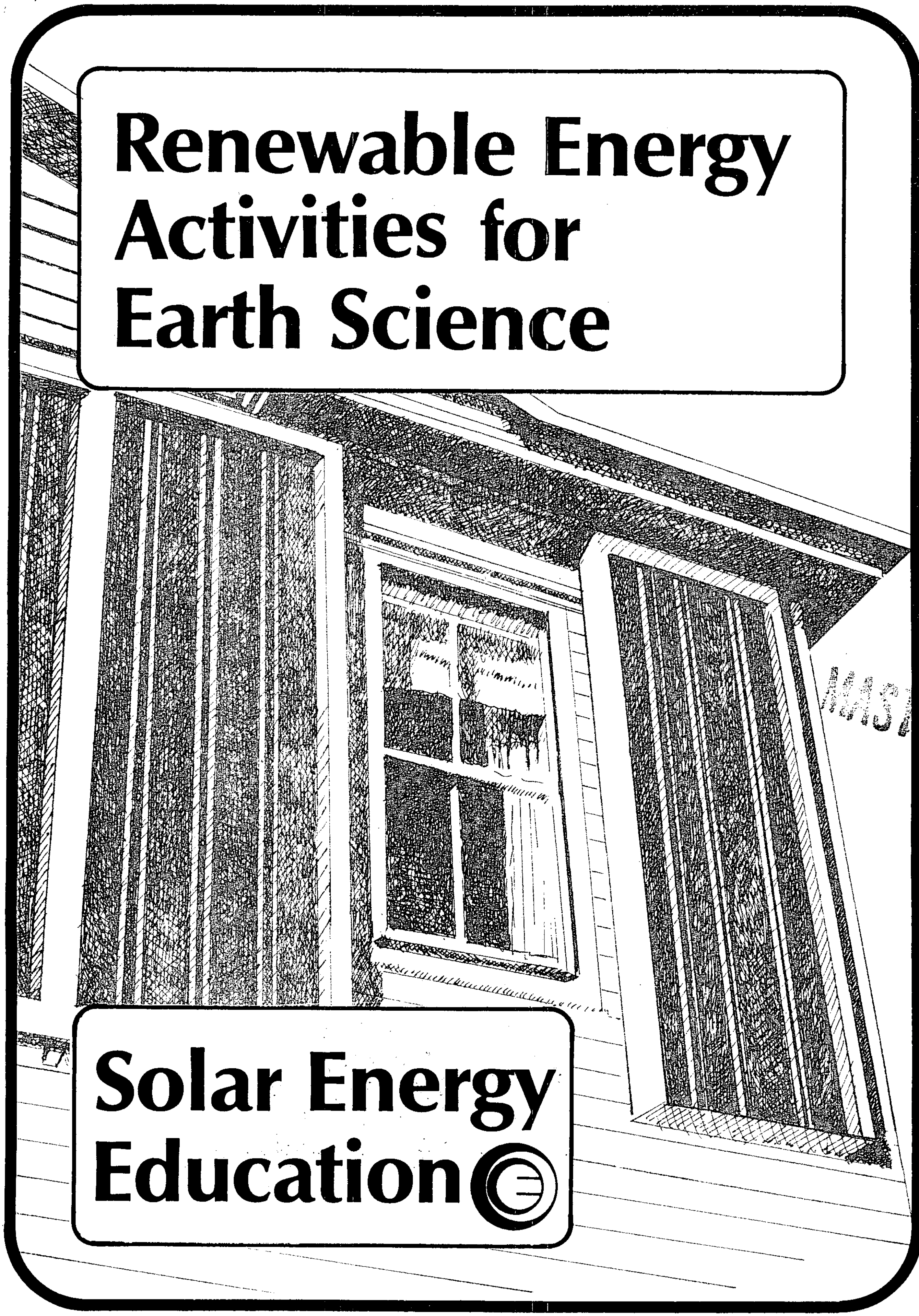
Renewable Energy Activities for Earth Science



Solar Energy Education

DISCLAIMER

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Solar Energy Project
SUNY at Albany
1400 Washington Ave., P.O. Box 22425
Albany, N.Y. 12222

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Introduction

For the teacher with a full workload and dozens of important topics to cover and skills to teach, the question that may occur in picking up this booklet is

Why Teach About Energy?

If you are asking that question, try to think of an area of human existence that is not affected by energy resources. Energy permeates our lives; it shapes our careers, our leisure, and our aspirations as well as providing food, clothing, and shelter.

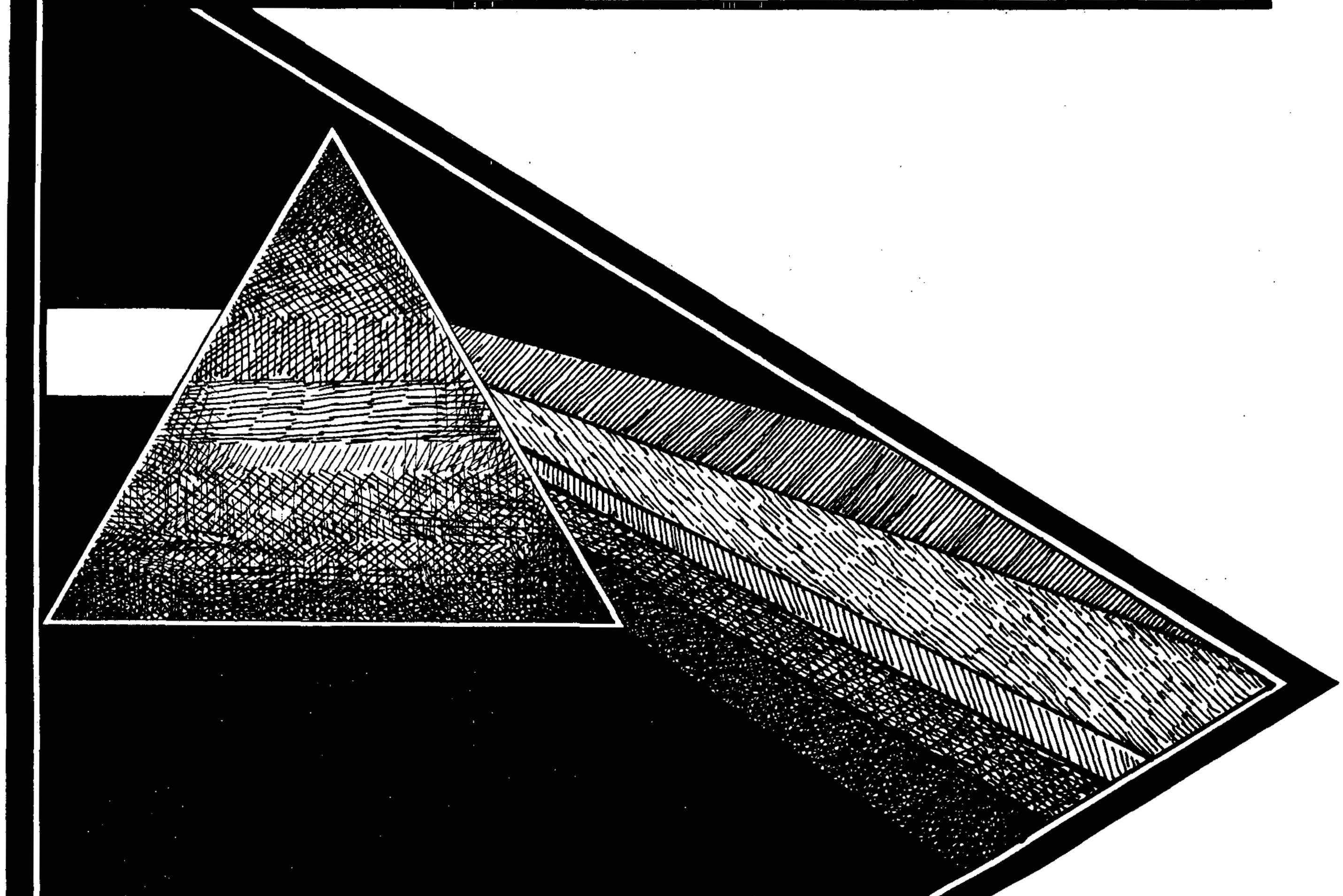
Students are aware of this reality. They see that, as available energy resources change, their lives will also change, in ways as yet unknown. They recognize energy as a factor that will have an impact on them personally, for the rest of their lives, and they want to understand their energy options.

Subject Skills/Energy Content

You can capitalize on your students' strong interest in the topic of energy. With renewable energy as the content matter, the following activities are designed to give students practice in the subject skills that are high on your teaching agenda. Whether it's observing, estimating and predicting, measuring, computing, graphing, or constructing apparatus, you'll find here a renewable energy activity, ready to use.

The Activities

1 What is Solar Energy?



There are many kinds of energy in the universe. The energy of the sun is radiant energy, scientifically called "electromagnetic radiation." Produced by nuclear reactions at the core of the sun, this energy streams from the surface of the sun in waves of many different wavelengths. The shortest and the longest wavelengths are invisible to our eyes, but the medium wavelengths are the visible radiation that we call sunlight. Most of the sun's energy is in these visible wavelengths.

All substances emit some radiation. The wavelengths emitted depend on the nature and the temperature of the substance. The range of wavelengths given off by a substance is called its spectrum.

In this activity you will investigate the solar spectrum and the spectra of two other light sources to see their similarities and differences.

objectives

At the completion of this activity, you should be able to

- list the various types of radiant energy in the electromagnetic spectrum;
- define the terms electromagnetic spectrum, radiant energy, wavelength, spectrum, continuous spectrum, and bright-line spectrum;
- identify different kinds of spectra and describe the conditions under which each is produced; and
- explain how the types of radiant energy in the electromagnetic spectrum affect man and are used by man.

skills and knowledge you need

Using science resource books to locate information

Using a spectroscope, a radiometer, and a glass prism

materials

an incandescent light source

a fluorescent light source

a spectroscope

a radiometer

small pieces of colored cellophane

red	green
orange	blue
yellow	violet

colored pencils

a glass prism

two Celsius thermometers

science resource books

procedure

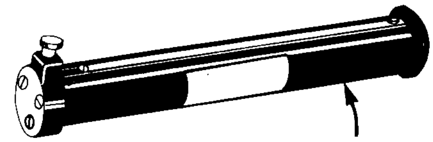
1. First, read "Electromagnetic Radiation" and study the diagrams carefully.

2. Use the spectroscope to observe the spectra of the following sources of light:

sunlight,
(DO NOT LOOK DIRECTLY AT THE SUN!)

an incandescent bulb, and

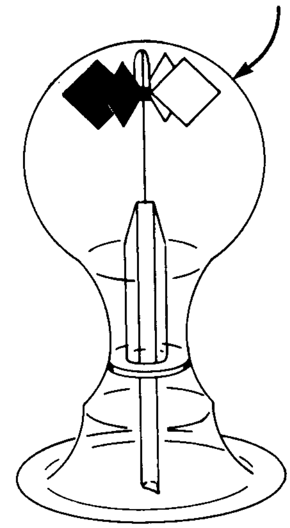
a fluorescent bulb.



3. Draw each spectrum in the "Spectrogram" box on the worksheet. Use your colored pencils to indicate the various colors of each spectrum.

4. On the line next to each drawing, identify the spectrum as continuous or bright-line.

5. In turn, hold two different colors of cellophane over the end of your spectroscope and point the spectroscope at the sky (BUT NOT DIRECTLY AT THE SUN). On the worksheet write the color of the cellophane filter used, and then draw the spectrum in the spectrogram box.



6. Complete the drawing of the electromagnetic spectrum at the bottom of the worksheet by placing these labels in the appropriate locations: visible light, infrared, and ultraviolet.

7. Use your eyes and a radiometer to detect whether visible light and infrared radiation are emitted by sunlight, an incandescent bulb, and a fluorescent bulb. Complete Data Table 1 by placing a check in the appropriate column whenever visible light or infrared radiation is detected.

Caution: Handle the radiometer carefully; if it breaks, flying glass may result.

8. Use a glass prism to separate sunlight into its spectrum. Place one thermometer in the blue band of the spectrum and another in the red band. When the temperatures stop changing, record them in Data Table 2. Then move the thermometer in the red band to just beyond the red, where there is no visible spectrum. When the temperature stops changing, record it in Data Table 2.

questions

Use the reading "Electromagnetic Radiation" and science resource books to help you answer the following questions.

1. Define the following terms.

   a. electromagnetic radiation
   b. radiant energy
   c. spectrum
   d. wavelength
   e. continuous spectrum
   f. bright-line spectrum

2. List the seven basic colors of the visible spectrum in order from longest wavelength to shortest wavelength.

3. Base your answers to the following questions on Diagram 2 in the reading.

   a. As the temperature of an object increases, what happens to the total amount of radiation it emits?

   b. As the temperature of an object increases, how does the wavelength at its peak intensity (the greatest proportion of its energy) change?

   c. If an electric stove's heating element were heated until it radiated visible light that was red in color, what is the next color it would radiate if it became even hotter?

   d. In which region of the electromagnetic spectrum is most of the sun's energy radiated? Which region contains the next highest proportion?

4. What are the characteristics of the following types of radiation? Include in your description any possible beneficial or damaging effects on humans and also any uses of the radiation by man.

   a. gamma rays
   b. x-rays
   c. ultraviolet radiation
   d. infrared radiation
   e. radio waves
   f. radar
   g. microwave radiation

5. a. In what ways are the spectra of sunlight, an incandescent bulb, and a fluorescent bulb alike? b. How are they different?

6. a. Which sources that you tested emitted visible light? b. Which emitted infrared radiation? c. How do you know?

7. What effect do filters have on the sun's spectrum?

8. What happened to the thermometers placed in the red and blue bands of the visible spectrum?

9. a. What happened when one thermometer was placed beyond the red band? b. What kind of radiation was being detected? c. How do you know?

looking back

Every substance gives off electromagnetic radiation. The radiation wavelengths given off by a substance are its spectrum. You have examined three spectra: those of the sun, an incandescent light, and a fluorescent light. You found that these spectra were different and that different instruments must sometimes be used to detect different parts of a spectrum.

The sun emits a very broad spectrum of radiation, but most of what reaches the earth is in the visible and infrared wavelengths. Humans have learned to put this radiation to a variety of uses, to improve life on earth.

going further

Investigate how dark-line spectra are produced. Set up gas tubes and observe the spectra produced.

Investigate the emission spectra of various elements. Ask your teacher to demonstrate these spectra by sprinkling various salts into a bunsen burner flame.

Find out how radiant energy is produced by the sun.

Research the latest developments in producing commercial energy from nuclear fusion, the same process that occurs in the sun's core.

Find out how infrared radiation is used in night photography, in mapping earth resources, and in heat loss studies.

Find out why filters are used over camera lenses.

Investigate how scientists use spectroscopes to study other planets and moons in our solar system, and stars in our galaxy.

What are Fraunhofer lines, where do they appear, and what causes them?

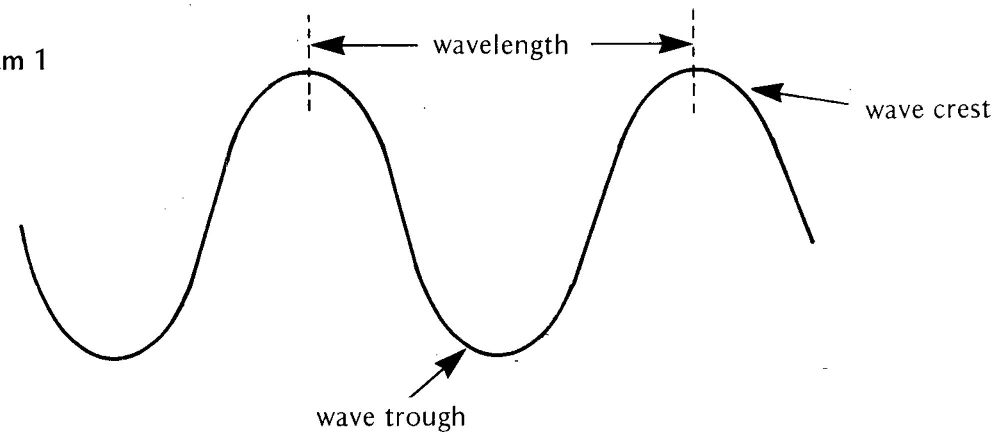
Investigate the kind of electromagnetic radiation given off by a "black light." What kind of emission spectrum does it produce?

To find out more about how a radiometer works, try Activity 3 in the Junior High/Middle Grades Activities book.

Electromagnetic Radiation

All objects are composed of charged particles in rapid and random motion. As a result of this motion, the atoms of an object release a kind of energy that has both electrical and magnetic properties. This energy is called electromagnetic radiation or radiant energy, and travels in a wave motion as shown in Diagram 1. All substances radiate energy in the form of electromagnetic waves.

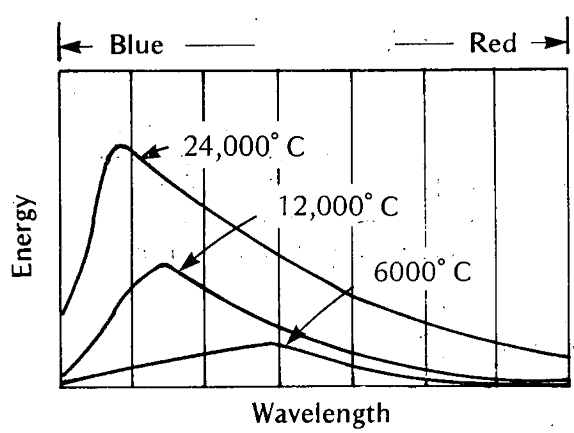
Diagram 1



The temperature of an object determines the wavelengths it radiates. Objects that are so hot that they glow are said to be incandescent. These objects glow because they radiate the wavelengths called visible light. The wavelengths, of course, are visible to the human eye. Your body also radiates energy, but it's invisible. This radiation is longer in wavelength than visible light and is called infrared radiation.

The temperature of the sun is very high -- about 6000°C at its surface. An object of this temperature looks yellowish-white. This doesn't mean that the sun emits only yellow light, but it does mean that the greatest proportion of its radiation is in the yellow band of visible light. If the sun were to become much hotter, it would look blue; if it were to cool a great deal it would look red. And a hotter sun would give off more radiation of every type, as shown in Diagram 2.

Diagram 2



Electromagnetic waves vary in length from very short waves (billionths of a centimeter) to very long waves (hundreds of kilometers). The sun emits all of these wavelengths in various proportions. The entire range of possible wavelengths is called the electromagnetic spectrum (Diagram 3).

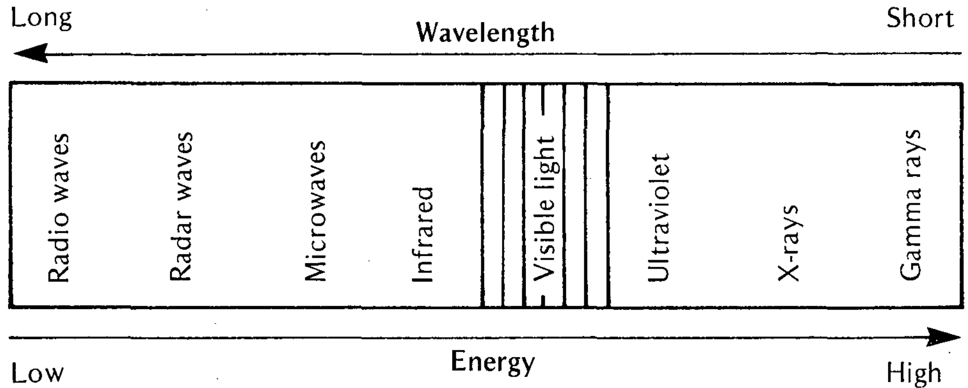


Diagram 3

The Spectroscope

The visible spectrum of an incandescent object can be seen with the aid of an instrument called the spectroscope. The spectroscope separates visible light into its component colors. There are two different types of spectroscopes: the prism spectroscope, which uses a glass prism to separate light, and the grating spectroscope, which replaces the prism with a piece of transparent material scored with a large number of parallel lines.

The Continuous Spectrum

If a spectrum shows a continuous band of color from red to violet, passing through all the intermediate colors without any gaps, then it is a continuous spectrum. A rainbow is an example of a continuous spectrum. All incandescent solids and liquids give off a continuous spectrum.

The Bright-Line Spectrum

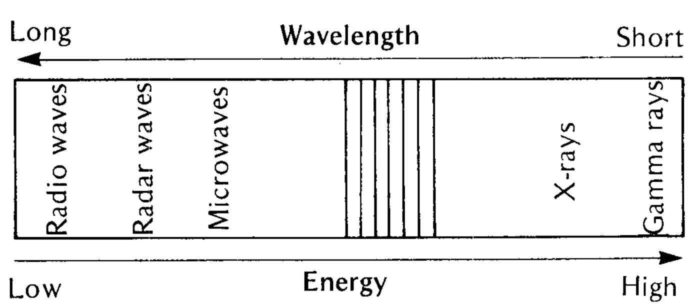
A bright-line spectrum shows a few isolated parallel bands of color on a black background. This spectrum is produced by any gas which radiates light. Each bright-line spectrum is characteristic of the gas which produced it, and can be used to identify the gas, much as fingerprints identify people.

The Invisible Spectrum

The spectrum from the sun includes much more radiation than the unaided human eye can see. Most of the invisible radiation is filtered out by the earth's protective atmosphere. Nearly all of the x-rays, gamma rays, and ultraviolet rays are absorbed before they reach the earth, while most of the visible light rays reach the earth. Some infrared radiation reaches the earth, but much is stored in the atmosphere.

How can we detect this invisible radiation? Scientists use modern technological instruments to detect much of it, but infrared radiation can be detected by a simple instrument called a paddle radiometer. The paddle wheel will rotate in the presence of infrared radiation.

