DOE/CS/34039--T1

# Renewable Energy Activities for Junior High/ Middle School Science

DOE/CS/34039--T1

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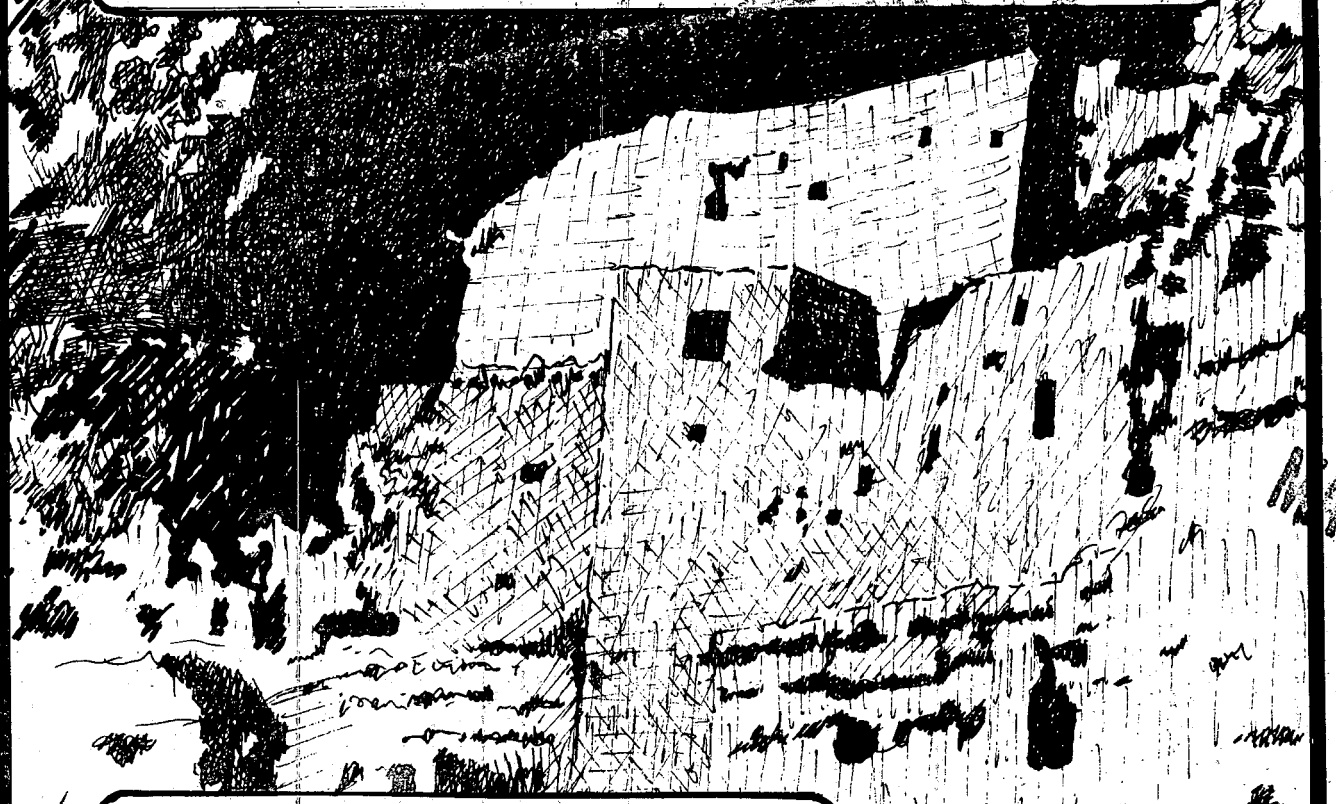

MASTER

## Solar Energy Education

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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.

