Problem Break 2-1 Chapter 2, when the power of the bulb was held constant and the distance varied, the relationship between temperature change and distance was an *inverse* square. That is, when the distance was doubled, the temperature change was ¼ as much (1 over 2 squared). In the problem with the sun the temperature change is held constant, and the power varies as a *direct* square of the change in distance. In this case if the distance is doubled, the power must be 4 times as much (2 squared).

When the original distance of 10 cm is doubled, the wattage of the source must be made four times greater (200 watts = 4 × 50 watts). When the original distance is increased four times, the wattage must be made sixteen times greater (800 watts = 16 × 50 watts).

☐ **1.** According to Table 2, how many times greater must the wattage be if the original distance is increased eight times?

Note the relationship between the times increase in the distance and the times increase in wattage.

Table 3

Distance Increase	Wattage Increase
2 times	4 times
4 times	16 times
8 times	64 times

The relationship between increase in distance and increase in wattage is called a "squared relationship." A number multiplied by itself is said to be "squared." The square of 2 is 2 × 2, or 4.

☐2. What is the square of 4?

☐3. What is the square of 8?

Now how can all this be used to determine the power of the sun? You can calculate the number of times 10 cm must be increased to become 15,000,000,000,000 cm (the distance to the sun).

☐4. How many times will 10 cm go into 15,000,000,000,000 cm?

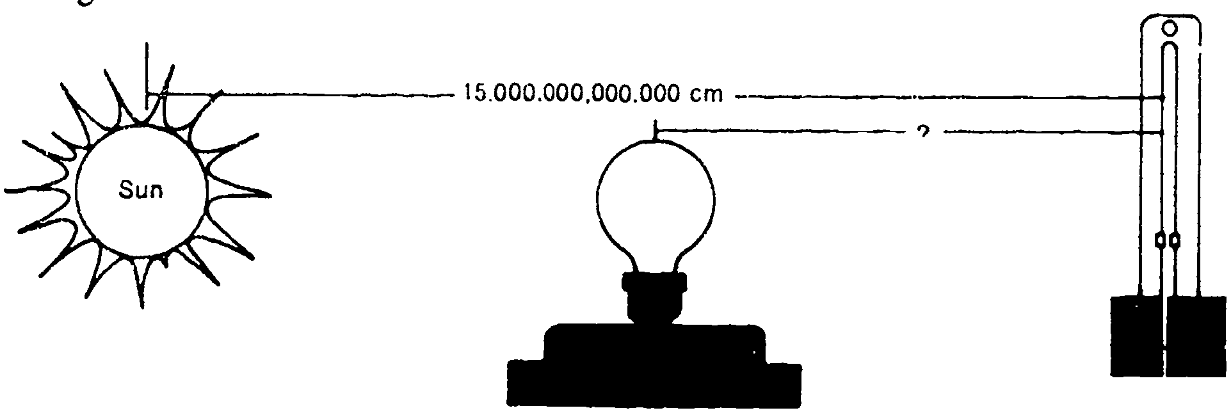
Now square your answer to question 4. Then multiply 50 watts by that number. The result will be the sun's power as calculated for the data given in Table 1.

However, the 10-cm distance measure in Table 1 was used to illustrate the method of calculating the sun's power. In Chapter 2, you actually compared the sun's effect with a 50-watt bulb. In question 2-18 of Chapter 2, you recorded a distance measure. This was the distance a 50-watt bulb had to be from your pyrheliometer to give the same temperature change effect as the sun.

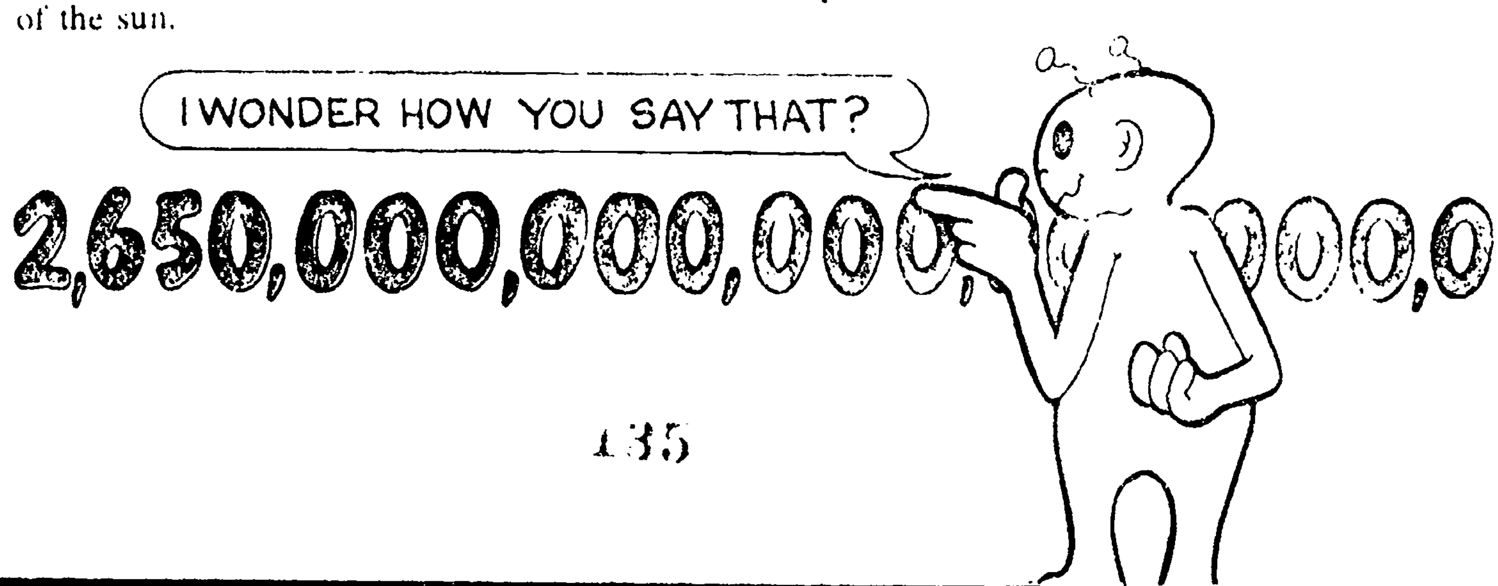
Iggy's question in the cartoon below is very apropos. The easiest way to "say" a huge number is with scientific notation. You may want to [illegible] into the subject with some of your more [illegible] students. For instance, 15,000,000,000,000 cm is 1.5 × 10^{13} cm. The power [illegible] to the 10 is equal to the number of places the decimal point is moved. If this number is divided by 10 cm, as in question 4, the answer is 1.5 × 10[illegible]. This number squared is 2.25 × 10[illegible]. Multiplied by 50 watts (that's 5 × 10 watts), the power of the sun is 1.125 × [illegible] watts.

Be sure that the number of cm used to divide into 15,000,000,000,000 cm is the one from question 2-18 in Chapter 2, and *not* the 10-cm sample.

5. As given in Chapter 7, the sun's power is actually about 3.7 × 10^{26} watts, or 5 × [illegible] horsepower.



☐5. Now use that distance measure to calculate the power of the sun.



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