Worksheet

Description of Radiation Source	Spectrogram	Kind of Spectrum Produced (continuous or bright line)
Sunlight		______
Incandescent Light		______
Fluorescent Light		______
Sunlight with ______ Filter		
Sunlight with ______ Filter		
Electromagnetic Spectrum		

Data Table 1

Light Source	Type of Radiation Emitted	
	Visible	Infrared
Sunlight		
Incandescent bulb		
Fluorescent bulb		

Data Table 2

Region of Spectrum	Temperature (°C)
Blue	
Red	
Beyond Red	

Teacher Information

What is Solar Energy?

Suggested Grade Level and Discipline

Science, grades 8-10
Earth Science
Physical Science

Skill Objectives

Using a spectroscope, prism, and radiometer

Comprehending a science reading passage by answering appropriate questions

Using science resource books to locate information

Defining science terms connected with electromagnetic radiation

Identifying and drawing different spectra

Major Understandings

The sun emits electromagnetic radiation in all wavelengths of the electromagnetic spectrum.

The hotter an object, the more total radiation it emits and the shorter the wavelength of the majority of its radiation.

A spectroscope can be used to view visible spectra.

The sun produces a continuous spectrum. Bright-line spectra are produced by gases which radiate light.

Electromagnetic radiation is both beneficial and harmful to people and is used by them for their own purposes.

Background

The sun emits electromagnetic radiation of all wavelengths. With a surface temperature of about 6000°C, the sun produces over 90% of its radiation in the visible and infrared regions of the spectrum. The small amounts of harmful ultraviolet and other high-energy radiation emitted by the sun are effectively screened by the earth's protective atmosphere. Visible light reaches the earth's surface with little filtering, but about half of infrared radiation is absorbed and stored by the near-earth atmosphere.

Electromagnetic radiation is produced as the result of thermonuclear fusion reactions in the sun's core. Traveling at the speed of 300,000 km/sec., electromagnetic radiation travels the 150 million kilometers to the earth in about 8 minutes.

Advance Planning

Obtain needed texts and reference books. Standard earth science, physics, and biology texts will contain all information required.

If necessary, borrow needed quantities of radiometers, spectroscopes, and prisms. Physics labs will have spectroscopes, while junior high science rooms will often have radiometers and prisms.

Set up the light sources. Only one of each will be needed. Lamps with protective reflectors can be mounted on ringstands.

If desired, pre-cut the small pieces of colored cellophane. This will save class time spent on the activity.

Duplicate needed quantities of the worksheet and data tables. Duplicate a class set of the reading and, if appropriate, of the teacher background section.

Suggested Time Allotment

One class period to introduce the activity and complete the reading

One to two class periods to perform the lab portions of the activity

One to two class periods to answer the questions and discuss results

Suggested Approach

Introduce the activity by displaying a large wall chart of the electromagnetic spectrum. Explain the importance of electromagnetic radiation as the energy source for all the earth's natural systems. Discuss how electromagnetic radiation affects man, as in causing skin cancer or sunburn.

Make sure students complete the reading. You may want to do the reading as a class activity or assign it as a silent reading or for homework. Some questions also may be assigned for homework.

If spectroscopes or prisms are in short supply, consider running several solar activities in the classroom at the same time. This will reduce demands on equipment, and small groups of students can move from activity station to activity station over the course of several periods.

Help students to locate needed information in the resource books and to answer the questions. Discuss the answers to the questions with the class.

If appropriate, discuss Planck's Law in conjunction with Question 3.

Precautions

Remind students never to look directly at the sun, even with spectroscopes.

Caution students about electrical hazards and heat when using the lamps. Don't allow students to set up the lamps themselves.

Remind students that the radiometer is fragile and may break when dropped or misused. Since it is vacuum packed, it will implode upon impact, and the danger from flying glass is high. It is recommended that students wear safety glasses when using the radiometers.

Points for Discussion

In what ways is electromagnetic radiation beneficial to man? In what ways is it harmful?

Why is electromagnetic radiation given the name "electromagnetic?"

How does the temperature of an object affect the type of radiation and the total amount of radiation it emits?

How are a continuous and a bright-line spectrum different?

Typical Results

The sun produces a continuous spectrum, as does an incandescent light. A fluorescent light produces a bright-line spectrum. The sun emits both visible and infrared radiation, as does the incandescent light. A fluorescent light emits visible light, but no infrared radiation. (The radiometer will not turn under fluorescent light.)

Filters transmit only the wavelength of light that corresponds to their color; all other wavelengths are absorbed.

The thermometer placed in the blue region of the visible spectrum will show the smallest increase in temperature, while that placed in the infrared region will show the greatest increase in temperature.

Evaluation

Check students' spectrograms and data tables for neatness and accuracy.

Check students' ability to use resource books. Check the answers to their questions for degree of understanding.

Ask students to list the types of radiation found in the electromagnetic spectrum.

Show students two typical spectra and ask them to identify each spectrum as continuous or bright-line.

Ask students to define the terms listed in Question 1.

Ask students to write a paragraph describing the effects of electromagnetic radiation on man and the ways in which man uses electromagnetic radiation.

Modifications

A lecture or a filmstrip presentation may be substituted for the resource books.

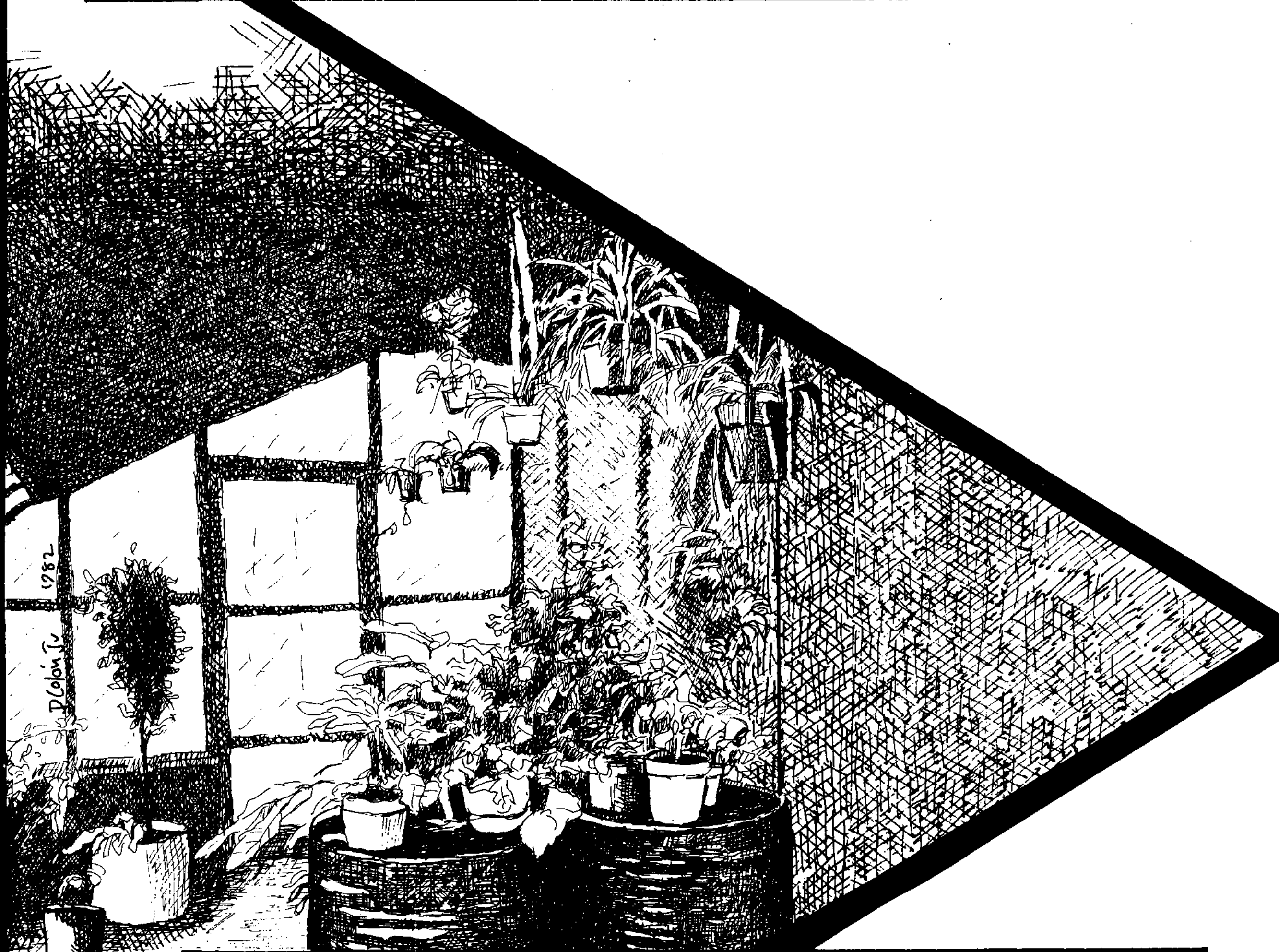
References

Earth Science: A Study of a Changing Planet, Robert Daley et al.
(Cebco Standard Publishing, 9 Kulick Rd., Fairfield, NJ 07006, 1976.)

Investigating the Earth, American Geological Institute.
(Houghton Mifflin Co., Wayside Rd., Burlington, MA 01803, 1978.)

Meteorology, Albert Miller.
(Charles E. Merrill Books, Inc., 1300 Alum Creek Dr., Columbus, OH 43216, 1976, $6.95/paper.)

2 The Greenhouse Effect



One of the fascinating things about solar energy is the way it changes from light to heat. This change takes place when light falls on a surface which absorbs its energy. The absorbing surface warms up from the absorbed energy and begins to give off heat. What happens next will be shown in this activity.

objectives

At the completion of this activity, you should be able to

- o construct a model apparatus that demonstrates the greenhouse effect;
- o define the terms infrared radiation, visible light, and wavelength;
- o use these terms to explain the greenhouse effect; and
- o describe how your model is similar to the earth and its atmosphere.

skills and knowledge you need

Reading a thermometer

Recording, graphing, and interpreting data

materials

two Celsius thermometers

two clear plastic shoeboxes

a clear plastic cover for one shoebox (or plastic wrap)

an outdoor reflector flood lamp, mounted on a ringstand

soil

water

cardboard

a watch, clock, or timer to measure seconds

an earth science textbook

procedure

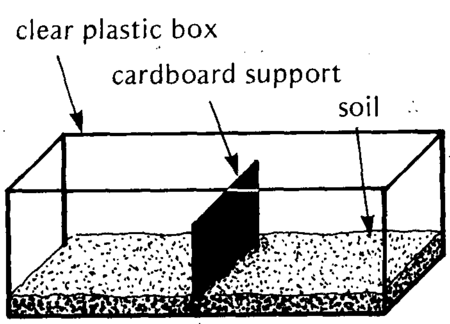


Diagram 1

1. Cut out a piece of cardboard so that when it is inserted into one of the clear plastic shoeboxes it will divide the box in half and will be only about three-fourths the height of the box (Diagram 1). Construct a second cardboard support for the other box.

2. Place soil to a depth of 2 cm in each of the shoeboxes. Thoroughly moisten the soil with water, but not so much that water sits on top of the soil.

3. Insert a cardboard support into each shoebox.

4. Lean a thermometer (with the bulb end up) against each support (Diagram 2).

5. Set the boxes side by side and about 2 cm apart under the flood lamp. Adjust the flood lamp so that it is about 25 cm above and equally distant from each box (Diagram 3). Place a clear plastic cover on one box.

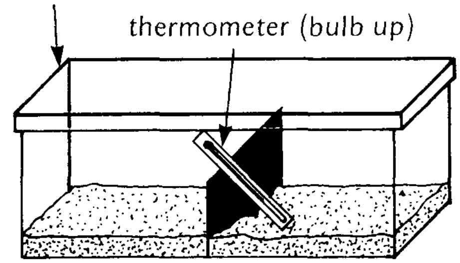
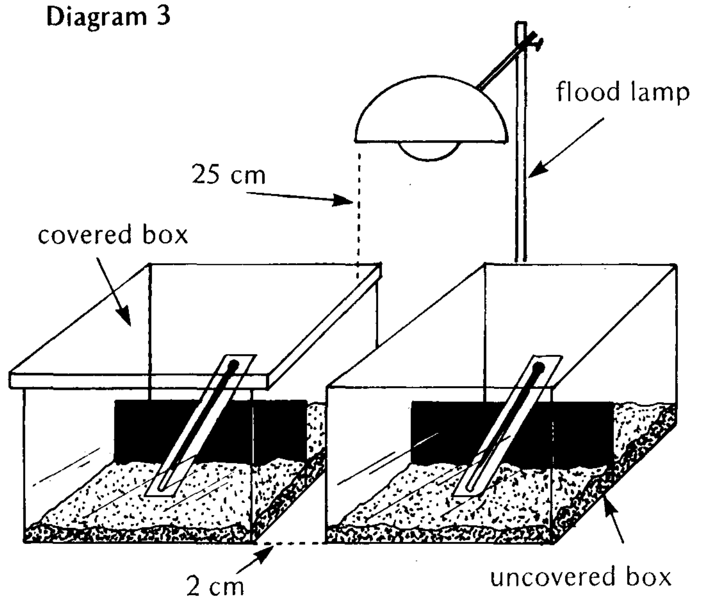


Diagram 2

Diagram 3



Caution: Locate your set-up away from direct sunlight or drafts from windows and heating or cooling systems, all of which may produce convection currents that could interfere with the activity.

6. When the temperatures of the thermometers stop changing, record them in the appropriate spaces of the "0 minutes" row of the data table.

7. Turn on the light. Read and record in the data table the temperature of each thermometer every 30 seconds for 15 minutes. Turn off the light.

Caution: Do not touch the flood lamp since it may become very hot. Do not look directly at the lamp either.

8. Plot the data from each shoebox on the graph provided. Be sure to label each line correctly with "covered shoebox" or "uncovered shoebox."

questions

1. a. What was the total temperature change of the air in the uncovered box? b. In the covered box?

2. a. In which box did the temperature change more? b. By how many degrees more?

3. How did covering one box affect the rate at which the temperature changed in that box?

4. Use an earth science textbook to help you define the following terms: infrared radiation, visible light, and wavelength.

5. Look up the "greenhouse effect" in an earth science textbook, and then use the terms you defined in Question 4 to explain the greenhouse effect. Be sure to distinguish between long and short wavelength radiation in your explanation.

6. Use your knowledge of the greenhouse effect to explain the difference in the heating rate of the air in the two boxes.

7. What part of the earth's atmosphere does the cover on the box represent?

8. What situation does the uncovered box represent?

9. Use your knowledge of how the covered box functioned to describe the way the atmosphere functions to keep the earth warm.

looking back

Sunlight (short wavelength radiation) passes easily through the earth's atmosphere. Falling on the surface of the earth, the radiation is absorbed and its energy is taken up by the earth's surface, which gradually heats up. The earth then gives off heat (long wavelength radiation) which can be trapped by components of the earth's atmosphere.

This greenhouse effect works to keep the earth warm, and it works the same way to warm solar houses, solar greenhouses, and solar collectors.

going further

Repeat this activity, continuing to collect data after the light is turned off. Graph your results. How does the greenhouse effect influence cooling?

How would different coverings affect the temperature change in your covered box? Repeat the activity using different coverings and compare your new results to the original data.

Research current scientific thought on how air pollutants might affect the greenhouse effect. Write a report on your findings for presentation to the class.

Research how solar collectors employ the greenhouse effect in collecting heat energy.

Visit a greenhouse to experience the conditions that gave rise to the term "greenhouse effect" as it is used to describe a form of atmospheric heating.

Explain why a car parked in the sun for a long time becomes very hot inside, even though the outside air may be very cold.

To see how the greenhouse effect works in a solar collector, try Activity 1, "Solar Energy in a Can," in the Junior High/Middle School Activities book.

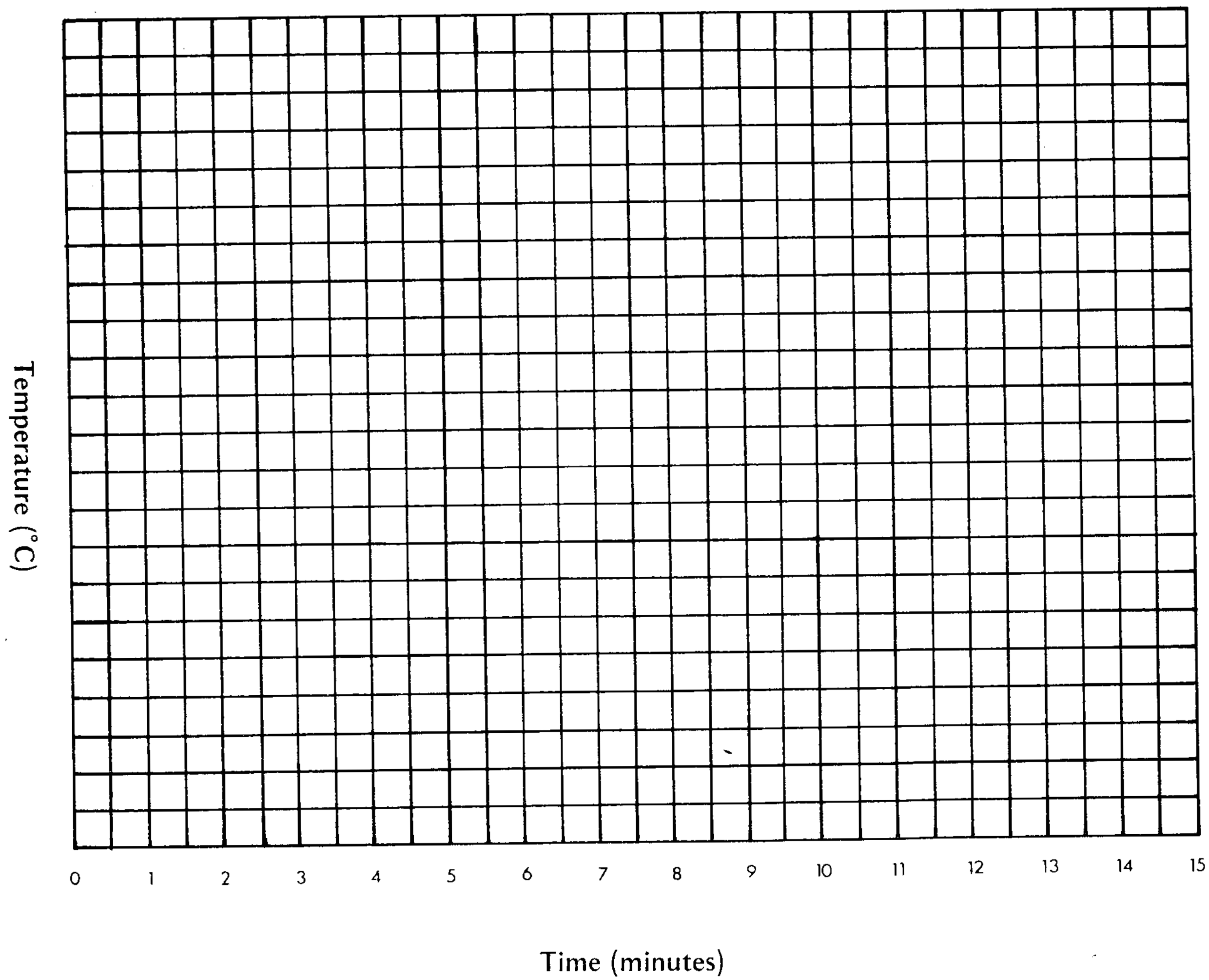
For additional information related to the greenhouse effect, try Activity 1 in this book, "What is Solar Energy?" and Activities 5 and 6 in the Junior High/Middle School Activities book.

Data Table

Time (minutes)	Temperature (°C)	
	Covered Box	Uncovered Box
0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		
4.5		
5.0		
5.5		
6.0		
6.5		
7.0		
7.5		

Time (minutes)	Temperature (°C)	
	Covered Box	Uncovered Box
8.0		
8.5		
9.0		
9.5		
10.0		
10.5		
11.0		
11.5		
12.0		
12.5		
13.0		
13.5		
14.0		
14.5		
15.0		

Graph



Teacher Information

The Greenhouse Effect

Suggested Grade Level and Discipline

Science, grades 6-9
Earth Science
Physical Science
General Science
Ecology
Outdoor Education

Skill Objectives

Recording and graphing data

Defining science terms

Developing and interpreting a model of real world conditions

Applying information gained from a model to the real world

Major Understandings

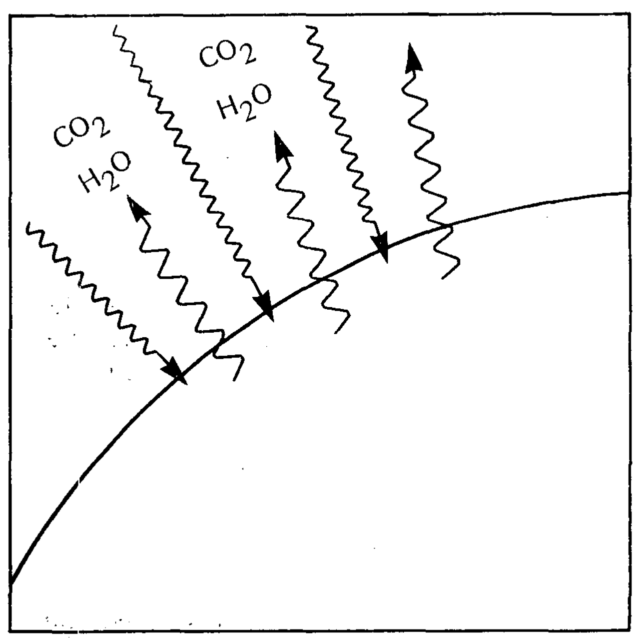
The covered shoebox serves as a simple model of the earth and its atmosphere and can be used to demonstrate the greenhouse effect.

Water vapor and carbon dioxide in the earth's atmosphere act much like glass in a greenhouse, preventing the escape of outgoing radiation and keeping the earth warmer than it would otherwise be.