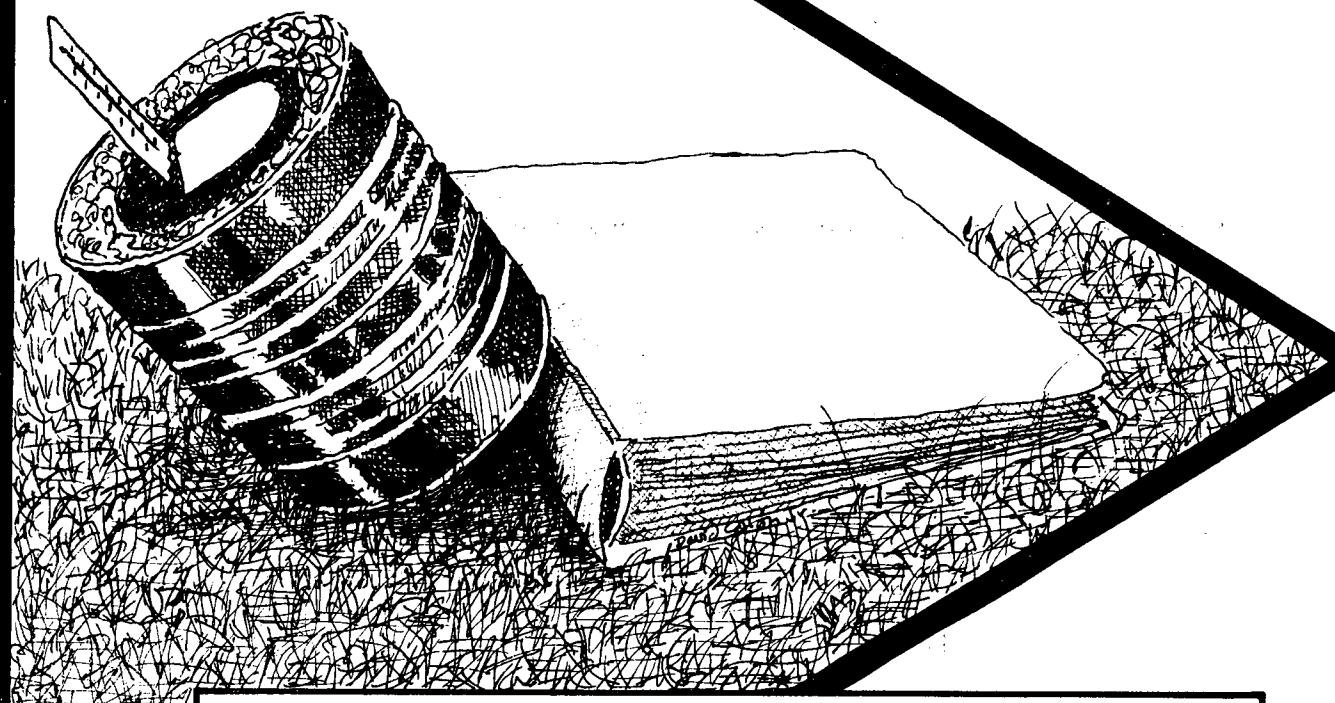
Students are aware of this reality. They see that, as available energy resources change, their lives will also change, in ways as yet unknown. They recognize energy as a factor that will have an impact on them personally, for the rest of their lives, and they want to understand their energy options.

## *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 Solar Energy in a Can



The sun is a huge furnace, giving off an enormous amount of energy. This energy can be trapped and used. People are learning how to do this; you may have seen collectors of solar energy on buildings in your area. In this activity, you will learn how to collect solar energy yourself, using simple materials.

To collect the sun's energy, let it pass through transparent material and fall on a dark surface. This turns the energy into heat, but you then have to keep the heat from escaping.

You will test a variety of transparent materials (glazings) and materials used to trap heat (insulation). When finished, you should have a clearer idea of how solar energy is collected.

# objectives

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

- o construct a solar collector,
- o determine how the type of cover material (glazing) affects the collector, and
- o determine how insulation affects the collector.

# skills and knowledge you need

How to read a thermometer and a stop watch or clock

How to graph data

# materials

a large can (about 15 cm in diameter)

a smaller can (about 10 cm in diameter) with the inside painted black and with a plastic cover

two Celsius thermometers

several pieces, approximately 15 cm square, of transparent and translucent cover materials, such as plastic wrap, polyethylene, and waxed paper

several types of insulation material, such as shredded paper (cellulose), cotton, styrofoam, fiberglass, cork, and sawdust

a watch or clock with a second hand

scissors

colored pencils

# procedure

1. Cut the center out of the smaller can's plastic lid, leaving a plastic semicircle on one side and a 1 cm rim around the rest of the lid's edge. (See Diagram 1.)

2. In the center of the plastic semicircle, cut a slit through which a thermometer will fit snugly.

3. Look at the cover materials and insulating materials. Which ones do you think will produce the highest temperatures in the collector? Why?

4. Choose a cover material. Stretch it across the top of the smaller can and hold it in place by putting the cut-out plastic lid over the can.

5. Make a hole in the cover material by poking a scissors point through the slit in the plastic lid. Insert a thermometer through the slit. Place the smaller can inside the larger can. (See Diagram 2.)