The earth's atmosphere transmits short-wave radiation (much of the incoming radiation) and traps long-wave radiation (much of the outgoing radiation). This long-wave radiation is felt as heat and can be detected as a rise in temperature.

Background

When solar radiation strikes the earth's atmosphere, it may be reflected, absorbed, or transmitted. Although the sun radiates energy in all the wavelengths of the electromagnetic spectrum, more than half of its emitted energy is in the form of visible light, a relatively short-wave radiation. On the average, about 35% of this visible light is reflected back into space, although on cloudy days the percentage is higher. Another 15-20% is absorbed by particles of dust and molecules of gases (especially water vapor and carbon dioxide) in the atmosphere. The rest, nearly 50% on the average, is absorbed by substances at the earth's surface, such as rocks, soil, water, and plants.



As the earth's surface absorbs visible light, it becomes warmer and radiates energy itself. Only the earth is much cooler than the sun, and so it radiates energy of a longer wavelength — infrared. But when infrared is radiated back toward space by the earth's surface, it is not transmitted through the atmosphere as easily as visible light. Water vapor, ever present in the earth's atmosphere, absorbs infrared radiation especially well and in turn, reradiates it. Some of this reradiated energy is returned to the earth's surface, resulting in additional heating. Carbon dioxide in the atmosphere also absorbs and reradiates infrared radiation, but not as effectively as water vapor.

Water vapor and carbon dioxide in the atmosphere function much as glass does in a greenhouse. Glass, too, transmits visible light but absorbs infrared radiation. Like glass in a greenhouse, the atmosphere traps and stores large amounts of heat energy by constantly absorbing and radiating infrared radiation, some of which returns to the earth. It is this greenhouse effect which keeps heat energy near the earth's surface and provides life-sustaining temperatures for the planet.

Advance Planning

Plastic shoeboxes are inexpensive and readily obtainable from hardware and discount stores. Try for shoeboxes with clear lids.

Inexpensive sterile potting soil is available from garden centers, or ordinary garden soil may be used.

Obtain thin pieces of cardboard. Sheets of this type are often used as filler in boxes of paper.

Mount the outdoor flood lamps on ringstands. Test one set-up to make sure that the lamps are placed far enough above the boxes to prevent melted tops.

You may want to prepare the boxes with soil and to cut the cardboard ahead of time. This will reduce class time spent on these portions of the activity. Don't forget that a few students can help you with these tasks outside of class time.

Duplicate needed quantities of the data table and graph. If desired, you may duplicate the teacher background section as a student reading.

Suggested Time Allotment

One-half to one class period to introduce the activity and prepare the boxes

One class period to perform the activity

One class period to answer questions and discuss results

Suggested Approach

Introduce the activity by discussing some common phenomena which illustrate the greenhouse effect: a closed car on a sunny day, a sunny room in winter, and greenhouses and sunspaces.

Allow students to work in groups of two or three. One student can keep time, while the other two read and record data.

If flood lamps and plastic boxes are in short supply, consider running this activity in conjunction with other solar activities, as suggested in the previous activity.

After students have performed the activity, discuss how the covered shoebox is a model for the earth and its atmosphere. Help students to define the terms in Question 4, then help them to explain the greenhouse effect.

Precautions

Remind students not to touch the flood lamps. Stress the need to take the same precautions with flood lamps as with any electrical device.

Make sure that the lamps don't melt the plastic boxes.

Position set-ups away from direct sunlight, open windows, and heating or cooling system vents.

Points for Discussion

In what ways does the greenhouse effect caused by the covered shoebox differ from the greenhouse effect caused by the earth's atmosphere?

Why are clear winter nights much colder than cloudy winter nights?

If increased use of wood and coal as energy sources results in an increase of carbon dioxide (a by-product of wood and coal burning) in the atmosphere, what effect would this have on atmospheric temperatures?

Might the greenhouse effect ever be harmful?

Is the earth or the sun primarily responsible for heating the atmosphere? Explain your answer.

Typical Results

The air in the covered box will reach higher temperatures than the air in the uncovered box.

Evaluation

Check students' data tables and graphs for completeness and accuracy. Check students' answers to questions for degree of understanding of the greenhouse effect.

Ask students to define the terms wavelength, infrared radiation, and visible light.

Have students write a paragraph explaining the greenhouse effect.

Ask students to describe how the covered shoebox simulates the earth and its atmosphere.

Modifications

Substitute the sun as the source of energy.

If equipment is in short supply, have each group collect data on only one of the boxes, then let each group share data with a group which collected data on the other box.

Substitute small fish tanks for the shoeboxes. Cover one fish tank with glass or turn it upside down over a tray.

References

Earth Science: A Study of a Changing Planet, Robert Daley et al.
(Cebco Standard Publishing, 9 Kulick Rd., Fairfield, NJ 07006, 1976.)

Investigating the Earth, American Geological Institute.
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The Passive Solar Energy Book, Edward Mazria.
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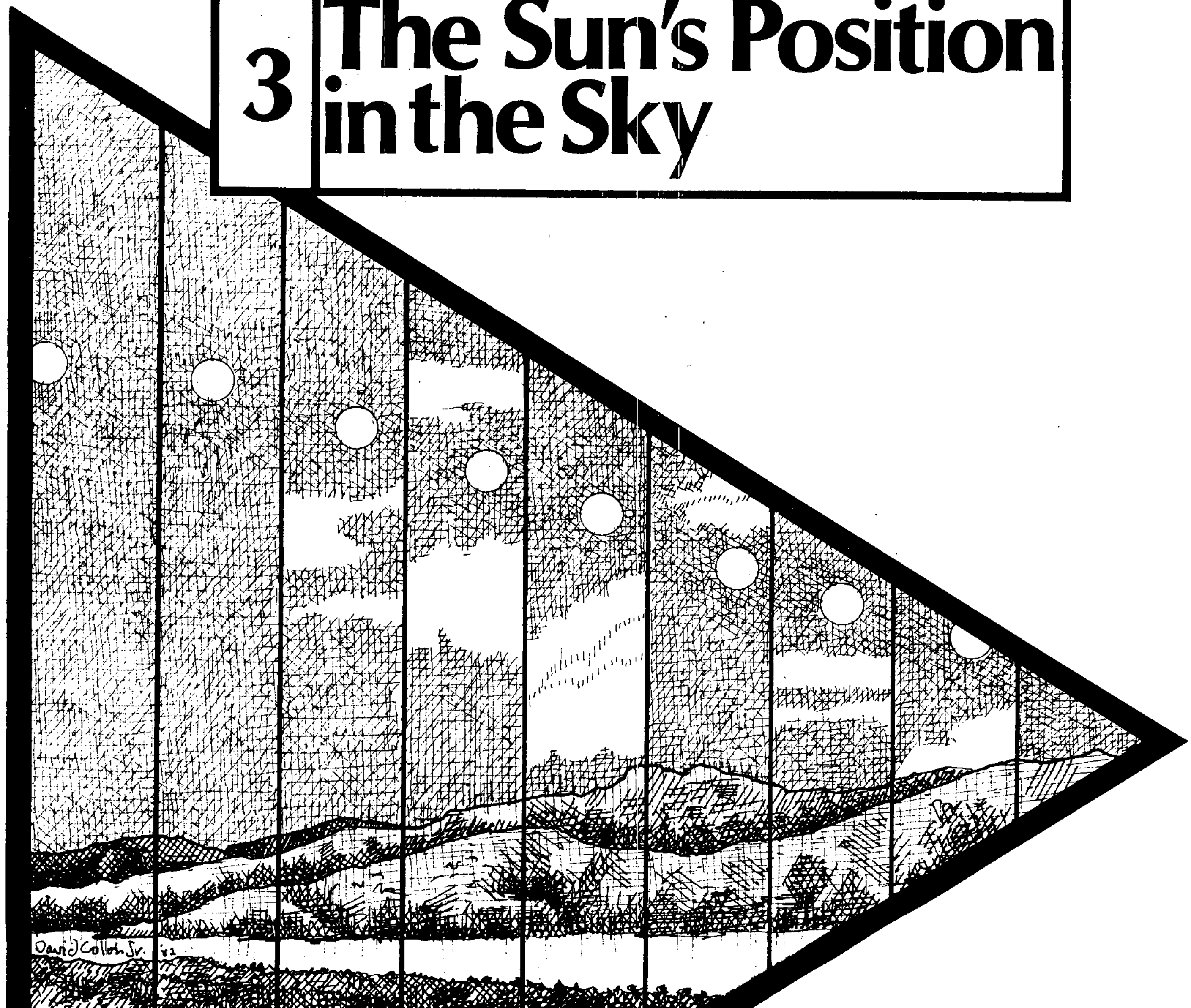
3 The Sun's Position in the Sky



Everyone is vaguely aware that the sun's position in the sky always appears to be changing. And everyone with a little knowledge realizes that this apparent movement is due to the earth's movement. As the earth rotates on its axis, the sun seems to revolve around us from east to west. As the earth on its tilted axis gradually travels around the sun from summer to winter, the sun seems to sink lower toward the horizon each day.

To use solar energy, you must be aware of where the sun will be in the sky, from hour to hour and season to season.

objectives

At the completion of this activity, you should be able to

- o measure and graph solar altitude and azimuth over the course of a day;
- o state the relationship between time of day and solar altitude, between time of day and solar azimuth, and between solar altitude and length of shadows;
- o describe a procedure for determining when the sun is highest in the sky;
- o calculate the sun's apparent rate of motion; and
- o determine the magnetic declination at your location.

skills and knowledge you need

Measuring angles with a protractor

Levelling a board with a bubble level

Using a magnetic compass

Recording and graphing data

materials

a piece of pegboard

a circular protractor with a dowel attached

a magnetic compass

a bubble level

a watch or clock

a sheet of paper slightly smaller than the pegboard

a straight edge

a 180^{o} protractor with a string attached

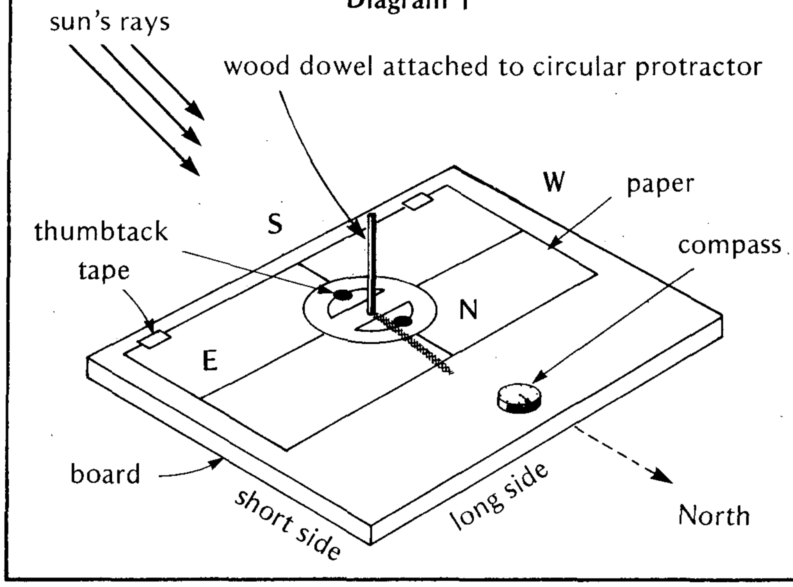
a metric ruler

a cork borer

masking tape

two thumbtacks

Diagram 1



procedure

Part 1: Setting Up the Apparatus

1. Use the cork borer to cut a hole in the paper about 6-8 cm in from the middle of one long side.

2. Draw two straight lines across the paper, each passing through the center of the hole, with one line parallel with the long side of the paper and the other line parallel with the short side.

3. The two lines you have drawn should be perpendicular to one another and should intersect at the center of the hole. As shown in Diagram 1, mark the ends of the short line N and S, and the ends of the long line E and W. You have now marked the compass directions you will use in orienting the board.

4. Find a hole in the pegboard that is located about 8-10 cm in from the middle of one long side. Place the paper on the pegboard so that the paper's hole lines up over the hole you just located and so that the long edges of the board and paper are parallel.

5. Push the portion of the dowel below the circular protractor through the hole in the paper and into the hole in the pegboard. Align the north, south, east, and west points of the protractor with the lines you labelled in Step 3.

6. Tape the paper to the board along its "southern" edge. Use the two thumbtacks to pin the protractor tightly to the board. This will ensure that the dowel is perpendicular to the board and that the protractor remains in its correct position.

7. Early in the morning, set the board where it will receive unobstructed sunlight for most of the day. Place the magnetic compass on the board. Turn the board until its north-south line is correctly aligned with the compass needle.

Caution: Make sure the board is not located near iron or steel objects (including belt buckles) that could affect the compass reading.

8. Use the bubble level to level the board.

9. Mark the exact position of the board so that if it must be moved it can be repositioned accurately. You might want to draw chalk lines around the board or drive stakes at its corners.

Part 2: Collecting the Data

10. Measure and record on the data table the height of the dowel (in cm) above the surface of the board.

11. Place a dot at the end point of the dowel's shadow (Diagram 2). Write the time next to the dot. Mark the point where the center of the shadow crosses the outer edge of the circular protractor. (This mark will allow you to check your data later, if necessary.)

Diagram 2

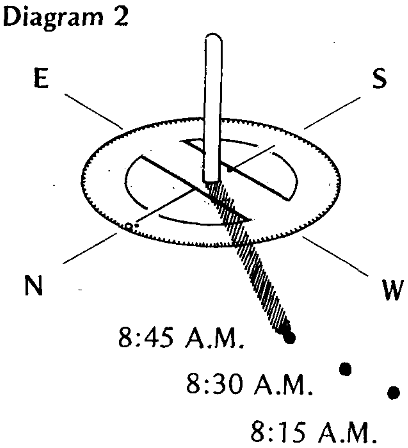
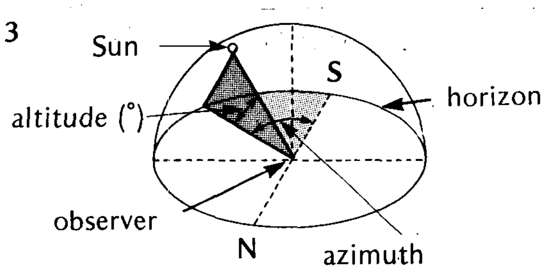
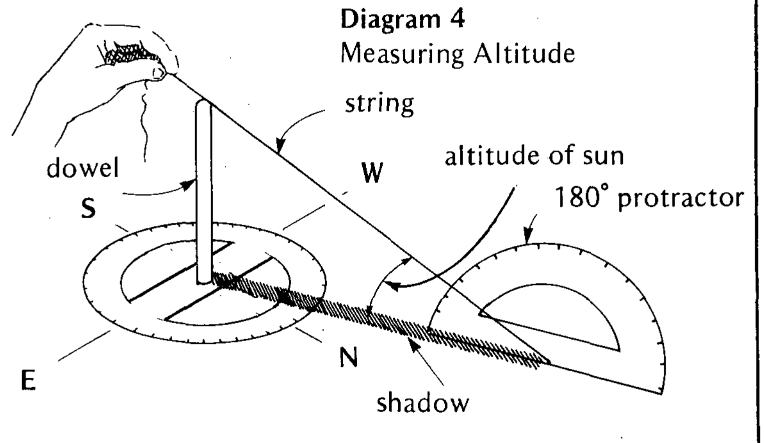


Diagram 3



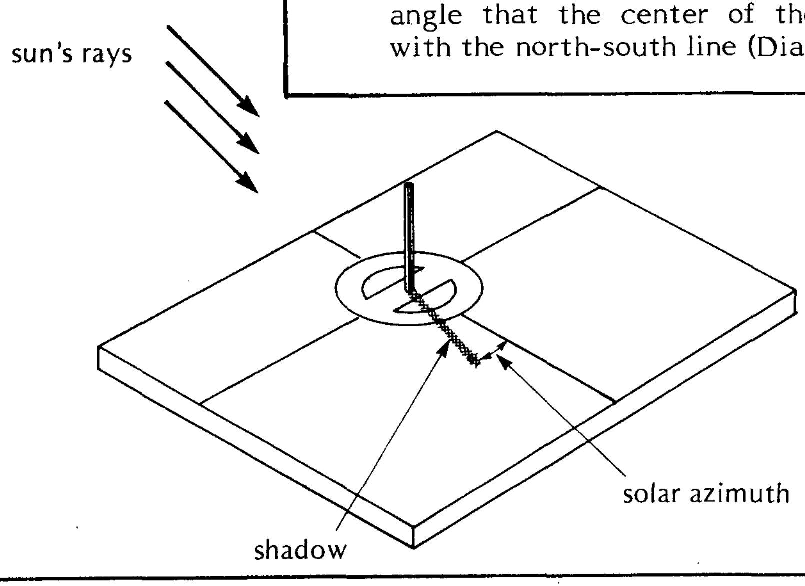
12. The angle of the sun above the horizon is called the solar altitude or angle of insolation, and is illustrated in Diagram 3. To measure this angle, align the 180° protractor with the shadow line, as shown in Diagram 4. Pull the string attached to the protractor taut across the top of the dowel and read the angle the string makes with the shadow. Record this angle in the appropriate space on the data table.

Diagram 4
Measuring Altitude



13. The angle of the sun from the north-south line is called the solar azimuth (Diagram 3). To measure this angle, read from the circular protractor the angle that the center of the shadow line makes with the north-south line (Diagram 5).

Diagram 5
Measuring Azimuth



Notice the difference in compass direction between the shadow and the sun. In Diagram 5, for example, the shadow is 30° to the east of the north-south line, but the sun's position is 30° to the west. Although you are measuring the position of the shadow, it's actually the position of the sun that you want to record, so exchange east for west or west for east when you record the azimuth. Record the azimuth in the appropriate space on the data table, then add E (for east) or W (for west) to it.

14. Repeat Steps 11-13 at 15 minute intervals until as late in the day as possible. Near midday, plot points at 5 or 10 minute intervals. (Actually, other classes may be recording some of the data for you and you will all share data later.)

Part 3: Interpreting the Data

15. If necessary, obtain any missing data by copying times, altitudes, and azimuths from other classes' data tables. Make a copy of the completed master sheet by taping the master sheet to a window, placing a clean sheet of paper over it, and carefully tracing the north-south and east-west lines and the "dots."

16. Find the length of the shadow for each time of day by measuring the distance between the intersection of the north-south and east-west lines and each dot. Record these lengths in the appropriate spaces on the data table.

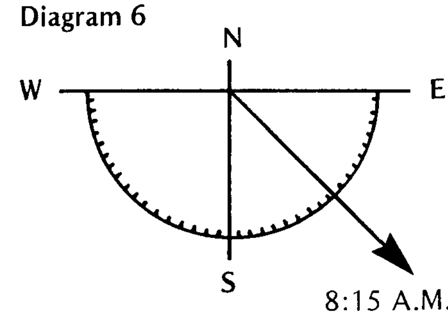
17. On your copy of the master sheet, carefully connect the dots that represent the end of the shadow at each time of day.

18. Use Graph 1 to plot shadow length vs. time of day.

19. Use Graph 2 to plot the sun's altitude vs. time of day.

20. For each time of day, draw an arrow on Graph 3 in the appropriate azimuth direction of the sun (see example, Diagram 6). Label the outer end of each arrow with the correct time of day.

Diagram 6



questions

1. What is the relationship between the time of day and the altitude of the sun?

2. What is the relationship between the time of day and the length of an object's shadow?

3. What is the relationship between the altitude of the sun and the length of an object's shadow?

4. Describe how solar azimuth changes during the day.

5. How could you use shadow length to determine when the sun is highest in the sky?

6. Calculate the rate at which the sun appears to move through the sky. Choose any two points on the master sheet. Obtain the requested information from your data table and use the equation given. Times should be at least an hour apart. SHOW ALL WORK.

a) Time at 1st point: _____hr. _____min. Azimuth for 1st point = _____°.

Time at 2nd point: _____hr. _____min. Azimuth for 2nd point = _____°.

Time difference = _________ min. Angular difference = _________°.

b) Rate of sun's apparent motion (°/min.) = $\frac{\text{Angular difference } (^\circ)}{\text{Time difference (min.)}}$

c) Repeat for two other sets of points, then average the three rates to obtain an average value for the sun's apparent motion.

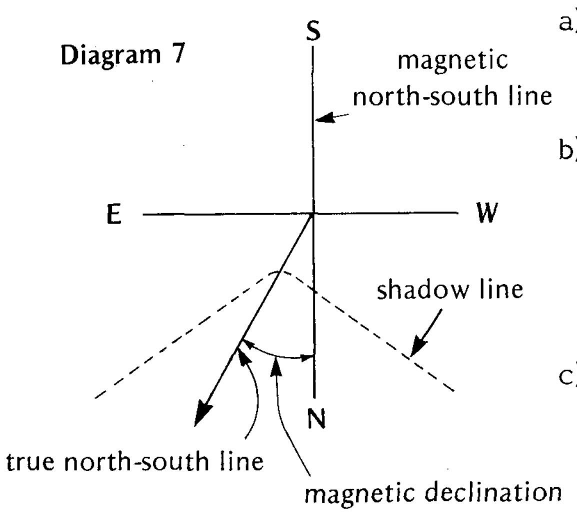
7. The sun is said to be highest in the sky "at noon." If noon is exactly 12:00 noon, then, according to your data, was the sun highest in the sky at that time?

8. If your answer to Question 7 was no, use your answers to Questions 5 and 6 to determine as accurately as possible the time of day when the sun was highest in the sky.

9. Shadows in the winter tend to be longer than shadows in the summer. What does this statement tell you about the relative position of the sun in the sky in winter and in summer?

10. Magnetic declination is the angular distance at your location between magnetic north and true north (the direction of the geographic North Pole). Determine the magnetic declination for your location as follows.

Diagram 7



a) Look at the line you drew in Step 17 of the procedure. Locate the exact point on the line where the shadow was the shortest.

b) Draw a line from the intersection of the north-south and east-west lines to the point where the shadow was shortest. This line is the true north-south line because, when the shadow was shortest, the sun was highest in the sky and cast a shadow true north.

c) Measure the angle between the magnetic north-south line (drawn originally on the master sheet) and the true north-south line. This angle is the magnetic declination at your site. Be sure to indicate whether your magnetic declination is east or west of the north-south line.

looking back

As you become more involved in using solar energy, it will be necessary for you to be able to track the sun. You will need to know how to predict its position in the sky at different hours of the day and different seasons of the year. This knowledge will tell you many things: during what hours a window will receive sunlight, whether a tree in the yard will shadow the window, how much roof overhang you will need in order to block hot summer sunshine, at what angle a solar collector should be mounted, and so on. With this kind of precise knowledge you can do real solar designing.

going further

Compare the results of this activity with published data on solar altitude and azimuth. (Solar data can be obtained from a local weather station, university, or National Weather Service office.) Explain discrepancies, if any, between your data and published data.

Research the ways in which solar collectors are oriented toward the sun. Compare the information gained from your research to the results obtained from this activity. Explain how solar altitude and azimuth affect the orientation of collectors.

Research the ways in which passive solar homes are designed and landscaped to take maximum advantage of the sun. Explain how these designs and landscapes are related to the sun's changing position in the sky. Try Activity 1, "A Passive Solar House," in the Renewable Energy Activities book for General Science.

Using published data on solar altitude and azimuth, show on a simple outline drawing of a house how the sun's rays would enter its windows at different times of the year. Indicate how changes in window size and position or roof overhang would affect incoming solar radiation. Convert the outline drawing into a model cardboard house and repeat the above suggestions.

Find out more about magnetic declination. Explain how magnetic declination would affect a person's use of a compass when finding directions from a map.

Find out about the equation of time, and how "sun time" differs from "clock time."

Continue to collect data on the sun's position in the sky. Set up a permanent apparatus outside the classroom and collect data on a weekly basis. Use your results to explain how the sun's apparent path changes during the year.

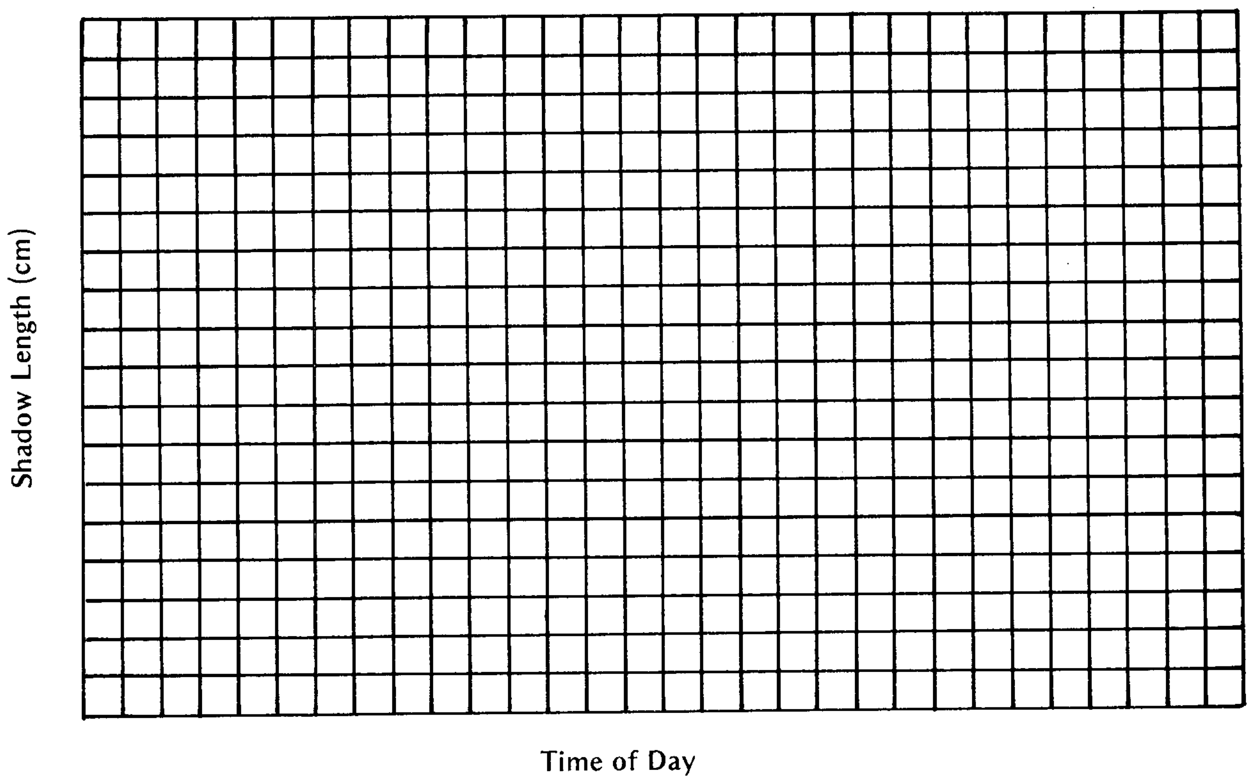
Data Table

Date: ______________________ Height of Wood Dowel: ______________________

Time	Sun's Altitude (°)	Sun's Azimuth (°E or W)	Shadow Length (cm)

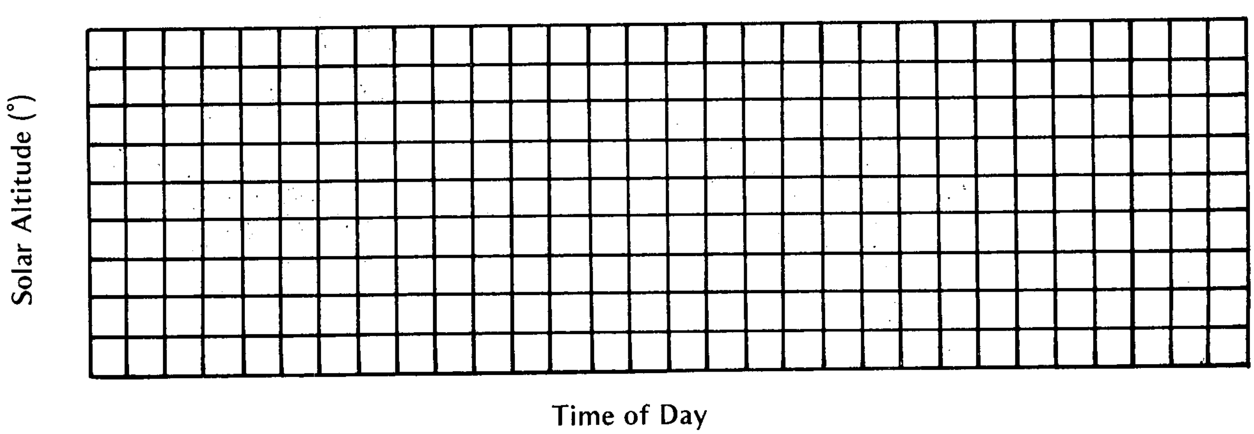
Graph 1

Shadow Length vs. Time of Day



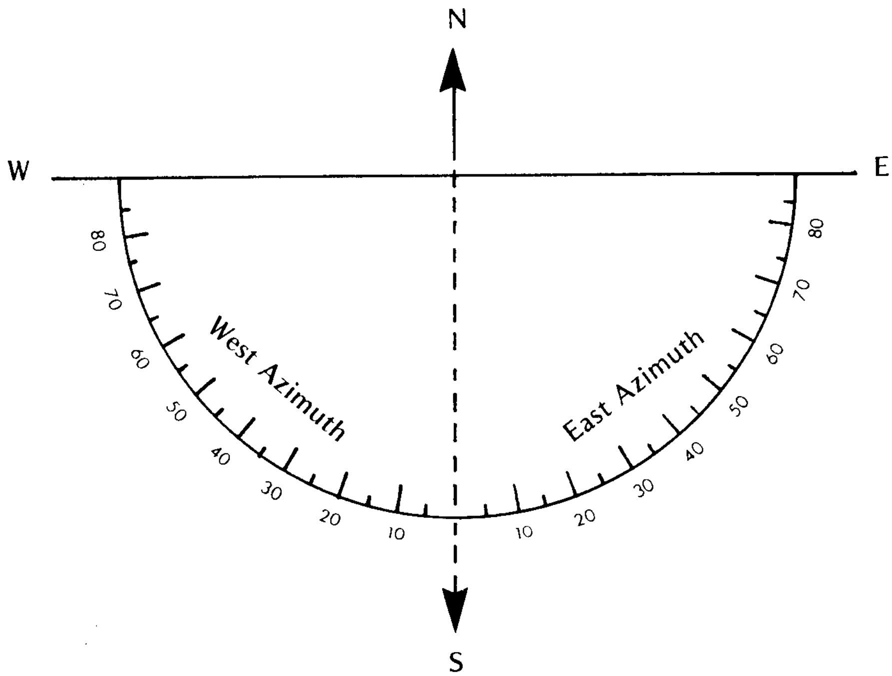
Graph 2

Solar Altitude vs. Time of Day



Graph 3

Solar Azimuth vs. Time of Day



Teacher Information

The Sun's Position in the Sky

Suggested Grade Level and Discipline

Science, grades 7-10
Earth Science
Outdoor Education
Mathematics

Skill Objectives

Measuring solar altitude and azimuth

Recording, graphing, and interpreting data

Determining the sun's greatest altitude on a given day

Calculating apparent rates of solar motion

Determining magnetic declination

Major Understandings

The sun's apparent path through the sky can be represented on a directional grid by plotting the end points of a shadow cast over time by a linear object set perpendicular to the grid.

Solar altitude is the angular distance between the sun's position in the sky and a point directly below on the horizon.

Solar azimuth is the angular distance east or west from true south to a point on the horizon directly below the sun.

Solar altitude increases from sunrise to midday, then decreases to sunset. Solar azimuth decreases from the east from sunrise until midday, then increases to the west until sunset. As solar altitude increases, the length of an object's shadow decreases.

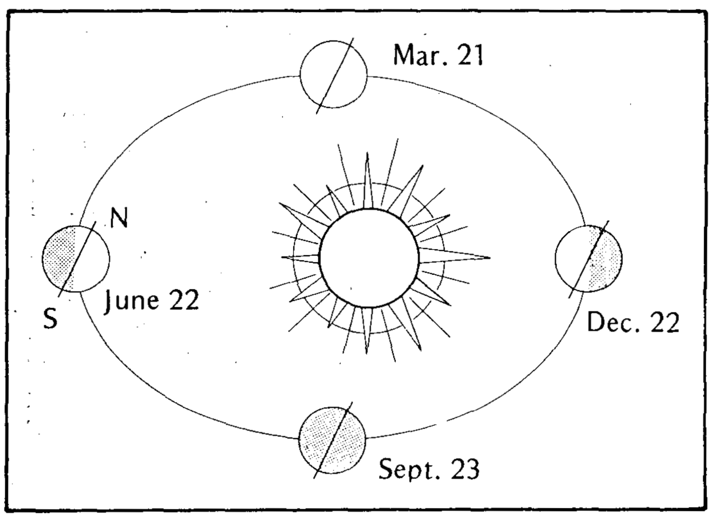
The sun is highest in the sky when an object's shadow is shortest.

The apparent rate of solar motion can be calculated.

Magnetic declination is the angular distance between the direction of true (geographic) north and the direction of magnetic north.

Background

The solar enthusiast must have a working knowledge of the sun's changing position in the sky. This position only seems to change, though, and is a result of the earth's daily rotation about its axis. The sun appears to rise each day in a generally easterly direction and to set in a generally westerly direction. During the course of a year, the sun's apparent path also changes as the earth revolves around the sun. This occurs because the earth's rotational axis is tilted $23\frac{1}{2}^{o}$ from the perpendicular of the earth's orbital plane. Only twice a year, then, (March 21st and September 23rd) does the sun appear to rise directly to the east and set directly to the west. In the northern hemisphere, the sun's lowest midday position in the sky occurs on December 22nd, while its highest midday position is on June 22nd.



Although several systems can be used to describe the position of celestial bodies, the solar field employs the straightforward horizon system used in navigation and surveying (with one important exception). The apparent position of the sun is therefore described in terms of its altitude and azimuth. The azimuth measurement, however, is different from that used by navigators and surveyors: solar azimuth is measured from true south, not true north, and is reported in degrees east (in the morning) or west (in the afternoon) of true south. Solar altitude and azimuth are diagrammatically illustrated in the student section.

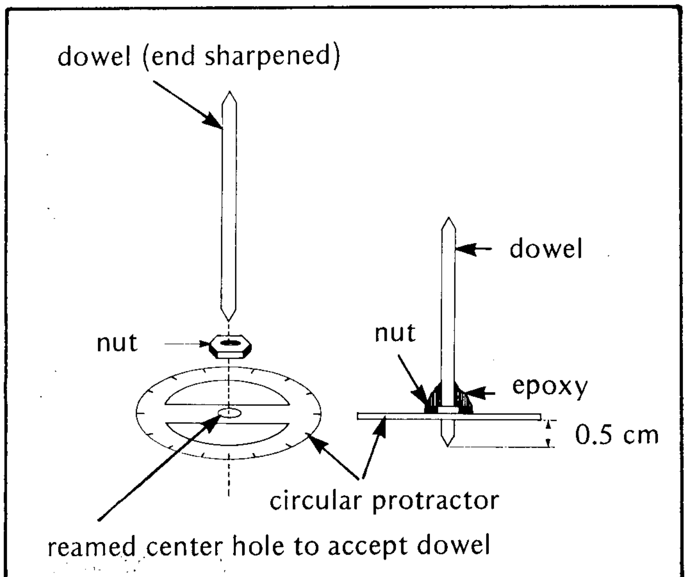
The directions used in the horizon system are true (geographic) north and south. However, in this activity students will be using magnetic north and south for orientation for two reasons: it is the simplest procedure and it allows them to determine true north as the culmination of the activity. Just remember, though, that student data using magnetic north and south will not agree with published data based on true north and south.

Advance Planning

Pegboard stands are common in many science classrooms and can be borrowed. Also, hardware or building supply stores might donate damaged, discarded, or even new pegboard.

You may want to ask the industrial arts teacher to let students construct the apparatus as a project.

Determine the hole size of the pegboard you'll be using. Obtain dowels to fit the hole size. Attach the dowels to the circular protractors as shown. Be careful to epoxy the dowel perpendicular to the protractor. If necessary, mark the circular protractors with directions.



Determine the size of pegboard and paper to be used in constructing the apparatus. This will depend on the height of the dowel, the times of day you'll be collecting data, and the time of year. Early and late in the day and during the winter the dowel's shadow will be longest. Collect solar altitude data on the earliest (or latest) time and near the date that you plan to use the activity. Then use simple proportions to determine the best paper and pegboard size, and the best dowel height. (At 42° latitude, for collection of data in January, a 7.6 cm dowel, a 61 x 102 cm pegboard, and a 56 x 97 cm paper were used. The dowel cast its longest shadow of 56 cm at 8:00 A.M.)

Attach strings to the 180° protractors by drilling a small hole directly above the center point, then notching the center point. Knot the string at the hole, then pass it through the notch.

Obtain a cork borer the same size as the pegboard holes. The chemistry lab should have a cork borer.

Duplicate needed quantities of the data table and graphs. If desired, duplicate the teacher background section for use as a student reading.

To reduce the amount of class time spent on the activity, you may want to prepare the apparatus yourself. This will eliminate Steps 1-6 in the activity. Don't forget that a few students can help you with this task outside of class time.

Suggested Time Allotment

One class period to introduce the activity and set up the apparatus

One class period to collect data (repeated by other classes over the course of the school day)

Two to three class periods to copy needed data, plot graphs, answer questions, and discuss results

Suggested Approach

You may want to prepare only one set-up and collect data as a class, or you may want to provide enough set-ups for students to work in small groups. In either case, allow for continuous collection of data by performing the activity with all your classes on the same day. If successive classes are working in small groups, these groups can be numerically assigned to particular set-ups. During lunch, preparatory, and supervisory periods, perhaps you can arrange for a few students to collect data. Think about collecting early morning or late afternoon data yourself and adding them to the class data.

Introduce the activity by discussing why the apparent path of the sun through the sky is important to the proper orientation of solar collectors. Use the teacher background section to explain why the sun only "appears" to move through the sky and what is actually happening. Explain the terms used in the activity.

Help students to prepare the apparatus. You may want to have one set-up already prepared as a model. Show students how to use a level and compass, if necessary. Demonstrate how to use the cork borer.

Demonstrate a sample reading and sample angle measurements to show students how they are done.

Allow time for students to copy the data tables from other classes and to trace the master sheet. You may want to duplicate data tables from each class, to distribute to students.

Help students with graphs and questions, as appropriate. Some questions may be assigned for homework.

Precautions

Remind students that they should never look directly at the sun.

Make sure ahead of time that the paper and pegboard are large enough to plot the early morning and late afternoon points.

Check to be certain that iron and steel objects (including belt buckles) are not in the vicinity of the magnetic compasses.

Be sure to collect data at shorter intervals at midday, or the shortest shadow length (sun's highest position) may not be apparent.

Points for Discussion

Would your results agree with published solar altitude and azimuth data? Why or why not?

Does the sun's apparent rate of motion change over the course of a day? Why or why not?

How would your results change if you corrected your pegboard orientation for magnetic declination?

How could you find true north by using only a straight stick?

Based on the results of this activity, what recommendations would you make for the orientation of a fixed solar collector?

Typical Results

Altitude and azimuth data may vary by several degrees among student groups if they did not set up the apparatus and orient the board carefully.

Morning and afternoon readings will be symmetrical.

Students will be surprised by how fast the shadow moves.

Evaluation

Monitor student preparation of the apparatus. Check how well students are able to follow directions. Assess their skill in making angular measurements.

Check data tables and graphs for completeness and accuracy. How well were students able to answer the questions?

Give students a sample solar position reading and ask them to measure the solar altitude and azimuth.

Quiz students on the relationships they stated in Questions 1-4.

From a sample set of data, ask students to determine when the sun is highest in the sky.

From sample data, ask students to calculate rates of apparent solar motion.

Modifications

Two 180° protractors (or even one, oriented to the north) may be substituted for the circular protractor. Devise a method for orienting the protractors so that all student data will be equivalent.

Other kinds of boards, plywood, or corrugated cardboard may be substituted for the pegboard.

Orient the board according to true north rather than magnetic north.

Use a sextant or astrolabe in conjunction with the altitude measurements.

References

Astronomical Phenomena for the Year ---, United States Naval Observatory and Her Majesty's Nautical Almanac Office.
(Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, contact GPO for price.)

Astronomy, Laurence W. Fredrick and Robert H. Baker.
(Van Nostrand Reinhold Co., Lepi Order Processing, 7625 Empire Dr., Florence, KY 41042, 1976, $20.95.)

The Nautical Almanac for the Year ---, United States Naval Observatory and Her Majesty's Nautical Almanac Office.
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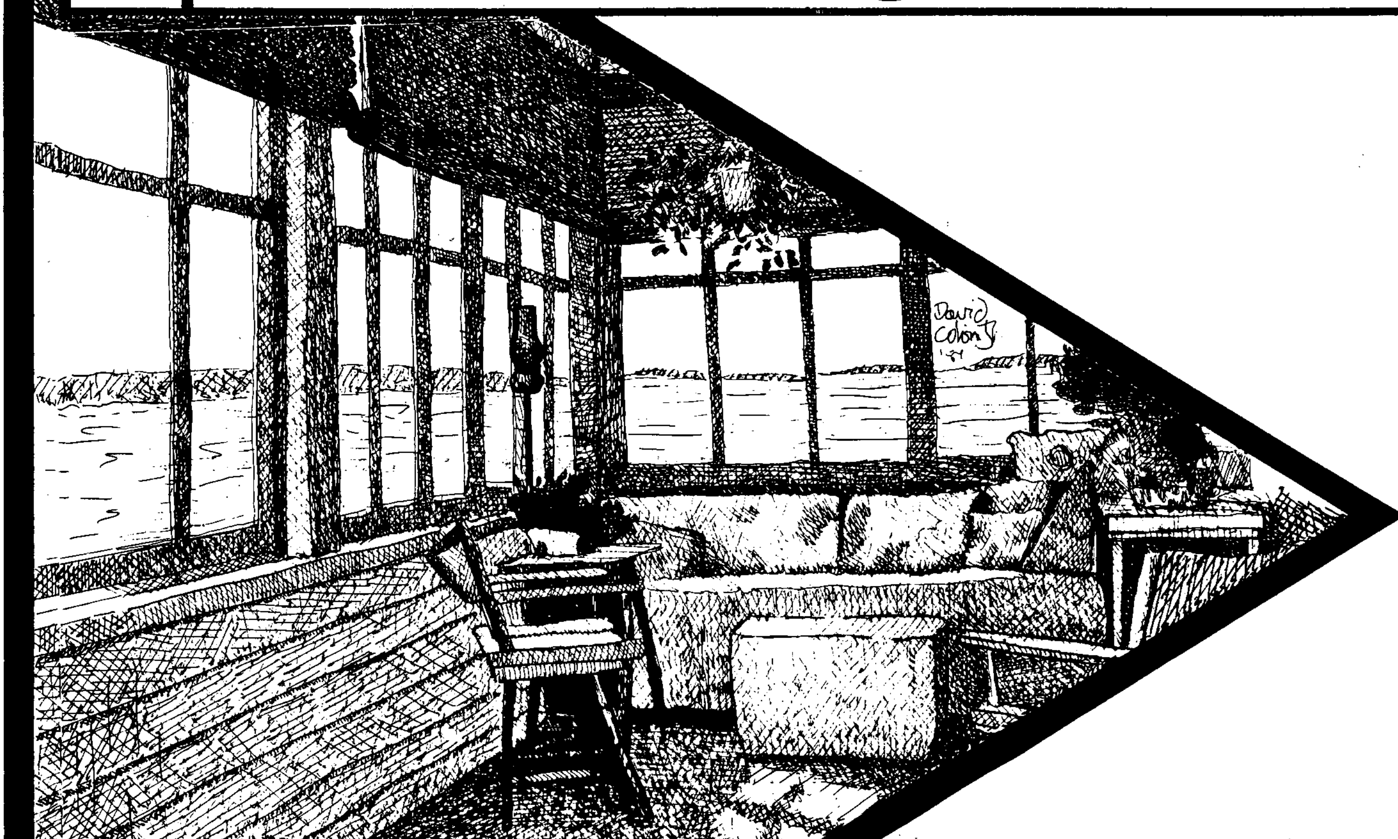
Principles of Astronomy, Stanley Wyatt.
(Allyn & Bacon, Inc., College Division, Rockleigh, NJ 07647, 1977, $19.95.)