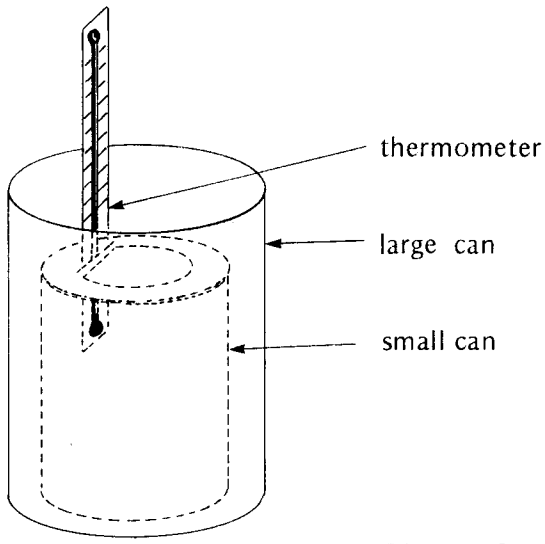



Diagram 2

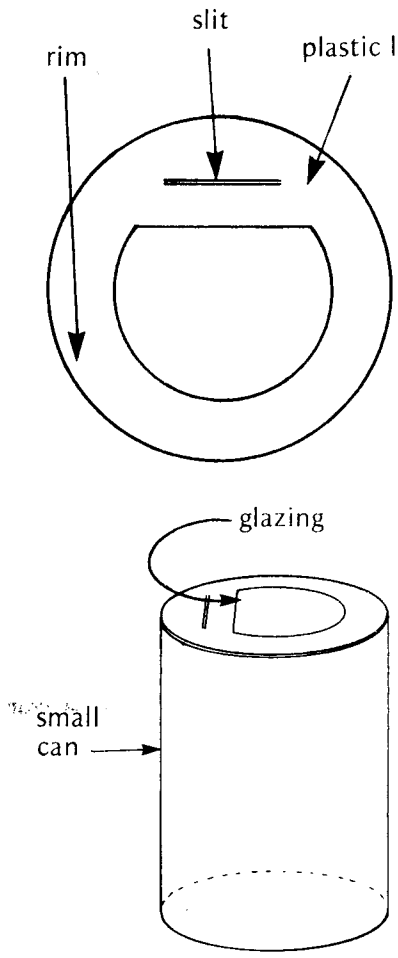



Diagram 1

6. Record the kind of cover material you are using in the third column of Data Table 1.

7. Now place your solar collector in the sun so that the tops of the cans face the sun. At the same time, face a second thermometer into the sun at the same angle as the solar collector's thermometer. Immediately take beginning temperature readings on each thermometer and record in Data Table 1.

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

8. Continue to take readings on both thermometers each minute for 30 minutes.

9. Repeat Steps 6 through 8 for two other types of cover materials. (Other students may be collecting these data for you.) Record the data in Data Table 1. Outside temperatures do not have to be recorded again.

10. Use Graph 1 to plot temperature vs. time for the outside temperature. Then, on the same graph, use different colored pencils to plot the temperature vs. time for each cover material. When you are finished, label each line with the correct cover material.

11. Inspect your graph to determine the best cover material and place this material over the smaller can.

*Caution: Always wear safety goggles and gloves when handling fiberglass insulation.*

12. Choose an insulating material and put it between the two cans. Make sure you put it in all the spaces, including under the smaller can.

13. Now repeat Steps 7 and 8. This time record the kind of insulating material and the temperature data on Data Table 2.

14. Repeat Step 13 for two other types of insulating material. (Other students may be doing this for you.)

15. Use Graph 2 to plot temperature vs. time for the insulating materials in the same way as you did the cover materials (Step 10).

# questions

1. Were your predictions in Step 3 correct or incorrect? Can you explain why?

2. According to your graphs, which type of cover material worked best? Why do you think it was best?

3. Why is it important to use insulation in a solar collector? Which type of insulation worked best? Why do you think it was best?

4. Of the materials you used, which combination of glazing and insulation material would you recommend for a solar collector? Why?

5. Which combination of glazing and insulation material would be least effective in a solar collector? Why?

6. Why were you asked to use just one cover material in testing the insulation materials?

# looking back

After doing this experiment, you probably realized that solar energy is a usable source of heat. It may not be easy to see or weigh or measure, like oil or coal, but it's definitely there. You were able to produce heat simply by letting solar radiation pass through a transparent material and strike a dark surface.

You probably also found out, however, that the heat produced was easily lost. Unless you did something to hold it, the energy "came in the window and went out the walls." The importance of insulation is very clear in this experiment. If you used the same glazing but changed your insulation, you should have been able to judge which insulation was the most effective.

By using simple materials, you've learned about the basic parts of any solar energy collector: a transparent glazing, a dark collector surface, and insulation to keep the heat.

# going further

What effect does the angle of a collector have on the temperature attained? Try setting the collector upright or tilting it away from the sun.

What effect would sub-freezing temperatures outdoors have on temperatures attained? Would solar collectors be practical in colder climates?

How would adding an additional cover material to the outer can affect performance? (Using two cover materials on a collector is known as double-glazing.)

Would changing the color of the inside of the small can affect the amount of energy collected? Test your hypothesis.

Test the sun's heating effect on other substances. Put small pebbles or rocks in the small can and record and graph the temperatures over time. Compare these results to your original results. Try the same thing with water in the can. Which substance reached the highest temperature? Which substance cooled most slowly? (Remember to control your variables so you can make comparisons.)