4 The Sun's Contribution to Home Heating



Every house, apartment, factory, and building is a solar collector. During an average day, thousands of kilowatts of solar energy fall on a structure. Some energy is absorbed by the walls, and some pours through the windows and heats the space inside.

The amount of heat a house or building gets from sunlight depends on several factors: the number, size, and placement of the windows; the building's orientation; the latitude of the location; and the local weather conditions. All these factors can save you money (or cost you money) in heating bills.

Today buildings and houses are being designed to allow the sun to bear more of the heating load. In this activity you will figure out how much of your own home's heat is supplied by the sun. Then you will calculate how much fuel the sun saves for you.

objectives

At the completion of this activity, you should be able to

- o list the factors which affect the solar heat gain of your home,
- o determine the amount of solar heat gained through the windows of your home during the winter heating season,
- o calculate the quantity and cost of fuel needed to equal this solar gain, and
- o explain the significance of this solar heat gain.

skills and knowledge you need

How to collect and organize data

How to read tables of information

Knowledge of the unit costs of natural gas, electricity, and oil in your area

Knowledge of the geographic latitude of your area

materials

tape measure

compass

calculator

procedure

Data Table 1

1. Take Data Table 1 home with you. Use the compass to determine the number of windows in your home which face each of these directions: north, northeast, east, southeast, south, southwest, west, and northwest. Place these counts in the spaces provided on Data Table 1, Column A. Some spaces will be left blank as your home will probably not have windows facing every one of the directions.

2. Measure the area of each window in square feet. To do this, multiply the length of each window by its width.

   Area = length x width

   Add the areas of the windows facing each direction and record the sums in the spaces provided in

Column B. You should now have a record of the total window area facing each of the directions given in Step 1.

3. Using the set of tables for clear-day solar heat gain, locate the specific table which comes closest to the latitude of your home. Now, for each window orientation, find the daily solar heat gain in Btu/sq. ft. for the months of November, December, January, February, and March. Record these values in Column C of Data Table 1.

   For example, if your home is located closest to 32° North Latitude, then you should refer to that table. The direct solar heat gain for north-facing windows during the month of January would be 152 Btu/sq. ft./day.

4. Next, multiply each daily solar heat gain listed in Column C by the total window area listed in Column B. You will obtain five monthly values for each of the window orientations. Record these values in the spaces provided in Column D.

5. In Column D you have listed the total daily solar heat gain for each orientation during each month. To convert to monthly solar heat gains, multiply each of the values in Column D by the appropriate number of days for the month specified. Record these findings in Column E.

6. To determine the solar heat gain throughout the winter months for the windows facing each direction, add the monthly values listed in Column E for each orientation and place the totals in Column F.

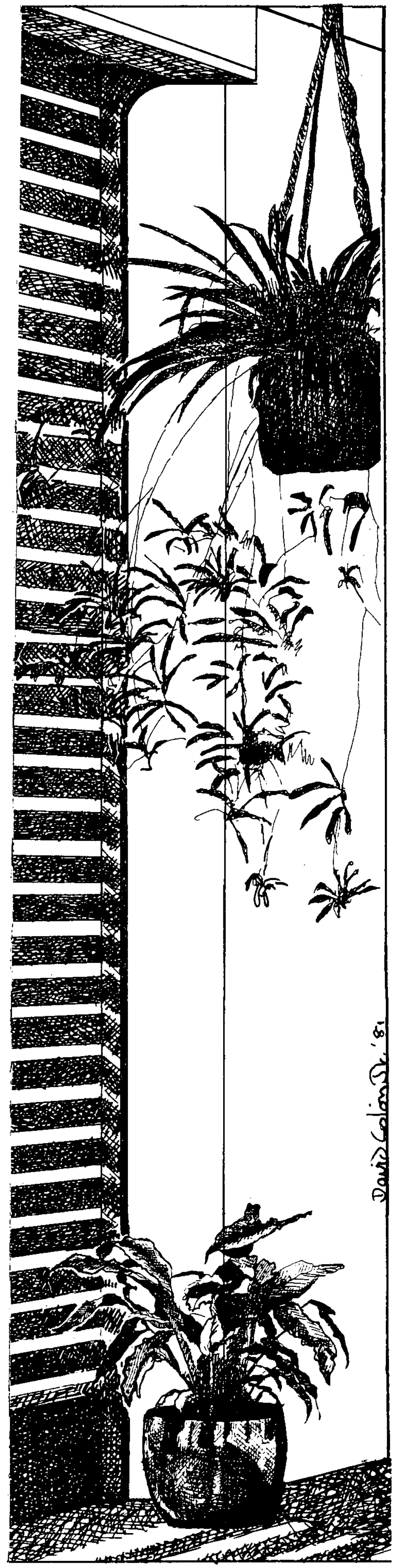
7. To obtain the total solar heat gain of your home throughout the winter months, add the recorded values of Column F and place this total at the bottom of Column F.

Data Table 2

8. Transfer the total heat gain to Column A of Data Table 2.

9. The heat contents of natural gas, oil, and electricity are provided below.

Fuel		Heat Content
1 cubic foot natural gas	=	750 Btu (75% burner efficiency)
1 gallon oil	=	89,700 Btu (65% burner efficiency)
1 kilowatt-hour electricity	=	3,413 Btu



Calculate how much natural gas, oil, and electricity would be necessary to supply an amount of heat equal to the solar heat gain through your windows during the winter.

To do this, divide the number of Btu provided through solar heat gain by the number of Btu in each fuel unit.

$$\text{Heat Equivalent (Units of Fuel)} = \frac{\text{Btu of Solar Heat Gain}}{\text{Btu/Unit of Fuel}}$$

Enter these values under Column B.

10. Using the current fuel costs/unit in your area for natural gas, oil, and electricity, compute the costs of the quantities of the fuels determined in Step 9.

$$\text{Cost} = \text{Quantity} \times \text{Cost/Unit}$$

Record these costs under Column C.

questions

1. Which window orientation receives the greatest solar heat gain during the winter months?
2. Why do those windows (Question 1) gain the most heat?
3. What fuel is used for heating your home? How much more would it cost to heat your home, November through March, if there were no solar energy entering the windows of your home?
4. Do you feel that this saving is significant? Why?
5. Look at the title of the set of solar gain tables. For what conditions have you calculated direct solar heat gain? How is your own situation different? Should you revise your calculations? (To do so, see "Going Further.")

looking back

Were you surprised to see how much heat your home gets through its windows from the sun? A lot depends on conditions, however. Notice that your calculations were based on a clear day and a house with double-glazed windows. Cloudy weather, single- or triple-glazed windows, or obstructions in front of the windows can make a big difference.

Of course, while heat may be coming in the windows, it's also going out the walls, ceilings, and floors. That is why fuel is still necessary to heat our houses, and why conservation is so important. Insulating the house and covering windows at night can help to keep the heat in and let the sun do a larger share of heating your home.

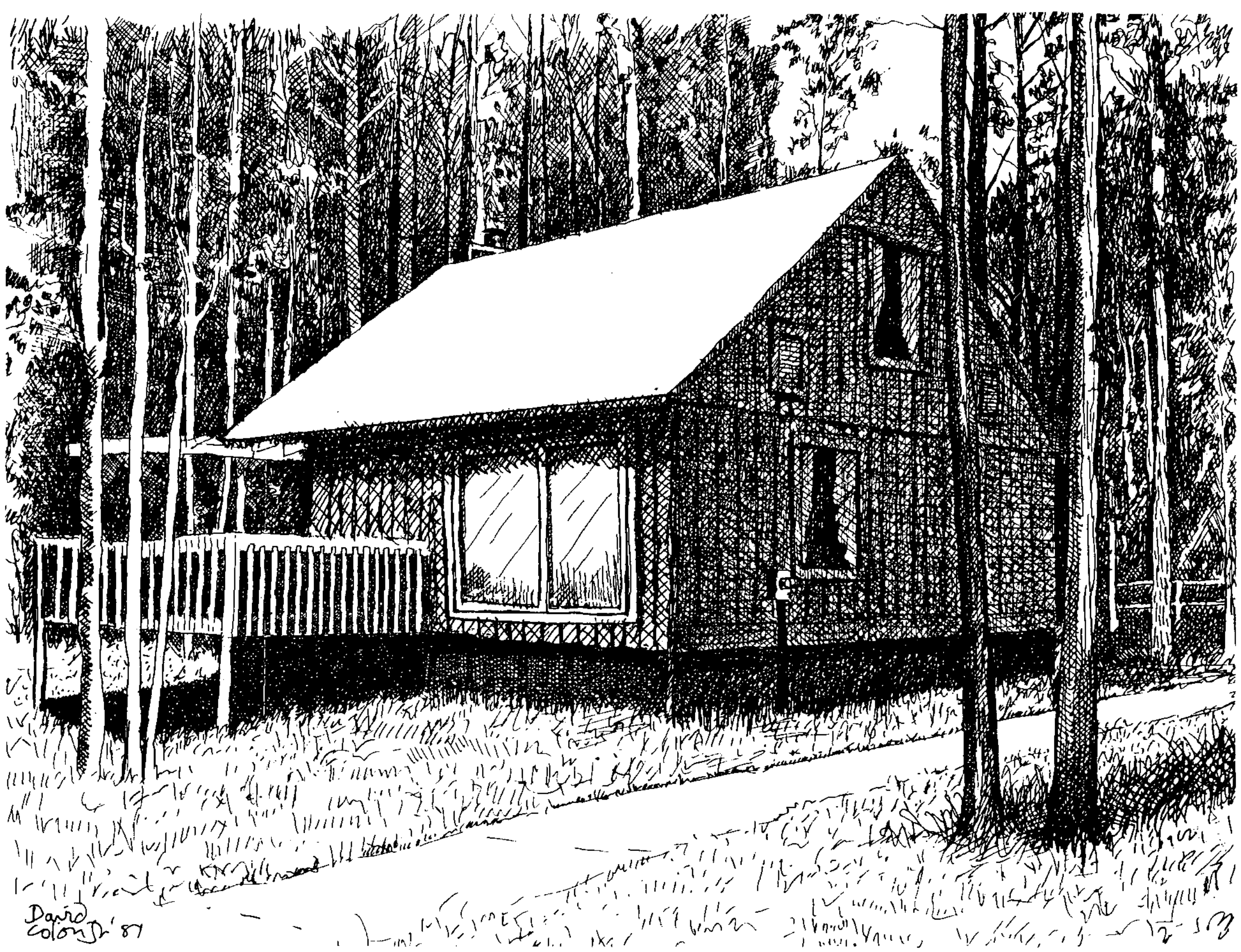
going further

Heat losses through windows are about 12 Btu per square foot per day per ^{o}F for double-glazed windows, and 24 for single-glazed. Finding the total window area of your home and the number of heating degree-days for the months of November, December, January, February, and March will allow you to estimate the windows' heat losses and to compare this value with the solar heat gain.

Find the average percentage of sunshine in your area for the winter months. Sources for this information might include the National Weather Service or your local weather station. Multiply this percentage by the total solar heat gain from Data Table 2. This will give you a more accurate estimate of the heat gain through your home's windows. Recalculate the costs of providing an equivalent amount of heat. Is the saving considerably less?

Arrange to visit a local passive solar house to see how the effectiveness of solar heat gain is increased. Report on your findings.

Invite an architect or building contractor to speak to the class about passive solar heating. Use the results of this activity to develop questions for the person to answer.



Data Table 1

	A	B	C	D	E	F
Window Orientation	Number of Windows	Total Window Area (sq.ft.)	Daily Solar Heat Gain (Btu/sq.ft.)	Total Daily Heat Gain (Btu)	Total Monthly Heat Gain (Btu)	Winter Heat Gain for Each Window Orientation
North			Nov Dec Jan Feb Mar	Nov (x30) Dec (x31) Jan (x31) Feb (x28) Mar (x31)	Nov Dec Jan Feb Mar	Btu
Northeast			Nov Dec Jan Feb Mar	Nov (x30) Dec (x31) Jan (x31) Feb (x28) Mar (x31)	Nov Dec Jan Feb Mar	Btu
East			Nov Dec Jan Feb Mar	Nov (x30) Dec (x31) Jan (x31) Feb (x28) Mar (x31)	Nov Dec Jan Feb Mar	Btu
Southeast			Nov Dec Jan Feb Mar	Nov (x30) Dec (x31) Jan (x31) Feb (x28) Mar (x31)	Nov Dec Jan Feb Mar	Btu
South			Nov Dec Jan Feb Mar	Nov (x30) Dec (x31) Jan (x31) Feb (x28) Mar (x31)	Nov Dec Jan Feb Mar	Btu
Southwest			Nov Dec Jan Feb Mar	Nov (x30) Dec (x31) Jan (x31) Feb (x28) Mar (x31)	Nov Dec Jan Feb Mar	Btu
West			Nov Dec Jan Feb Mar	Nov (x30) Dec (x31) Jan (x31) Feb (x28) Mar (x31)	Nov Dec Jan Feb Mar	Btu
Northwest			Nov Dec Jan Feb Mar	Nov (x30) Dec (x31) Jan (x31) Feb (x28) Mar (x31)	Nov Dec Jan Feb Mar	Btu

Latitude = ____________________

____________________ Btu

Data Table 2

A	B	C
Total Passive Solar Heat Gain	Heat Equivalent	Cost of Heat Equivalent
________ Btu	Cubic feet of natural gas ________ cubic feet Gallons of oil ________ gallons Kilowatt-hours of electricity ________ kWh	Natural gas @ _____/cubic foot $________ Fuel oil @ _____/gallon $________ Electricity @ _____/kWh $________

Solar Heat Gain Tables

Clear-Day Solar Heat Gain Through Double-Glazed Windows at Various Orientations
(in Btu/sq.ft.)

28° North Latitude

	N	NE, NW	E, W	SE, SW	S	HORIZ
January	168	192	634	1172	1558	1454
February	206	310	816	1191	1350	1832
March	248	464	923	1074	912	2184
April	306	658	989	893	492	2428
May	402	809	1023	758	368	2576
June	464	861	1019	695	360	2610
July	416	808	1006	741	372	2494
August	324	656	961	862	482	2386
September	260	456	883	1029	884	2110
October	214	311	788	1143	1296	1796
November	170	194	625	1151	1526	1444
December	152	162	564	1151	1586	1306

32° North Latitude

	N	NE, NW	E, W	SE, SW	S	HORIZ
January	152	166	574	1146	1560	1288
February	192	278	772	1200	1424	1688
March	240	433	904	1116	1034	2084
April	302	636	997	955	600	2390
May	396	789	1040	823	422	2582
June	450	841	1038	758	390	2634
July	408	789	1024	803	420	2558
August	320	636	968	920	582	2352
September	250	426	864	1067	1000	2014
October	200	280	746	1151	1364	1654
November	154	168	567	1125	1528	1280
December	136	144	518	1128	1574	1136

36° North Latitude

	N	NE, NW	E, W	SE, SW	S	HORIZ
January	136	147	528	1123	1550	1120
February	178	247	722	1197	1474	1534
March	230	404	882	1153	1146	1974
April	298	615	1002	1016	720	2338
May	390	769	1054	888	500	2574
June	442	822	1056	823	446	2644
July	402	768	1037	867	492	2552
August	318	616	973	978	694	2304
September	242	399	842	1100	1102	1906
October	186	250	697	1147	1410	1506
November	140	150	522	1101	1516	1114
December	120	125	463	1083	1526	960

40° North Latitude

	N	NE, NW	E, W	SE, SW	S	HORIZ
January	120	128	474	1079	1506	948
February	164	215	666	1180	1502	1374
March	220	376	858	1183	1244	1852
April	294	593	1002	1075	838	2274
May	384	747	1063	952	598	2552
June	446	816	1083	894	528	2648
July	398	749	1048	931	586	2534
August	312	595	975	1034	806	2244
September	230	370	816	1126	1190	1796
October	170	218	642	1129	1436	1348
November	122	130	466	1056	1472	942
December	102	105	393	1007	1434	782

44° North Latitude

	N	NE, NW	E, W	SE, SW	S	HORIZ
January	102	107	405	1004	1420	772
February	148	183	603	1148	1506	1208
March	208	347	829	1206	1324	1720
April	288	572	1000	1128	954	2196
May	386	738	1081	1021	710	2522
June	458	819	1116	968	628	2642
July	400	741	1067	999	694	2508
August	308	575	972	1085	916	2172
September	218	343	787	1144	1262	1660
October	154	187	582	1098	1438	1186
November	104	109	399	983	1388	768
December	82	83	307	895	1292	608

48° North Latitude

	N	NE, NW	E, W	SE, SW	S	HORIZ
January	82	84	320	894	1284	598
February	130	153	540	1106	1486	1040
March	194	318	795	1218	1386	1578
April	280	551	994	1177	1060	2106
May	394	736	1105	1091	828	2482
June	468	820	1144	1042	740	2626
July	408	741	1092	1068	806	2474
August	300	553	965	1131	1018	2088
September	206	315	753	1151	1318	1522
October	138	159	523	1056	1414	1022
November	86	87	317	875	1252	596
December	66	66	237	777	1130	446

52° North Latitude

	N	NE, NW	E, W	SE, SW	S	HORIZ
January	64	64	240	767	1112	434
February	114	131	485	1057	1442	870
March	180	290	757	1220	1430	1428
April	270	528	984	1219	1156	2006
May	400	736	1127	1159	942	2434
June	472	817	1167	1113	856	2596
July	416	741	1114	1134	920	2430
August	290	532	956	1171	1108	1990
September	190	286	714	1148	1352	1374
October	120	136	466	1005	1368	856
November	66	66	237	749	1084	434
December	46	46	166	631	918	294

56° North Latitude

	N	NE, NW	E, W	SE, SW	S	HORIZ
January	46	46	170	620	900	282
February	96	109	420	982	1358	700
March	166	261	714	1207	1452	1268
April	260	506	970	1254	1240	1892
May	406	735	1144	1221	1052	2374
June	494	830	1199	1183	972	2562
July	420	739	1130	1195	1026	2372
August	280	511	943	1204	1188	1884
September	176	258	670	1130	1364	1220
October	102	113	403	930	1282	688
November	48	48	168	603	876	284
December	24	24	86	428	622	156

SOURCE: Taken from computer studies by M. Steven Baker, University of Oregon, Eugene, Oregon, 1977.

Teacher Information

The Sun's Contribution to Home Heating

Suggested Grade Level and Discipline

Science, grades 7-10
General Science
Physics
Earth Science

Skill Objectives

Measuring area

Reading tables and collecting and organizing data

Calculating solar heat gain

Converting heat measurements into equivalent quantities of gas, oil, and electricity

Major Understandings

All buildings experience passive solar heating.

The amount of solar heat gain depends upon such factors as latitude, size and orientation of windows, and season of the year.

The quantity of heat provided by passive solar energy is significant and can be equated to amounts of natural gas, oil, and electricity.

Solar heat gain can be influenced by degree of cloud cover, type of window glazing, and shading of windows by obstructions.

Passive solar heat gain cannot be considered in isolation, for uncovered windows contribute to home heat loss during cloudy periods and at night.

Background

In this activity students are asked to look at one specific aspect of passive solar heating, the amount of heat gained from the transmission of sunlight through their homes' windows. While they will discover that a significant amount of heat enters a home in this manner during the winter months, it should be stressed that their calculations are assuming optimal conditions and that the final pattern of heat gain will depend on many additional variables. Modifying their homes into more effective passive solar collectors would entail the addition of insulation, weather stripping, thermal window coverings, attached greenhouses, thermal storage systems, and/or several other features.

The heat equivalents in the student activity are given in Btu because the Btu remains the standard unit for engineering work and for rating heating systems. If you prefer to have students work in metric units, use these equivalents.

1 Btu	=	.252 kilocalories
1 CF natural gas	=	189 kilocalories (75% burner efficiency)
1 gal. fuel oil	=	22,604.4 kilocalories (65% burner efficiency)
1 kWh electricity	=	860.1 kilocalories

The burner efficiencies are assumptions based on various reported averages.

Advance Planning

Obtain the current unit prices for fuel oil, natural gas, and electricity in your locality.

For students working on the "Going Further," obtain heating degree-day data for the months of November, December, January, February, and March. Also obtain data on percentage of winter sunshine for your locality.

Have copies of Data Tables 1 and 2 and the set of solar gain tables prepared for every member of the class, even if students share other sheets in groups.

If you are unable to supply a tape measure and inexpensive compass yourself, indicate well ahead of the activity that students will need these items for their home measurements.

Suggested Time Allotment

One class period to introduce students to the activity and give directions for home measurements

One evening for students to take measurements of their windows' surface areas and orientations

One class period for students to complete Data Tables 1 and 2 using their collected data

One class period to discuss results and answer questions

Suggested Approach

Introduce the concept that every home is a passive solar energy collector. Encourage students to debate the validity of this concept.

Work through a sample orientation to show students how the solar gain values are calculated.

Direct each student to complete Procedures 1 and 2 for homework. On the following day, provide supervised time for completing Data Tables 1 and 2. Check to make sure students are following the procedures correctly and in sequence.

Use a follow-up period to discuss students' findings and their answers to the questions.

You may want to introduce and use the concept of scientific notation in determining solar heat gain values.

Precautions

Students should be cautioned to take care when measuring the dimensions of windows far above the floors of their homes. All measurements should be taken inside.

Students' homes will not have windows facing every one of the eight directions listed. Assure students that some portions of Data Table 1 can therefore be left blank without affecting the final results.

Points for Discussion

Does the passive heat gain of your home significantly reduce the quantity of fuel required for space heating?

In what ways might you increase the level of solar heat gain in your home?

Why is passive heat gain insufficient for maintaining the indoor temperature of your home at a constant and comfortable level?

Typical Results

An average home uses about 121 million Btu for heating each year. A typical 2-bedroom ranch having a southern exposure for most of its windows and located at 42° latitude has an optimal solar heat gain of almost 19 million Btu for the heating season. A 4-bedroom Cape Cod in the same area, again with a southern exposure, has a heat gain of 31.7 million Btu.

Students will find that passive solar heating provides an amount of energy equivalent to tens of thousands of cubic feet of natural gas, hundreds of gallons of fuel oil, and thousands of kilowatt-hours of electricity. Specific results will vary greatly because of the diversity of housing designs.

Evaluation

Inspect Data Tables 1 and 2 for accuracy and completeness.

Ask students to list the factors which influence solar heat gain.

Ask students to explain how solar heat gain can provide savings in fuel costs.

Modifications

This entire activity could be assigned as a student project.

Students might enjoy determining solar heat gain for their classroom or school in addition to their homes.

References

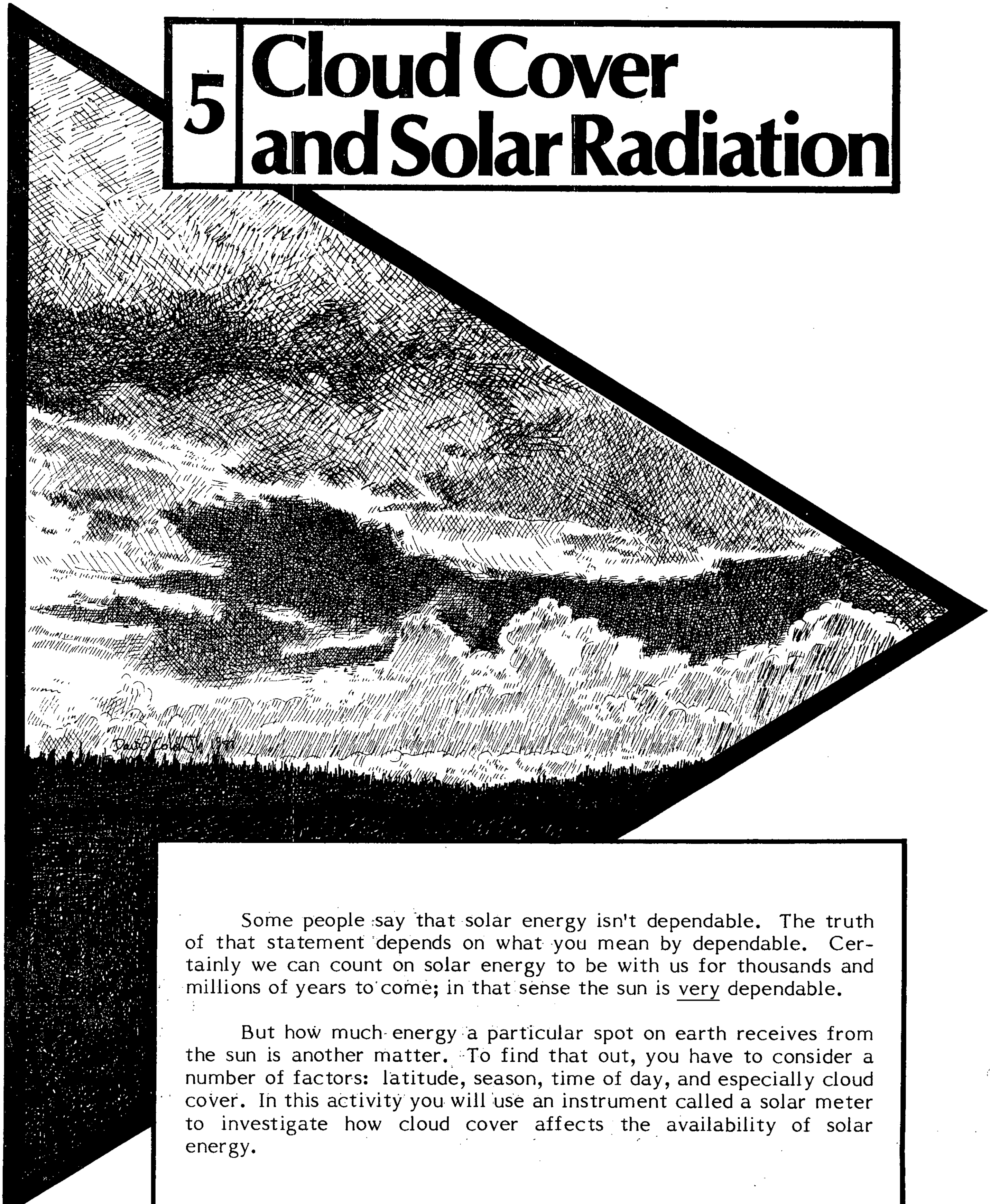
1979 NYSERDA Passive Solar Design Awards.
(New York State Energy Research and Development Authority, Technology Transfer, Rockefeller Plaza, Albany, NY 12223, 1980, $7.00/paper.)

The Passive Solar Energy Book, Edward Mazria.
(Rodale Press, Inc., 33 E. Minor St., Emmaus, PA 18049, 1979, $12.95/paper.)

Solar Energy Adult Education: Curriculum and Resources for Programs in Solar Energy and Conservation, John K. Pearce and Jerome B. Skapof.
(Northeast Solar Energy Center, 470 Atlantic Avenue, Boston, MA 02110, 1980, contact NESEC for price.)

Southern Solar Homes: A Planbook of Energy Efficient Designs for the Southern U.S.
(Southern Solar Energy Center, 61 Perimeter Park, Atlanta, GA 30341, 1980, contact SSEC for price.)

5 Cloud Cover and Solar Radiation



Some people say that solar energy isn't dependable. The truth of that statement depends on what you mean by dependable. Certainly we can count on solar energy to be with us for thousands and millions of years to come; in that sense the sun is <u>very</u> dependable.

But how much energy a particular spot on earth receives from the sun is another matter. To find that out, you have to consider a number of factors: latitude, season, time of day, and especially cloud cover. In this activity you will use an instrument called a solar meter to investigate how cloud cover affects the availability of solar energy.

objectives

At the completion of this activity, you should be able to

- o operate and explain the purpose of a solar meter,
- o state the relationship between cloud cover and the amount of solar radiation received at the earth's surface, and
- o explain how the annual percentage of cloudy days in an area would affect the use of solar energy.

skills and knowledge you need

Reading a meter accurately

Estimating cloud cover

Recording and graphing data

Calculating percentages and averages

Reading maps with isolines

materials

a solar meter

procedure

Caution: Treat the solar meter carefully. The solar cell is extremely fragile.

1. Carefully read and then follow these directions for using the solar meter.

   a. Take all measurements outdoors at a location away from shadows and away from bright objects which might reflect sunlight onto the solar meter.

Caution: Never look directly at the sun. Permanent eye damage can result.

   b. Hold the solar meter at a comfortable height.

   c. Be careful not to let your shadow block any sunlight.

   d. Aim the solar cell of the meter directly at the sun. Move the instrument slightly in all directions to be sure that the cell is receiving the maximum energy possible.

2. Read the maximum value of the solar meter and at the same time observe the sky conditions.

3. Record the meter reading in the appropriate space on the data table.

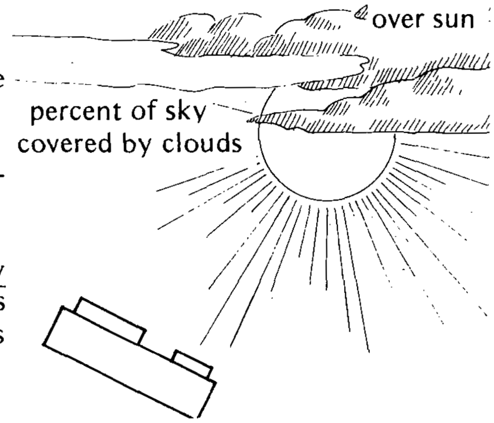
4. Record the following information on sky conditions in the appropriate spaces on the data table.

   a. Approximate percentage of sky covered by clouds. Use one of the following percentages to estimate the portion of total sky that is covered by clouds:

      0% 10% 25% 50% 75% 100%

   b. Cloud cover conditions over the sun. Use one of the following phrases to describe the cloud cover directly over the sun:

      - clear
      - thin cloud cover over the sun
      - cloud edge over the sun
      - heavy cloud over the sun



5. Repeat Steps 2 to 4 at 5-minute intervals for as long as possible. Remember to follow the directions in Step 1.

6. Use Graph 1 to plot the solar meter reading vs. time.

7. Use Graph 2 to plot percentage of sky covered by clouds vs. time.

8. Use Graph 3 to plot cloud cover conditions over the sun vs. time.

questions

1. What was the purpose of the solar meter as you used it in this activity?

2. What is the relationship between the amount of solar radiation striking a solar cell and the reading shown on the solar meter?

3. a. What was the maximum reading you recorded? b. What were the cloud cover conditions over the sun at the time of this reading?

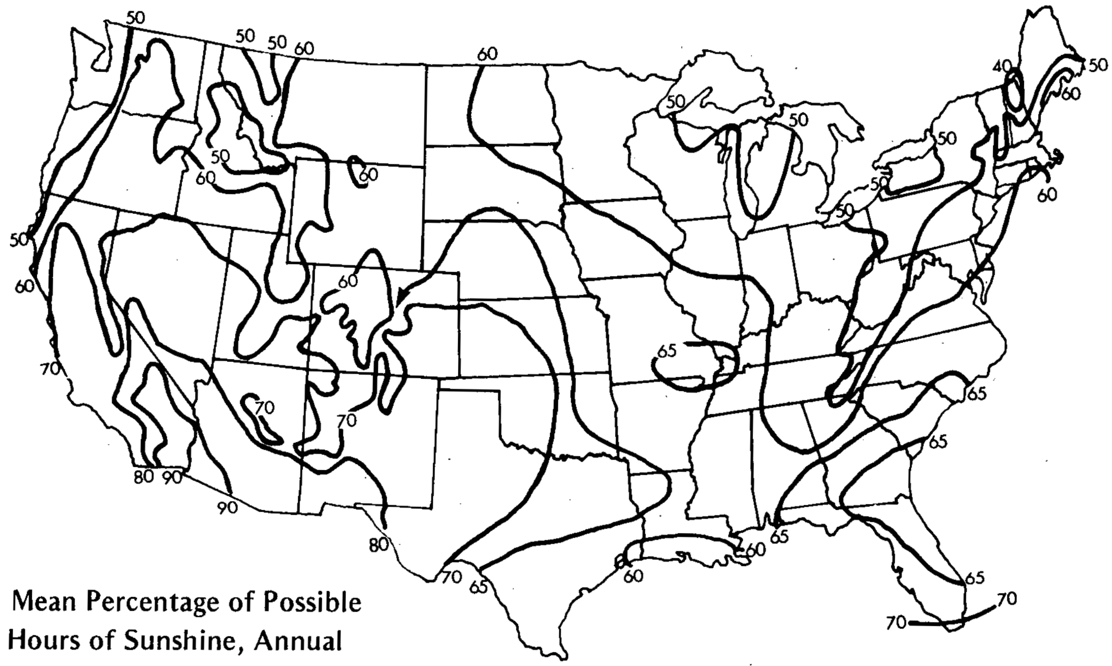
4. a. What was the minimum reading you recorded? b. What were the cloud cover conditions over the sun at the time of this reading?

5. Examine your graphs and your answers to Questions 3 and 4. What seems to be the relationship between cloud cover conditions over the sun and the amount of solar radiation received at the earth's surface?

6. What percentage of the time was the sun clear of clouds? Use Graph 3 and the following equation to determine your answer. Show all work.

$$\text{Percentage of time the sun was clear of clouds} = \frac{\text{Number of times sun was clear of clouds}}{\text{Total number of readings}} \times 100$$

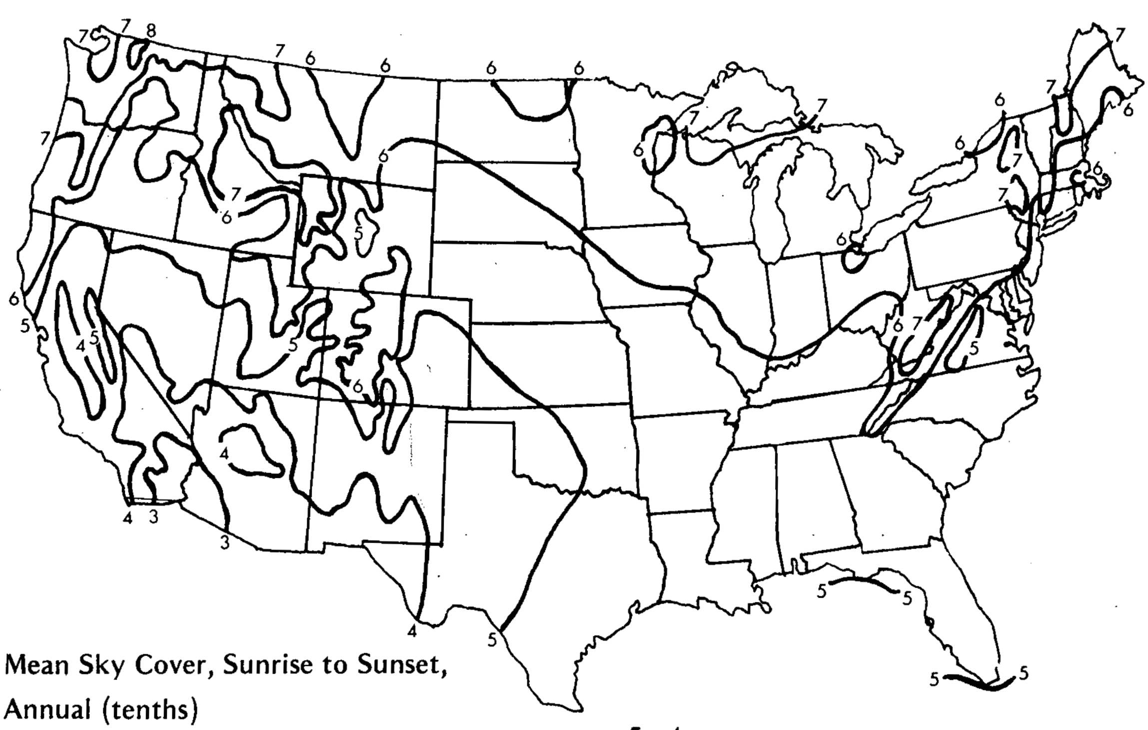
7. Look at the map below. How does your answer to Question 6 compare to the annual average percentage of sunshine for your area?



Mean Percentage of Possible Hours of Sunshine, Annual

8. Find the average percentage of cloud cover by averaging the percentages in Graph 2.

9. Look at the map below. How does your answer to Question 8 compare to the annual average percentage of cloud cover for your area?



Mean Sky Cover, Sunrise to Sunset, Annual (tenths)

10. How would the annual percentage of cloud cover in an area affect the use of solar energy?

looking back

Cloud cover is an important factor in determining how much solar radiation you can depend on in your area. In this activity you graphed the relationship between cloud cover and available radiation. If you did this over an extended period of time, you could determine seasonal and annual averages for cloud cover in your area. Then you could calculate how dependable the sun would be as an energy source for you.

going further

To obtain more valid data for your locality, continue to take solar meter readings over many days or weeks. Choose a few times a day to take readings, perhaps early morning, noon, and early evening. Graph results and determine average percentage of direct sunlight over time.

To obtain data for an even longer period, record just the average cloud conditions every day. Determine the percentage of clear days in your area. How does the percentage you obtained compare to published data for your area?

Write to the National Weather Service or to your local weather station to obtain information on the percentage of cloudy days in your area.

Take solar meter readings from early morning to late afternoon. How does the time of day affect the amount of solar radiation striking the earth's surface?

Find out how the season of the year affects cloud conditions in your area.

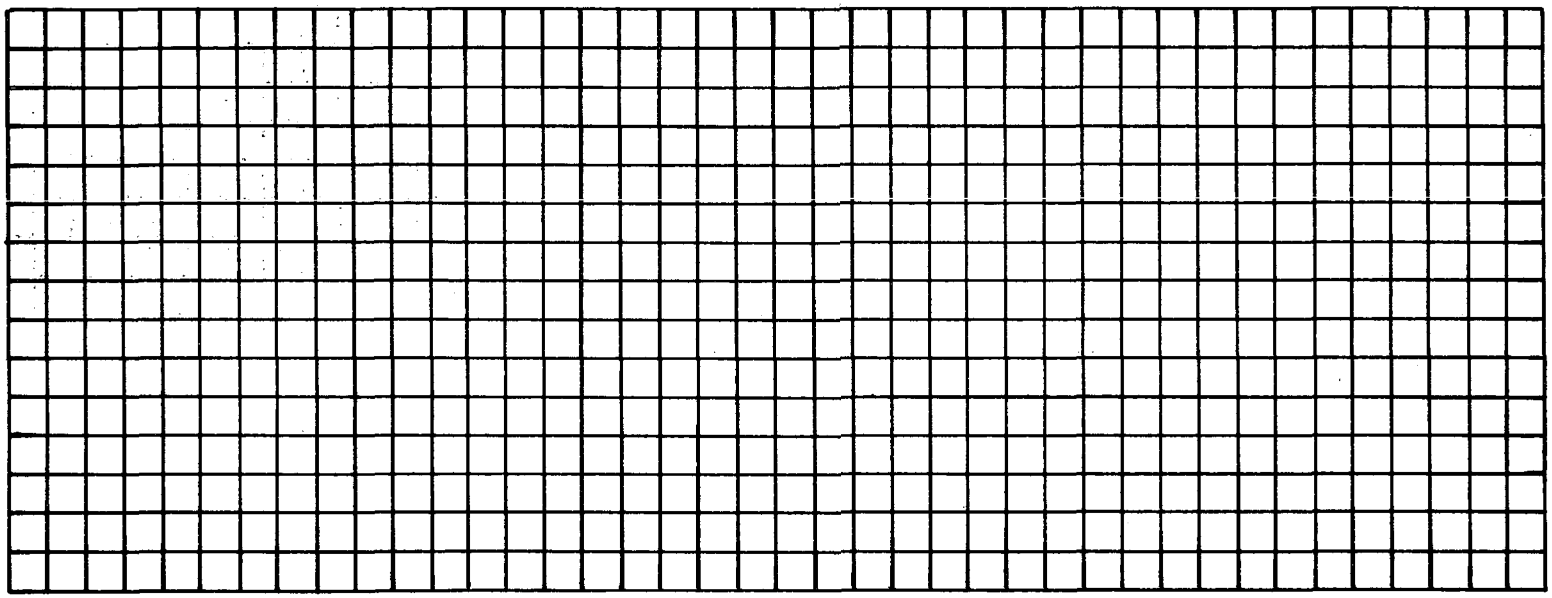
Do research to find out the minimum amounts of sunlight needed for effective use of solar energy, either in terms of intensity of available solar radiation or in terms of yearly averages of solar radiation.