## Data Table 1

| Time (minutes) | Outside Temperature (°C) | Temperature Inside Collector for Different Cover Materials | | |
|---|---|---|---|---|
| | | Kind: | Kind: | Kind: |
| 0 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
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| 28 | | | | |
| 29 | | | | |
| 30 | | | | |

Teacher Information

# Solar Energy in a Can

## Suggested Grade Level and Discipline

Science, grades 7-9
Earth Science

## Skill Objectives

Constructing a functional solar energy collector

Recording, graphing, and interpreting temperature data

Controlling one variable while altering a second variable

## Major Understandings

Covering and insulating materials are important components of a solar energy collector.

The best glazing material is that which allows the most sunlight into the collector but prevents the most heat from escaping the collector.

The best insulating material is that which prevents the most heat from escaping the collector.

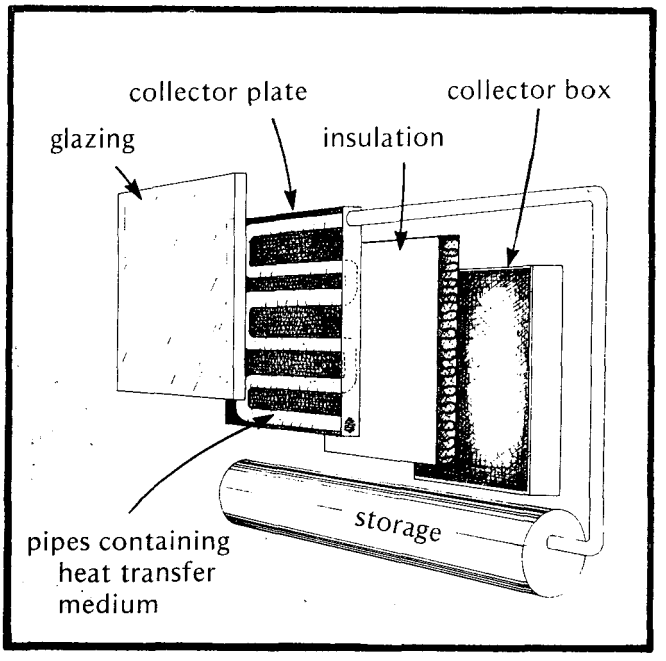
The most effective solar collector will possess the best possible glazing and the best possible insulation.

## Background

A solar collector can be used for space heating or to provide hot water for commercial or domestic uses. It has five basic parts. Students will investigate each of these in this activity.

One major part of a collector is a covering material, called glazing, which transmits solar energy and then traps it inside the collector. The glazing should be able to withstand high temperatures without decomposing or melting, and it must be able to withstand impact from objects that might fall on it.

Next is the collector plate, which absorbs the energy transmitted by the glazing. The collector plate is usually coated with a dark-colored material that increases the absorption of solar energy. The plate and its coating must be able to withstand high temperatures without vaporizing or otherwise breaking down. It is often made from copper or aluminum but other materials may be suitable. In this activity the black-painted interior of the small can is the collector plate.




A third component, the collector box, houses the various parts of the collector. It can be made from materials such as aluminum, wood, fiberglass, or steel. It must be sturdy and able to withstand temperature extremes. The larger can in this activity represents the collector box.

Fourth is the insulation that lines five sides of the collector box. Conduction losses of trapped solar energy are substantial unless the collector box is well insulated. Fiberglass and various foams are commonly used for this purpose.

A fifth part of the collector is the heat transfer medium, usually air or a liquid. This medium absorbs the solar energy as heat and is then distributed through a space heating system or a water heating system. If water is used as a medium in cold climates, it is often mixed with an antifreeze to prevent freezing. In this activity, air is the heat transfer medium, but it is not being distributed through a system.

## Advance Planning

Several weeks in advance, have students start bringing in cans. The larger cans should be the size of #10 cans or 3 lb. coffee cans. The smaller cans can be 1 lb. coffee cans or flavored-drink mix cans with plastic lids. Forty-six ounce juice cans will also work, but the covering materials will then have to be secured with rubber bands. A good source of cans is the school cafeteria.

Students can also bring in scrap insulation and cover materials from home.

The insides of the small cans must be spray-painted black. We suggest that you do this yourself to save time and to protect students from fumes.

Have several extra covers in case the students do not cut them properly.

Practically any thermometer will work in this activity. Although inexpensive metal-backed thermometers are recommended, standard lab thermometers will work just as well. The slit in the plastic lid can be changed to a hole made with a punch.

If additional information for students is needed, the background information can be duplicated.

## Suggested Time Allotment

One period to construct the collectors

Two to five periods for collection and interpretation of data

## Suggested Approach

Divide each class into several groups. Each group can test a different glazing, then test different insulations using the same glazing. This will help to control the variables in the activity. Groups should be using the same kinds of cans so that they can compare their results. One timer and one outside temperature reader for the entire class helps to coordinate the activity.

All data should be collected under the same environmental conditions, again to control variables. If students are to collect data on successive days or over changing weather conditions, then outside temperatures should be recorded for other glazings and insulations.

Try to do the activity on a cloudless day.

Career education can be infused into this activity by inviting industry, utility, and business representatives in the energy field to speak to the class. Or students may be asked to visit local firms and interview individuals associated with the energy industry or energy planning.

## Precautions

*Can edges should be checked prior to the activity and sanded if necessary.*

*Advise students to use care as they handle thermometers.*

*Remind students never to look directly at the sun.*

*Fiberglass insulation should be handled only with gloves.*

## Points for Discussion

Why is it best to test different cover materials and different insulating materials separately?

Why does using cover and insulating materials increase the temperature obtained in the smaller can of the collector?

Why doesn't the solar collector continue to heat up for as long as it remains in the sun?

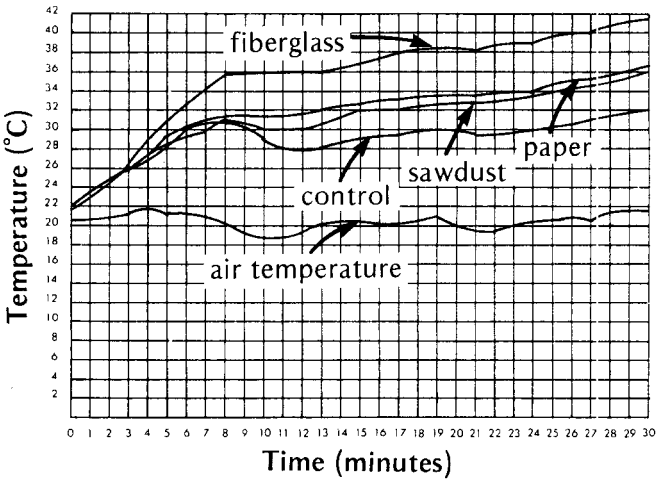
At what time of day would your solar collector reach the highest temperature?

## Typical Results

The different combinations of insulation and glazing used will cause results to vary.

Greater amounts of and higher R-values of insulation will cause higher temperature readings.

Actual student results for some different insulation materials are plotted below.




## Evaluation

Observe your students' ability to follow instructions, construct the collector, and work with other class members.

Collect and review the data gathered by each student. Are they well organized? Are the graphs usable for data analysis?

Check students' answers to the questions.

## Modifications

Using the temperature graphs produced, ask students to rank the combinations of glazing and insulation from most effective to least effective.

Two pound coffee cans might be substituted for either one or three pound cans.

If plastic lids are not available, the cover material can be secured with a rubber band. A slit can be cut in the cover material and the thermometer inserted. A second rubber band around the thermometer will hold it in place in the cover material.

If necessary, substitute infrared or flood lamps for sunlight.

If less time is available, reduce the number of minutes spent recording temperature data.

## References


Catch a Sunbeam: A Book of Solar Study and Experiments, Florence Adams.
(Harcourt Brace Jovanovich, Inc., 757 Third Ave., New York, NY 10017, 1978, $7.95, for student reading.)

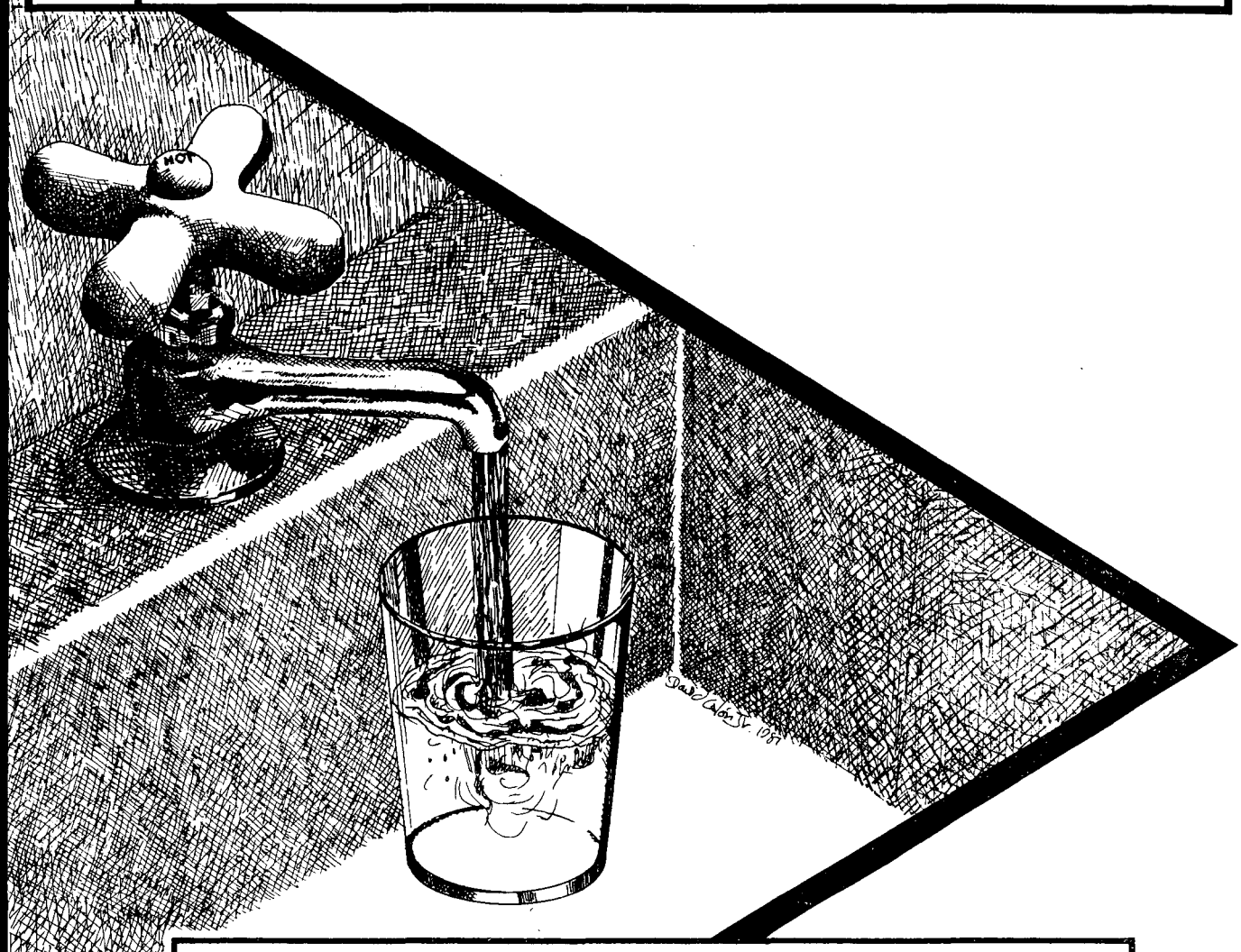
Direct Use of the Sun's Energy, Farrington Daniels.
(Ballantine Books, Inc., 400 Hahn Rd., Westminster, MD 21157, 1974, $1.95/paper.)