Data Table

Time (minutes)	Solar Meter Reading	Percentage of Sky Covered by Clouds	Cloud Cover Conditions over Sun
0			
5			
10			
15			
20			
25			
30			
35			
40			

Graph 1
Solar Meter Reading

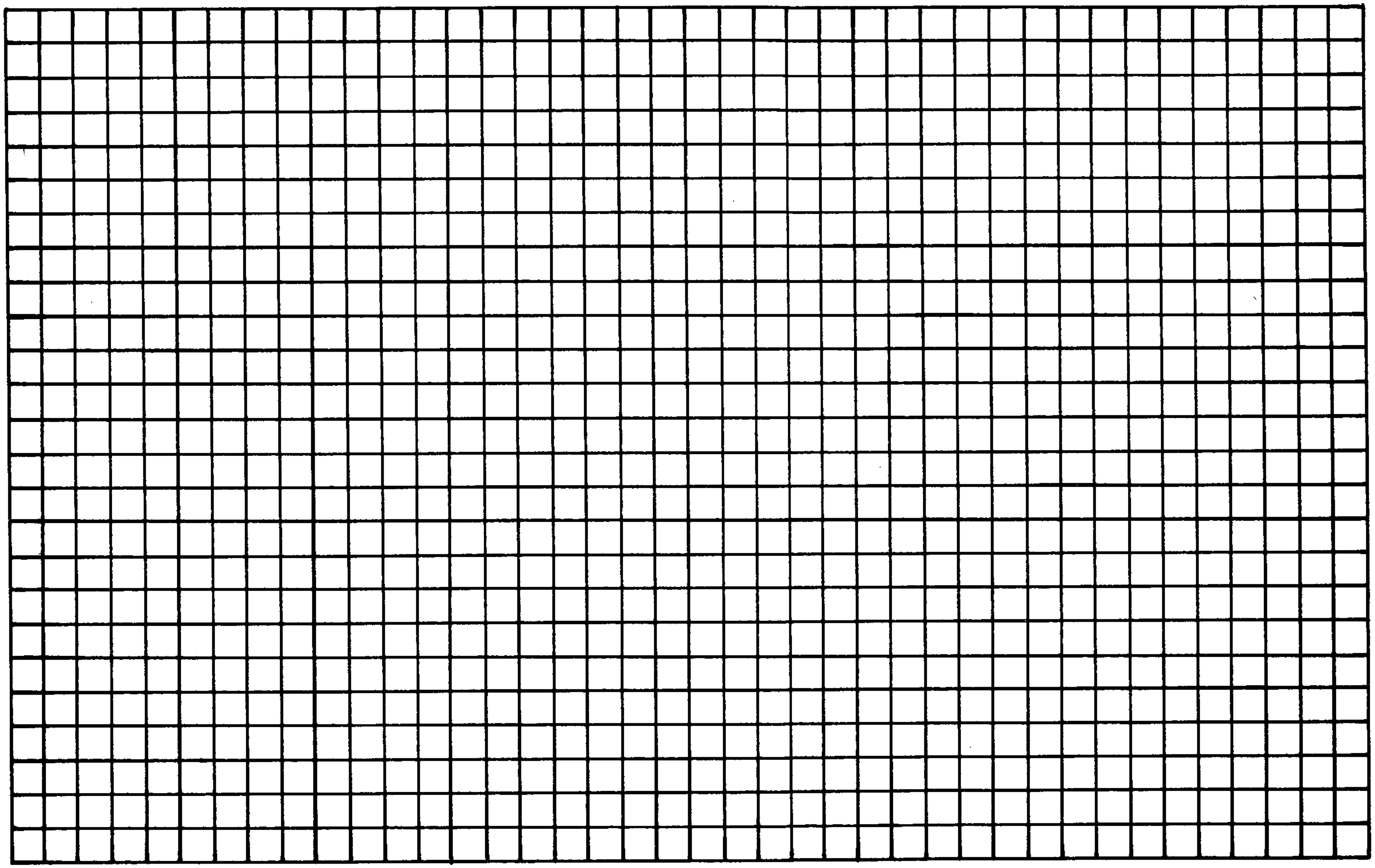
Solar Meter Reading



Time (minutes)

Graph 2
Percentage of Sky Covered by Clouds

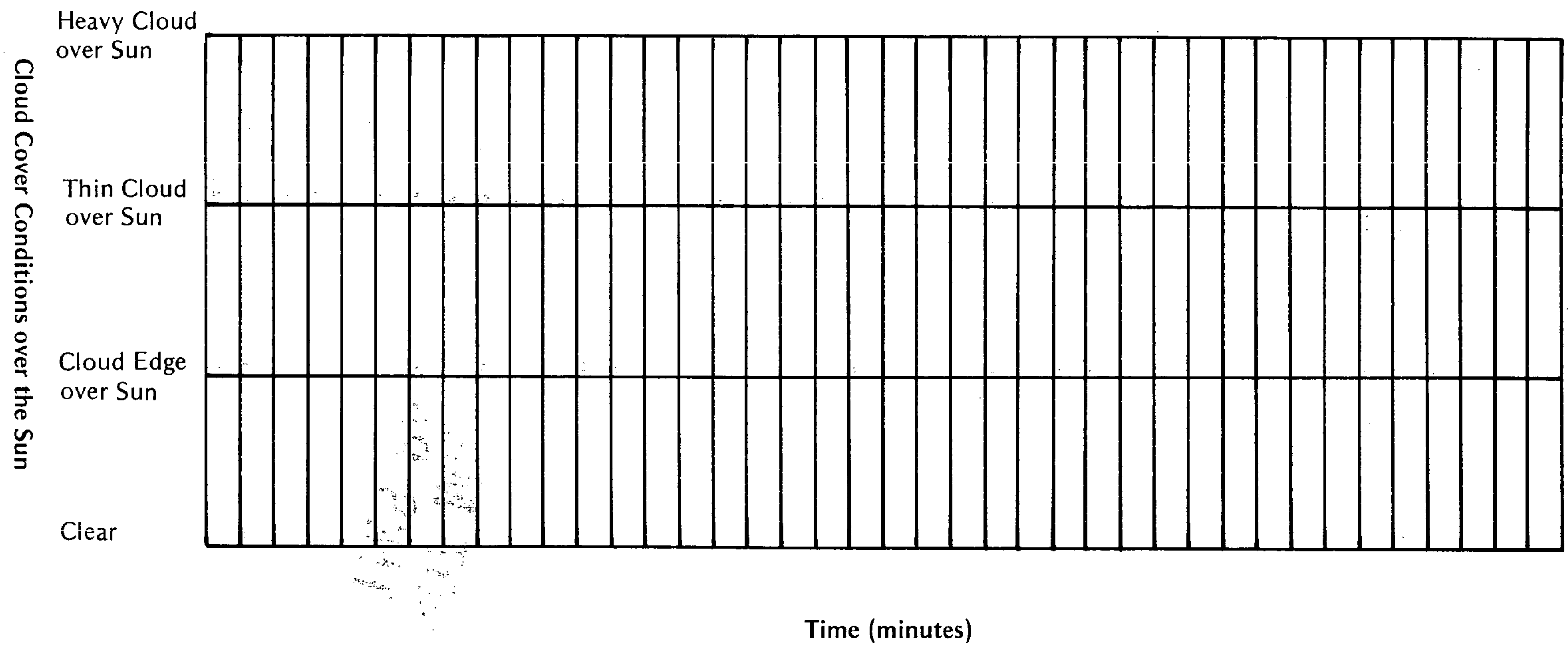
Percentage of Sky Covered by Clouds



Time (minutes)

Graph 3

Cloud Cover Conditions over the Sun



Teacher Information

Cloud Cover and Solar Radiation

Suggested Grade Level and Discipline

General Science, grades 7-9

Earth Science

Outdoor Education

Skill Objectives

Using a solar meter

Observing and estimating cloud cover

Collecting, graphing, inferring from, and interpreting data

Calculating percentages and averages

Major Understandings

A solar meter records the intensity of solar radiation at a particular spot.

As the thickness of the cloud layer over the sun increases, the amount of solar radiation incident on a surface decreases.

Calculating the percentage of time the sun is clear of clouds can, over the long term, serve as a measure of available incident solar radiation at a particular site.

The percentage of clear or cloudy days at a particular site will determine which systems of solar collection will be cost effective and will affect the choice of a particular method of collection. In areas with extremely cloudy weather, solar collection systems may never become cost effective.

Background

Solar radiation is the sum of all the electromagnetic radiation emitted by the sun as the result of thermonuclear fusion reactions in its core. This radiation is usually measured in langleys/minute (one langley = 1 cal/cm^2), watts/m^2, or Btu/ft.^{2} /hr. The intensity of the solar radiation on a particular surface varies with many factors, including latitude, season of the year, time of day, cloud conditions, and air pollution.

A photovoltaic or solar cell measures the intensity of solar radiation. It is a thin disc or rectangle composed of two layers of a semi-conductor, usually silicon, "doped" with arsenic for the negative N-layer and with boron for the positive P-layer. When light strikes these layers, its energy knocks electrons loose. Electrons flow through connecting wires, creating an electric current.

This electric current, read from the meter attached to the cell, varies directly with the intensity of the solar radiation striking the cell's surface. In this activity, students examine the effect of cloud cover on the amount of solar radiation received at a particular site. The amount of cloud cover over time is of particular interest to those who are considering installing solar energy systems for space heating, hot water, or electricity. The amount of cloud cover will determine whether these systems will be cost effective when compared to fossil fuels, and which of the systems will be best in a particular location. Flat plate collectors, for example, will function under both direct and diffuse radiation and so will provide heat even under somewhat cloudy conditions. Concentrating collectors, however, need direct radiation to provide heating. So percentages of sunshine and cloud cover are important factors to consider in selecting solar systems. They are also important to consider in determining the size and number of collectors to be used in the system. Cloudy areas may need more square feet of collector space to provide the same amount of heat as sunnier areas. At least one factor in sizing thermal mass in passive systems is the amount of storage needed to provide heat during extended cloudy periods. Knowing that your area may have a mean annual cloud cover of six tenths of the sky, for example, will tell you much about choosing and sizing a solar system.

The maps in the student section, taken from the Climatic Atlas of the United States, show the mean annual percentage of sunshine and the mean annual amount of cloud cover (over a day) for the United States. Monthly means are also given in the atlas.

Advance Planning

This activity should be performed only on a variably cloudy day. Otherwise, the data collected will be too uniform in nature. Continue with other class activities as you wait for the proper day.

Duplicate class quantities of the data tables and graphs. If appropriate, also duplicate the teacher background information for student use.

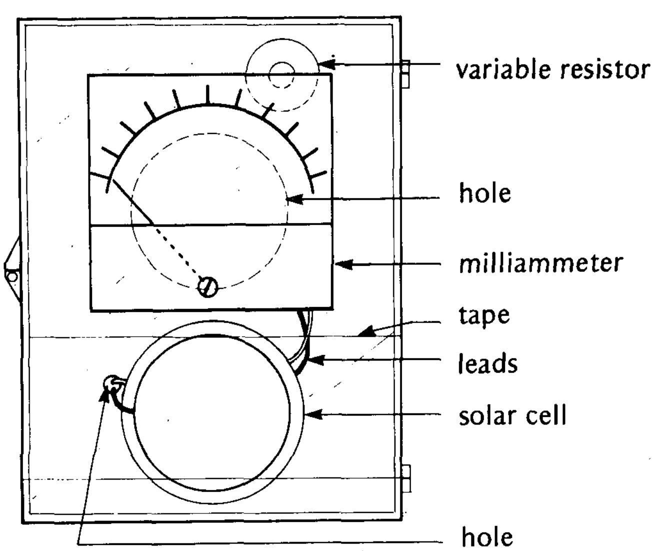
Determine a suitable area of the school grounds for performing the activity.

If your school does not have pyranometers or other solar meters, they can be made easily by wiring together a solar cell, a shunt resistor, and a milliammeter, as indicated in the directions below. Although the complete directions are for a self-contained and permanent instrument, don't forget that you can simplify them according to your own needs.

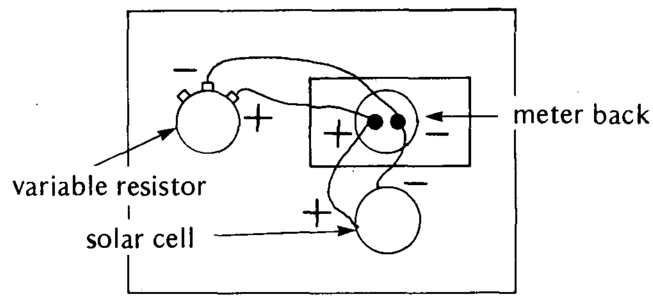
Building the Solar Meter

Materials

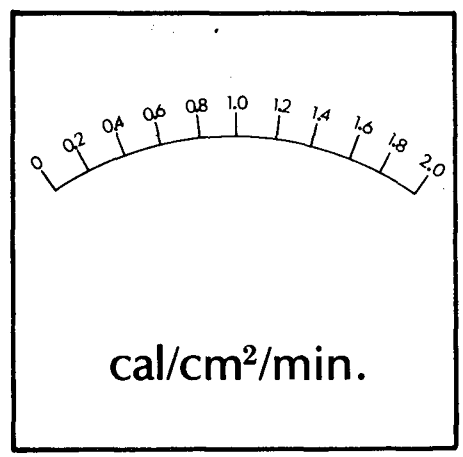
photovoltaic cell (at least 1 cm^2)
milliammeter (Radio Shack #270-1752, 0-1 mA)
variable resistor (0-1000 ohm potentiometer)
plastic case (about 9 x 12 cm with clear plastic top)
wire



1. Cut two holes in the top of the plastic case, one to hold the back of the meter and the other to carry the solar cell wires into the case.
2. If the solar cell does not have presoldered wire leads, carefully solder a lead to either side.
3. Use transparent tape to attach the solar cell to the front of the plastic case. This tape will also protect the solar cell.
4. Insert the meter into the hole cut for it and glue into place.
5. Attach the solar cell to the milliammeter. Connect the variable resistor in parallel with the meter. Solder the leads if necessary.



6. Remove the cover from the meter face. Place the scale provided (calibrated in $cal/cm^2/min.$) over the original meter face or develop one of your own according to the conversion formulas given below. Replace the cover.



Conversion Factors

To convert	to	multiply by
$cal/cm^2/min.$	langleys/min.	1.
	Btu/sq.ft./hr.	221.
	$watts/cm^2$	0:07

Calibrating the Solar Meter

1. Between 11:30 A.M. and 12:30 P.M., place the solar meter in bright sunlight. Adjust the variable resistor to provide the appropriate scale deflection:

	cal/cm²/min.
winter months (November 1 to February 1)	1.24
fall or spring months	1.36
summer months (May 15 to August 15)	1.47

(For latitudes below 37°N, add 10% to these values.)

2. Repeat this activity on five subsequent sunny days. Adjust the resistor to provide the desired deflection on the brightest of the days. (If the deflection is less than the original, do not adjust. If the deflection is greater than the original, readjust to the desired deflection.)

3. Close the solar meter and do not readjust the resistor unless you damage or replace some of the parts. Keep the solar cell clean at all times because dirt or dust affects the calibration.

NOTE: While this calibration procedure provides an approximate scale, a more exact calibration can be achieved by adjusting your solar meter to agree with a pyrheliometer or insolometer at a weather station or university.

Suggested Time Allotment

One-half to one class period to prepare students for the activity

One or two class periods to collect data

One class period to graph and discuss results

Suggested Approach

Discuss the term solar radiation. Ask students why the amounts of solar radiation which can be collected at various sites are different. Discuss how these differences affect each site's potential for solar energy use.

If students are unfamiliar with solar meters, demonstrate how one operates and its purpose. Stress the delicacy of the solar cells. Explain the relationship between solar intensity and the reading on the solar meter.

To save time, you may want to have students help calibrate the meters.

If enough solar meters are available, this activity can be performed in groups of two or three students. Otherwise, consider either doing a teacher demonstration or performing this activity as one of several solar activities occurring in the classroom at the same time, with small groups rotating from activity to activity.

Explain the procedures for data collection before the students attempt the activity. Show students how to estimate cloud cover.

If necessary, help students with data collection, graphing, and interpretation of results.

Precautions

Remind students never to look directly at the sun.

Remind students that the solar cells of the meters are extremely fragile.

Plan the activity for a variably cloudy day only.

Points for Discussion

Why were you asked not to stand near bright objects when you gathered your data?

If heavy clouds were to pass in front of the sun, would the solar meter reading fall to zero? Why or why not?

Do you think there is enough available sunlight in your area to use solar energy collectors? Why or why not?

Can you answer the previous question based on the data you gathered in this activity? Why or why not?

Typical Results

The results of this activity will be highly variable, depending on the kind and extent of cloud cover during the data collection period.

Evaluation

Ask students to demonstrate the proper operation of a solar meter. Ask students to explain the purpose of a solar meter.

Check students' data tables and graphs for accuracy and completeness. Check students' responses to the questions.

Prepare questions which test the students' understanding of the functional relationship between cloud cover and the solar radiation received at the earth's surface.

Modifications

Photographic light meters may be substituted for solar meters. These are often available from the photography classroom. Filters may be needed for this activity if the light meters are very sensitive.

References

Climatic Atlas of the United States, U.S. Department of Commerce.
(National Climatic Center, Federal Building, Asheville, NC 28801, contact the center for price.)

Direct Use of the Sun's Energy, Farrington Daniels.
(Ballantine Books, Inc., 400 Hahn Rd., Westminster, MD 21157, 1974, $1.95/paper.)

The Passive Solar Energy Book, Edward Mazria.
(Rodale Press, Inc., 33 E. Minor St., Emmaus, PA 18049, 1979, $12.95/paper.)

6 A Solar Still

"Water, water everywhere,
And if you want your fill,
Just dig a hole in the ground
And make yourself a still."

Keeping in mind that water can be found in such places as streams, lakes, rivers, oceans, polar ice caps, the atmosphere, and in the ground.... it shouldn't be a surprise to you that there isn't any place on the surface of this earth where water isn't available in one form or another. Unfortunately, while water is everywhere, it isn't always available in a readily usable form. However, even in a desert, if you know where to look and if you have the proper equipment, you can obtain water.

In this activity you will find out how to get a surprising amount of water from an unlikely source.

objectives

At the completion of this activity, you should be able to

- build and operate a simple solar still;
- define the terms evaporation, condensation, distillation, greenhouse effect, capillary water, and gravity;
- use these terms to explain how a solar still functions;
- calculate rates of temperature change and water collection; and
- suggest possible practical applications for a solar still.

skills and knowledge you need

Measuring temperature and volume

Solving simple mathematical equations

Graphing and interpreting data

Being able to describe and explain the greenhouse effect

materials

Method A: Constructing and Operating a Model Still

a plastic shoebox

plastic wrap (of a length approximately twice the width of the shoebox)

moist soil

a marble or other dense object

a collecting cup

two thermometers (-10°C to 110°C)

a watch, clock, or timer to measure minutes

two small wooden blocks

two small pieces of cardboard

a light source with a mounting stand

a metric balance

cobalt chloride test paper

a large rubber band

Method B: Constructing and Operating an In-ground Still

a piece of thick, transparent, flexible plastic (at least 1 m square)

several fist-sized rocks

a collecting can (coffee can)

a shovel

two thermometers (-10°C to 110°C)

a timer to measure minutes

two small wooden blocks

two small pieces of cardboard

a graduated cylinder

cobalt chloride test paper

a protractor

Method A: Constructing and Operating a Model Still

1. Cover the bottom of the shoebox with 3 cm of moist soil. Slope the soil up the sides of the container, as shown in Diagram 1.

2. Mass the empty collecting cup and record its mass in the appropriate space on the data table.

3. Dig a hole in the soil at the center of the box. Place the cup in the hole. Smooth the soil around the cup. (Be sure to clean up after Steps 1 and 2.)

4. Place one wooden block on the soil surface as shown in Diagram 2. Rest the thermometer across the block to elevate the bulb above the soil. Be sure to position the thermometer so it can be read. Bend the cardboard to make a tent. Place the tent over the bulb to shield it from direct light.

Diagram 1

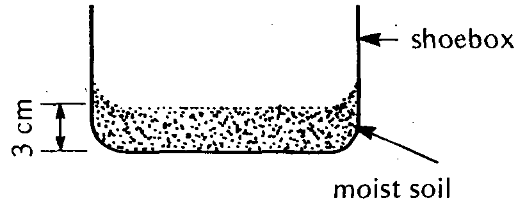
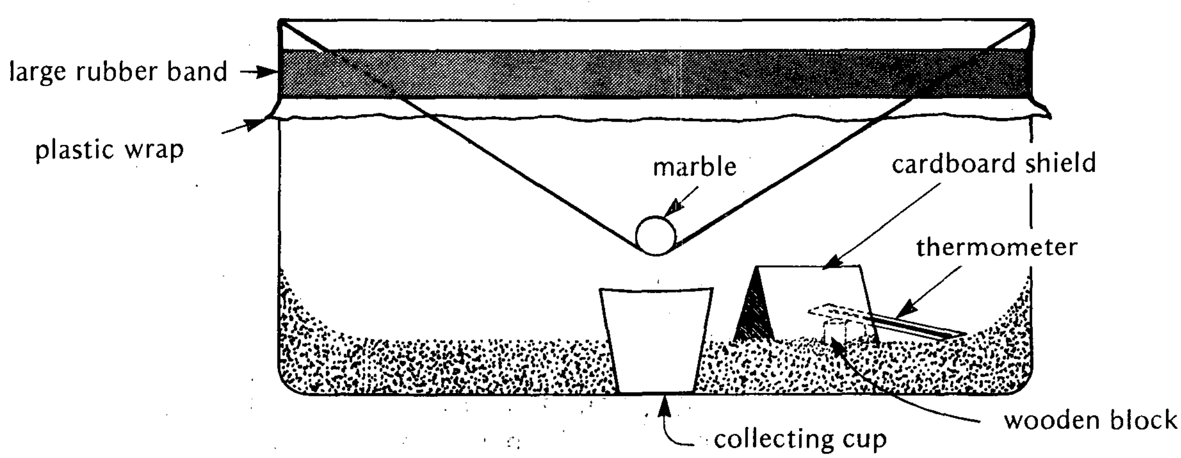


Diagram 2

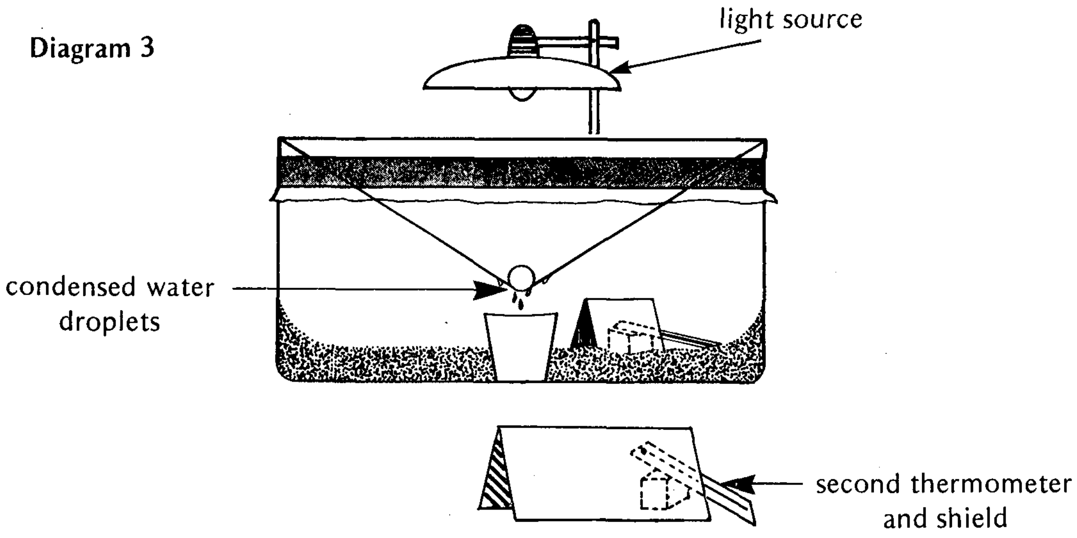


5. Place the plastic wrap over the top of the shoebox. Loosen the wrap enough so that when the marble weight is added, the wrap will sag to within 1-2 cm of the top of the cup. Place the rubber band around the top of the shoebox to hold the wrap in place.