Solar Energy: Science Activities in Energy.
(U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830, 1980, free, student activities.)

The Solar Home Book: Heating, Cooling, and Designing with the Sun, Bruce Anderson and Michael Riordan.
(Brick House Publishing Co., 34 Essex St., Andover, MA 01810, 1976, $9.50/paper.)

Sun Up to Sun Down: Understanding Solar Energy, Shawn Buckley.
(McGraw-Hill Book Co., 1221 Avenue of the Americas, New York, NY 10020, 1979, $6.95/paper.)

# 2 Hot Water from the Sun




Is the sun powerful enough to use as a source of energy? Sitting in the sun on a sunny day seems to indicate that it is, at least for heating. Think about all the solar energy that strikes the earth but is not used. If this energy-packed sunlight could be collected, it would provide a large source of clean, free, and much-needed energy. In this activity you will learn how a solar energy collector works and build a simple solar water heater.

Every solar collector requires certain basic parts. An outer covering, or glazing, transmits sunlight energy into the collector but prevents the heat produced from escaping. Within the collector there exists a plate or object needed to absorb the solar energy and convert it into heat. The collector box itself may be insulated to help prevent heat loss. Finally, the collector uses air or a liquid to transfer the heat produced to where it is needed or can be stored.

As you construct and use your solar water heater, be thinking of the function of each of its parts.

# objectives

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

- o construct a solar energy collector that heats water,
- o explain the functions of the parts of this solar collector, and
- o measure the amount of heat absorbed by this solar collector.

# skills and knowledge you need

The skill of reading a thermometer

The skills of recording and graphing data

The skills of measuring metric length and volume

The knowledge that a calorie is a metric unit of heat energy

# materials

one large wide-mouth jar, with lid

one can (to fit inside jar), painted black

a Celsius thermometer

a graduated cylinder or beaker (250 ml)

modeling clay

a balloon

corrugated cardboard

aluminum foil

rubber bands

scissors

water

a watch, clock, or timer to measure minutes

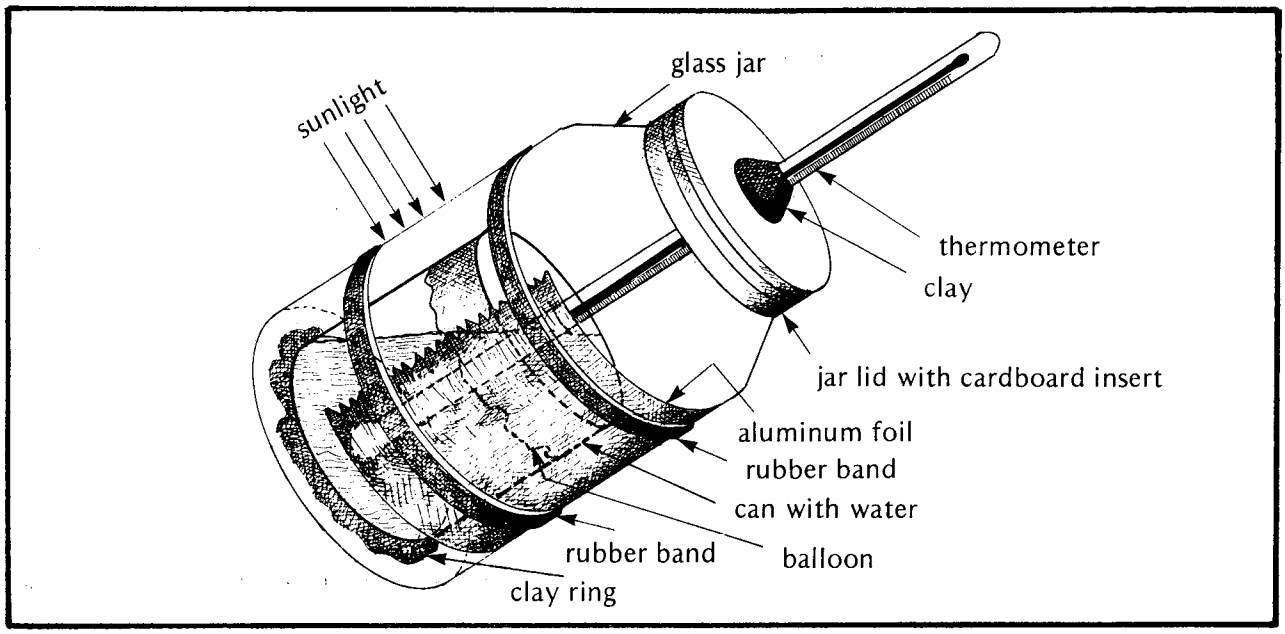
# procedure

1. Cut a circle of cardboard to fit inside the jar lid.

2. Have your teacher punch or drill a hole in the center of both the lid and the cardboard so a thermometer will fit through.

3. Put 200 ml of water into the can.

4. Cut off the end of the balloon and fit the balloon over the open end of the can. Puncture the balloon so that the thermometer can pass through it and into the water in the can.




5. Place a ring of clay on the bottom of the can. (See diagram.) Position the can in the center of the jar and anchor it by pressing down. Be careful not to spill the water.

6. Screw the lid on the jar.

7. Cut a piece of aluminum foil to fit halfway around the outside of the jar. Secure the foil in place, shiny side in, with rubber bands.

8. Carefully fit the thermometer through the jar lid and into the can. Make sure the thermometer tip is in the water, then position the thermometer so you can read the water temperature. Once the thermometer is in place, do not turn the jar lid.

*Caution: Handle the thermometer carefully, since it is easily broken. Do not force the thermometer through the jar lid or balloon.*

9. Plug the hole in the jar lid by packing a small amount of clay around the thermometer. This will make the jar airtight.

10. Fill in the top portion of the data sheet with the information requested.

11. Place your newly constructed solar water heater at an angle directly facing the sun, with the foil side away from the sun. Make sure the thermometer tip is still in the water. Take temperature readings every 2 minutes for a total of 30 minutes. Record your data in the Data Table. In the "Notes" column, list any changes, such as cloud cover or movement of the collector, which occur during the experiment.

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

12. On the graph provided, plot water temperature versus time.

# questions

1. List five different parts of your solar water heater and explain their functions.

2. By how much did the temperature of the water increase? According to your graph, at what point in time did the water reach its highest temperature?

3. Account for any decreases or increases in temperature shown by your graph. If your graph leveled off, explain why.

4. How many calories of heat energy were collected by your water heater? Use the following formula:

   Heat (cal) = mass of water (grams) x temperature change ($^{o}C$)
   x specific heat of water.

   The specific heat of water = 1 cal/g$^{o}$C.
   The mass of 200 ml of water = 200 grams.

# looking back

Your solar collector should have increased the temperature of the water several degrees. This simple device made with everyday items works well and could have many practical uses if built on a larger scale. The glazing and collector box (glass jar), collector plate (blackened can), transfer medium (water), and insulation (cardboard) are all basic parts of any solar collector. The aluminum foil served to focus solar energy on the can, thereby increasing the efficiency of the collector.

# going further

Turn your collector into a solar air heater by removing the water. Redo the activity to see how air functions as a transfer medium.

Design a solar water heater that could be used to provide hot water for your home.

Investigate the effects of the following variables on the temperatures reached in your collector:

a) the angle at which the collector faces the sun,
b) the wind and cloud cover conditions,
c) the temperature of the outside air (Will your collector work as well in winter as in summer?),
d) the color of the can (collector plate),
e) the use of other liquids as the transfer medium,
f) the kind of metal the can is made of, or
g) placing the collector inside a larger glass jar to provide double glazing (better insulation).