6. Place the marble weight in the center of the plastic wrap, directly over the collecting cup. Make certain that the plastic wrap dips to within 1-2 cm of the top of the cup, but does not touch the cup.

7. Place the remaining wooden block near the shoebox and rest the second thermometer across it. Make another cardboard tent to shield the thermometer bulb.

Diagram 3



8. Position the light source above the shoebox still but don't turn it on yet. The distance between the light source and the top of the still will vary depending on the type and strength of the light source, so ask your teacher for the correct distance. At the same time, ask your teacher to check your set-up.

9. Read both thermometers and record the temperatures in the appropriate spaces in the "0" row of the data table.

Caution: Do not look directly at the light source. It may be very bright.

10. Remove the marble from the top of the still. Turn on the light source and leave it on for 15 minutes. Read the thermometers at one minute intervals and record the temperatures in the data table.

11. Turn off the light source AND MOVE IT AWAY FROM THE SOLAR STILL. Replace the marble weight on the plastic wrap. Continue to measure and record the temperatures for an additional 15 minutes.

12. Carefully remove the collecting cup from the still and clean away any loose soil. Mass the collecting cup and its contents. One gram of water has a volume of 1 milliliter. Record the volume of the liquid in the data table.

13. Test the liquid with cobalt chloride paper to be sure it is water.

14. On the graph provided, plot both the temperatures inside and the temperatures outside the still over time. Be sure to label each line.

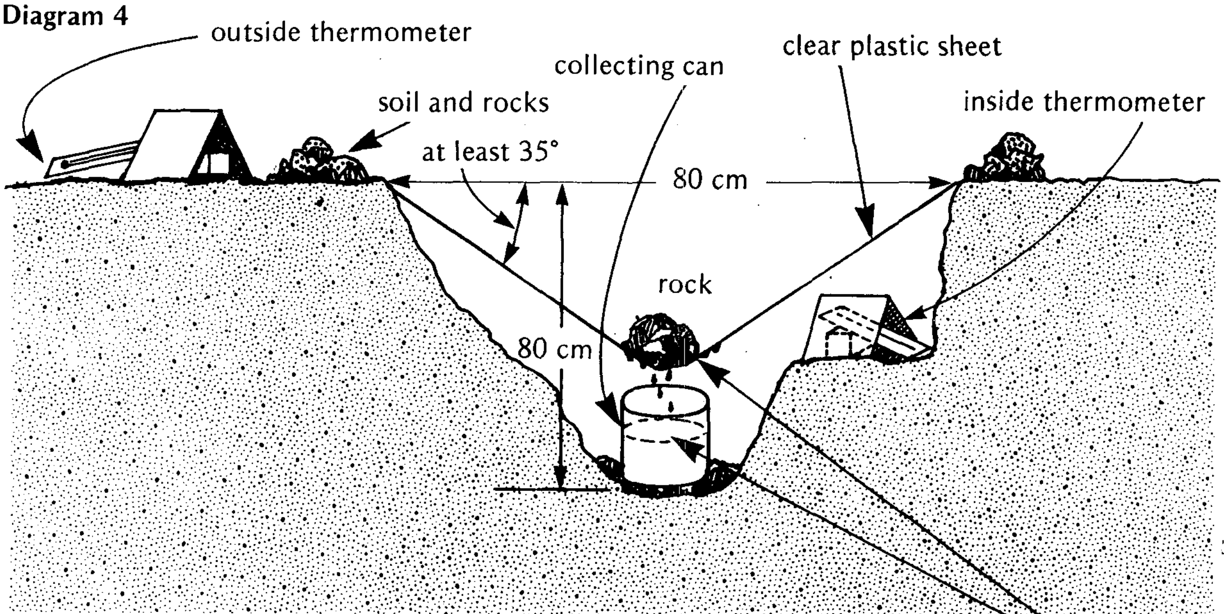
Method B: Constructing and Operating an In-ground Still

1. Choose a spot in direct sunlight and away from buildings and pathways. Dig a hole about 80 cm in diameter and 80 cm deep, placing the soil to one side. Center the collecting can in the bottom of the hole.

Caution: Be sure to obtain your teacher's permission to dig in the spot you choose before you actually start digging.

2. Place a wooden block near the top of the hole, as shown in Diagram 4. Rest the thermometer across the block to elevate the bulb above the soil. Be sure to position the thermometer so it can be read from above. Bend the cardboard to make a tent. Place the tent over the bulb to shield it from direct sunlight.

Diagram 4



3. Place the piece of plastic over the hole. Firmly anchor one side with rocks.

4. Place one rock in the center of the plastic sheet, directly over the collecting can. Allow the plastic to sag to at least a 35° angle from the horizontal.

5. Anchor the other sides of the plastic with rocks, then seal all edges by covering them with soil.

6. Place the remaining wooden block near the solar still and rest the second thermometer across it. Make another cardboard tent to shield the thermometer bulb.

7. Read the temperatures of both thermometers at one minute intervals for a total of 30 minutes. Record your measurements in the appropriate spaces in the data table.

8. Carefully remove the plastic from the still and clean away any loose soil from the collecting can. Use the graduated cylinder to measure the amount of liquid in the can and record the volume in the data table. (If no liquid has collected, allow the still to continue operating, perhaps for several more hours. Then redo this step.)

9. Test the liquid with cobalt chloride paper to determine if it is water.

10. Clean up your solar still site as directed by your teacher.

11. On the graph provided, plot both the temperatures inside and the temperatures outside the still over time. Be sure to label each line.

questions

These questions may be answered for either Method A or Method B or for both methods together.

1. Were the starting temperatures the same for the air inside and the air outside the still?

2. At what rate (how fast) did the air temperature change, both inside and outside the still? Use the following equation to determine your answers and show all work.

$$\text{Rate of temperature change } (^{\circ}\text{C/minute}) = \frac{\text{Total change in temperature } (^{\circ}\text{C})}{\text{Total time (minutes)}}$$

(For Method A, this should be calculated for only the first 15 minutes of the test period, when the light source was on.)

3. Use your knowledge of the greenhouse effect to explain why the inside and outside air temperatures changed at different rates.

4. a. Did liquid collect in the cup or container? b. If so, how much? c. Where did it come from? d. If liquid did not collect in the cup, try to explain why it didn't. (Be specific.)

5. How did you know the liquid collected was water?

6. From your observations of the solar still, what evidence can you present to confirm that the processes of evaporation and condensation had taken place?

7. Where did the energy to cause evaporation come from? How was energy removed from the water vapor to cause condensation?

8. At what rate was water removed from the soil and collected in the container? Use the equation below to determine your answer and show all work.

$$\text{Rate of water collection (ml/minute)} = \frac{\text{Total volume of water collected (ml)}}{\text{Total time of collection (minutes)}}$$

9. Describe the process by which the water left the soil and entered the collecting container. Look up the following words in a dictionary or earth science book, then include them in your description: evaporation, condensation, distillation, greenhouse effect, capillary water, gravity.

10. List some practical uses for a solar still.

looking back

You have just seen how a simple apparatus can be used to produce pure water. The sun's energy recycles the water of the earth in the same way. It removes water by evaporation from plants, fields, lakes, and oceans. When the water vapor cools and condenses into clouds and rain, we have fresh water again, ready to use.

Today the sun is being put to work evaporating and condensing water in solar stills to produce distilled water for many human uses.

going further

Place different types of soil in a model still and investigate their differing abilities to hold capillary water.

Investigate how the size of an in-ground solar still affects the rate of water collection. Vary the depth and/or width of the still and tabulate the results.

Place living plants in a solar still and collect water that is transpired from the plants. Compare the rate of water collection from equal areas of bare soil and soil covered with plants.

Check the purity of the water obtained from a solar still.

In many areas of the world, pure water is becoming very scarce. Research national and international plans and projects for obtaining pure water.

To find out more about another kind of solar still, a solar desalinizer, try Activity 10 in the Junior High/Middle Grades Activities book.

For more information on the greenhouse effect, try Activity 2 in this book.

Data Table

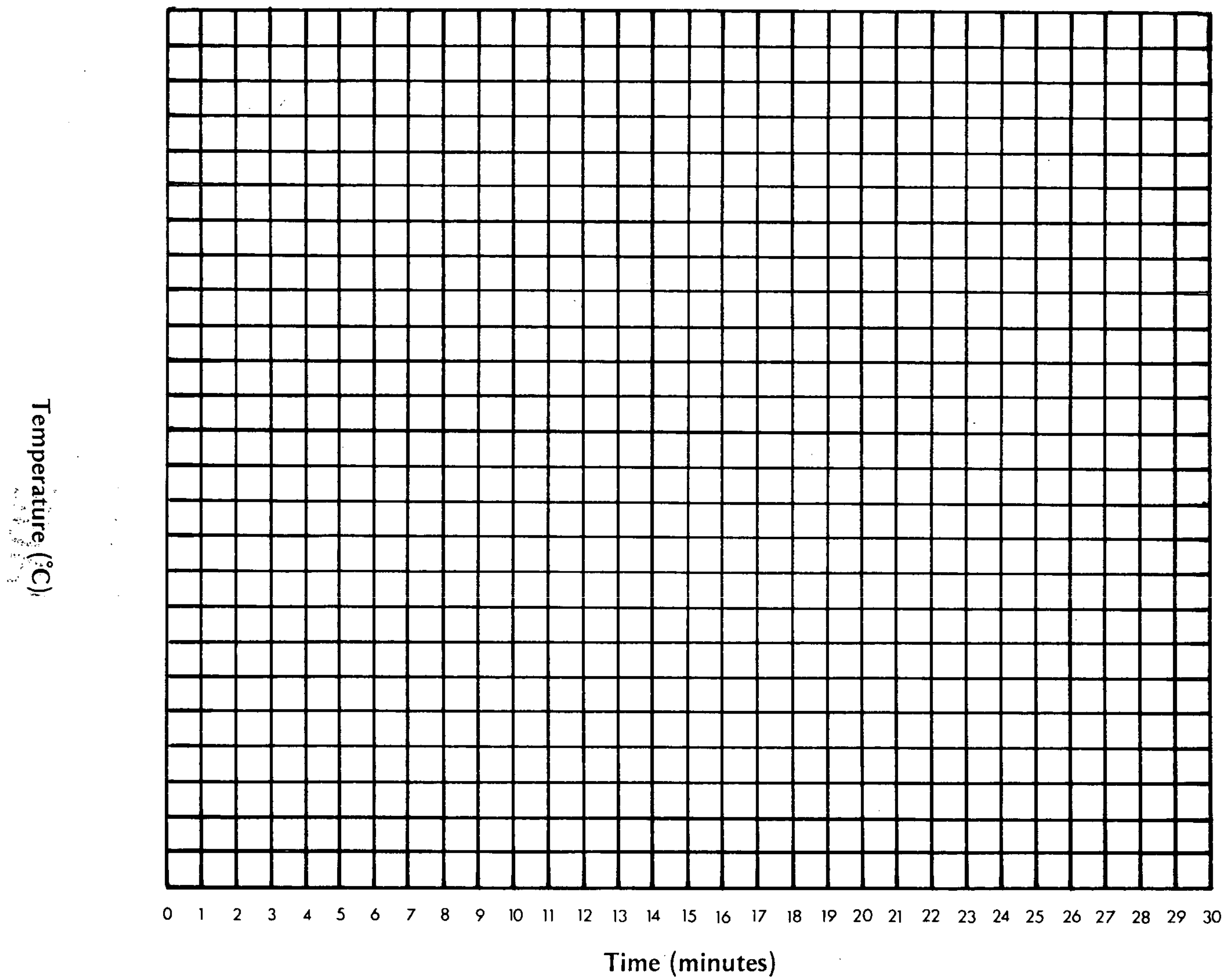
Method of Collection: ____________________

Mass of Empty Collecting Cup (Method A only): ______g

	Temperature (°C)			Temperature (°C)	
Time (minutes)	Inside Thermometer	Outside Thermometer	Time (minutes)	Inside Thermometer	Outside Thermometer
0			16		
1			17		
2			18		
3			19		
4			20		
5			21		
6			22		
7			23		
8			24		
9			25		
10			26		
11			27		
12			28		
13			29		
14			30		
15					

Volume of liquid in cup or container: ______ml

Graph


Temperature (°C)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Time (minutes)

Teacher Information
A Solar Still

Suggested Grade Level and Discipline

Science, grades 7-9
Earth Science
Outdoor Education

Skill Objectives

Building a model and/or full-scale solar still

Defining science terms and principles and relating them to their associated processes

Calculating rates of change

Collecting, graphing, inferring from, and interpreting data

Applying investigative results to practical uses

Major Understandings

Distillation can be a simple process. Heat is first added to a liquid to evaporate it and produce a gas or vapor, then heat is removed from the vapor to condense it back to a liquid.

A solar still uses the greenhouse effect to trap energy from the sun. One type collects water from soil by the processes of evaporation and condensation.

Large amounts of capillary water are present in soil, but this water is not immediately available to us as pure drinking water. Solar distillation makes this water available.

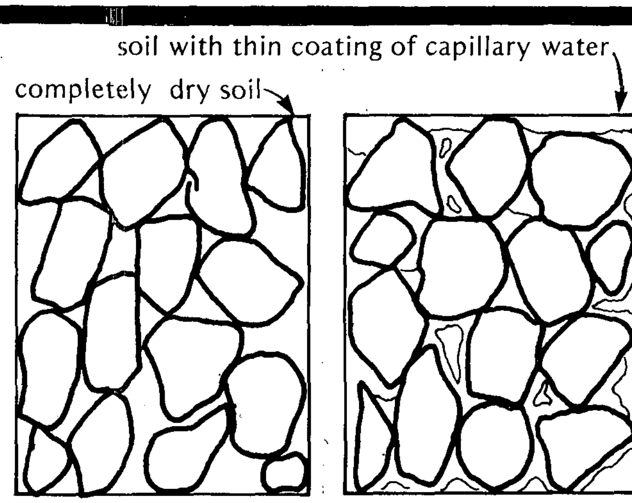
Solar stills may be used in seemingly dry areas or in areas where pure water is scarce to produce limited quantities of potable water.

Background

Stills are commonly used to purify liquids. Through the process of distillation, non-volatile impurities can be separated from the liquid. In this activity, water is both purified and recovered from soil.

Soil always contains some moisture, but it is often in the form of capillary water and not immediately available for use. Capillarity is the force that exists between soil particles and water molecules. This force prevents all the water in the soil from draining down through the soil in response to the force of gravity. The water that remains as a thin coating around the soil particles is known as capillary water.

A solar still allows this capillary water to be recovered (and purified in the process). Whether the still is a model still such as the one in Method A or an in-ground still such as that in Method B, the process is the same.



By creating a closed space with a transparent cover material, one can produce a greenhouse effect that causes the temperature inside the space to rise rapidly. The trapped heat is absorbed by the soil and causes its moisture to vaporize. This vapor then rises and touches the cooler undersurface of the plastic, where it condenses and runs down the plastic to drip into a container (instead of reentering the soil).

The model still constructed in Method A serves as a good demonstration of scientific principles, while the in-ground still demonstrates a basic survival technique. There are also above-ground stills (generally blackened trays with glass or plastic tents above them and collecting troughs along the sides), which are commonly used in remote areas where potable water is scarce. These small family stills can produce as much as 4 liters/ m^2/day.

Advance Planning

If both methods are to be performed, duplicate double quantities of the data table and graph.

Cobalt chloride test paper can be obtained from the chemistry lab.

The background section may be duplicated to provide additional information to students.

Method A

Plastic shoeboxes are inexpensive and easily obtained from discount or hardware stores.

Use flood or 200-watt incandescent lamps for the light sources. Add reflectors and mount on ringstands. Determine the optimum distance from light source to still for the bulbs you are using.

Obtain sand or soil (ordinary potting soil can be used) and moisten so that it is saturated but not "dripping" wet.

One-ounce plastic medicine cups work well for the collecting cups; or the tops can be cut off small styrofoam or paper cups and the bases used.

You may want to prepare shoeboxes with soil yourself, both to save time and to eliminate a possible mess. Don't forget that students can help with this task outside of class time. In any case, have moist paper towels available for cleaning off hands and tables.

Method B

Plastic storm window sheeting works well as the transparent covering for the still. Students may have scrap plastic sheeting at home. Hardware and building supply stores may be willing to donate damaged or discarded (or even new) plastic.

Shovels are available from the grounds maintenance staff.

Check the soil where you plan to dig to make sure it is suitable. It should not be too rocky, too hard, too dry, or too loose.

Decide how and when you will have students clean up the solar still site.

Suggested Time Allotment

One class period to prepare each method

One class period to perform each method (You may need to let the in-ground still operate for a full day, including overnight.)

One class period to graph and discuss results

Suggested Approach

This activity is divided into a Method A and a Method B. You may select either method to perform, depending on your circumstances, or you may perform the methods sequentially. The questions apply to both methods.

Discuss the terms and principles associated with the process of solar distillation before the class performs the activity. Be sure to include the terms listed in Question 9.

Divide the class into groups of three and make sure each student has a task to perform in constructing the still.

For Method A, find a way to keep the marble weights cool after students remove them from the stills and until they are replaced. This provides an energy sink, which hastens condensation of the water vapor.

Attempt Method B only on a warm, sunny day.

Help students to calculate the rates of temperature change and water collection. Also help with the graphing.

Discuss some of the applications of a solar still.

You may want to use Method B as a "Going Further."

Precautions

Method A

Remind students not to look directly at the light source.

Remind students to remove the marble before turning the light source on and to replace it after turning the light source off.

Remind students to take the same safety precautions with the light source as with any electrical device.

Do not allow students to taste the water collected by the still because of the possibility of using contaminated soil.

Method B

Supervise students closely while they are outside. Do not let them go out alone.

Obtain permission from your principal or grounds supervisor to dig holes for the stills. Dig away from highly used locations and paths. Leave signs to caution passers-by if stills are left in operation with no attendants.

Fill in the holes as soon as the activity is completed.

The slope of the plastic cover should be at least 35°. However, greater slopes (within reason) will hasten the collection of water.

You may have to allow the still to operate for a full day to collect an appreciable amount of water.

Do not allow students to taste the water collected by the still because of the possibility of polluted ground water.

Points for Discussion

Why was the marble removed and then replaced in Method A?

Assume that your still collects water at a constant rate. How much water would be collected over a 12-hour period of sunlight?

Assume that a person needs one liter of water a day to survive. Could your still provide this amount of water? Why or why not?

In what ways might the assumption that your solar still collects water at a constant rate be incorrect?

What are some of the limitations or disadvantages of solar stills?

Typical Results

The model still should produce several milliliters of condensed water, especially if a cooled marble was used to speed condensation. The in-ground still will produce an appreciable amount of water over several hours, but only if there is strong direct sunlight on the apparatus.

Evaluation

Check students' data tables and graphs for completeness and accuracy. Look over students' answers to questions for degree of understanding.

Ask students to define the terms associated with solar distillation from soil. Then ask them to use these terms to describe the operation of a solar still.

Give sample problems on calculating rates of change.

Ask students to list practical applications of solar stills.

Modifications

Calibrated collecting cans may be used, eliminating the need for graduated cylinders.

References

Direct Use of the Sun's Energy, Farrington Daniels.
(Ballantine Books, Inc., 400 Hahn Rd., Westminster, MD 21157, 1974, $1.95/ paper.)

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Solar Energy for Man, B. J. Brinkworth.
(Halsted Press, Division of John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10016, 1972, $12.95.)

Solar Science Projects for a Cleaner Environment, D. S. Halacy, Jr.
(Scholastic Book Services, 906 Sylvan Ave., Englewood Cliffs, NJ 07632, 1974, $0.85/paper.)

Metric Conversion Table

Unit of Measure	English Unit	Multiply By ➤ ◄ Divide By	Metric Unit	Symbol
Length	inches feet feet yards miles	2.54 30.0 0.3 0.91 1.61	centimeters centimeters meters meters kilometers	cm cm m m km
Area	square inches square feet square yards	6.5 0.09 0.8	square centimeters square meters square meters	cm^2 m^2 m^2
Mass (Weight)	ounces pounds	28 0.45	grams kilograms	g kg
Volume	gallons cubic feet	3.8 0.03	liters cubic meters	l m^3
Temperature	degrees Fahrenheit	5/9 (after subtracting 32) 5/9 plus 32	degrees Celsius	°C
Heat	Btu	252	calories	c
Speed	miles per hour	1.61	kilometers/hour	km/hr

Energy Units

barrel: a liquid volume equal to 42 gallons or 159 liters. One barrel of crude oil has about the same heat energy as 350 pounds of bituminous coal, 5.8×10^9 joules or 5.5×10^6 Btu or 1.39×10^6 kcal.

Btu: British thermal unit, a unit for measuring heat; a Btu is the quantity of heat necessary to raise the temperature of one pound of water one degree Fahrenheit, about one-fourth of a kilocalorie (252 calories).

calorie (also: gram calorie): a metric unit of heat energy; the amount of heat needed to raise the temperature of one gram of water one degree Celsius. It equals 0.0039 Btu. One thousand calories make one kilocalorie (kcal), sometimes called a Calorie or food Calorie.

kilowatt: a measure of power, usually electrical power or heat flow; equal to 1,000 watts or 3,413 Btu per hour.

kilowatt-hour: the amount of energy equivalent to one kilowatt of power being used for one hour; equals 3,413 Btu, or about 860 kcal.

watt: a unit of measure for electrical power equal to the transfer of one joule of energy per second. The watt is the unit of power most often associated with electricity and is determined by multiplying required volts by required amperes. One horsepower = 746 watts.