# Data Table

## Solar Water Heater

Name: _____

Date: _____

Weather Conditions: Wind Speed _____

Cloud Cover _____

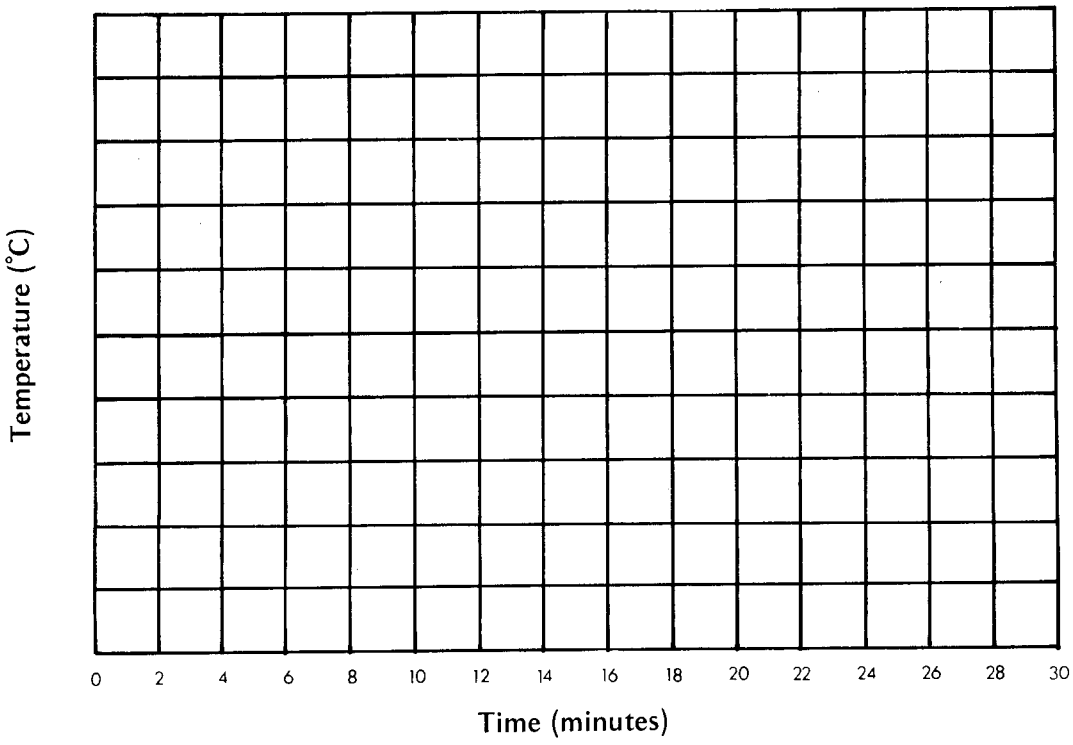
Amount of Water in Collector: _____ ml

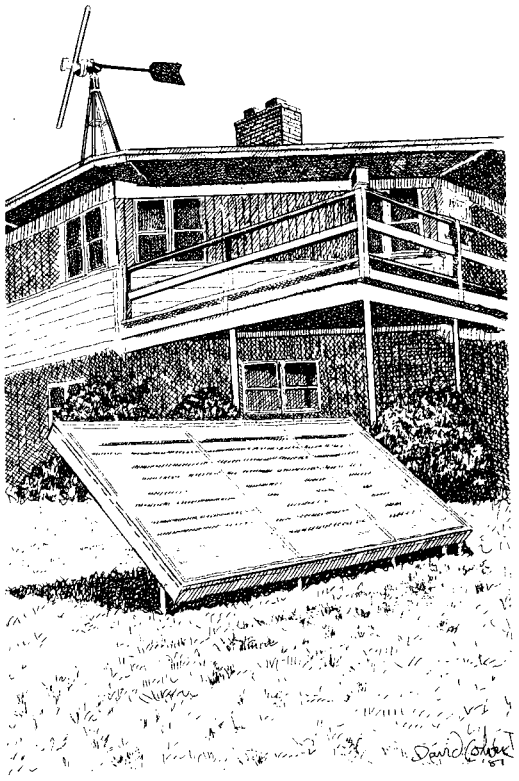
Beginning Temperature of Water: _____ °C

| Time (minutes) | Water Temperature (°C) | Notes |
|---|---|---|
| 2 | | |
| 4 | | |
| 6 | | |
| 8 | | |
| 10 | | |
| 12 | | |
| 14 | | |
| 16 | | |
| 18 | | |
| 20 | | |
| 22 | | |
| 24 | | |
| 26 | | |
| 28 | | |
| 30 | | |

# Graph

## Solar Water Heater Temperatures



Teacher Information

# Hot Water from the Sun

## Suggested Grade Level and Discipline

Science, grades 7-9
Earth Science
Physical Science

## Skill Objectives

Constructing a simple solar energy collector by carefully following directions

Measuring and graphing the change in the water temperature of the collector over time

Calculating the heat absorbed by the collector in calories

Identifying the component parts of a solar collector

## Major Understandings

Glazing, a collector box, a collector plate, insulation, and a transfer medium are the primary components needed in any solar energy collector.

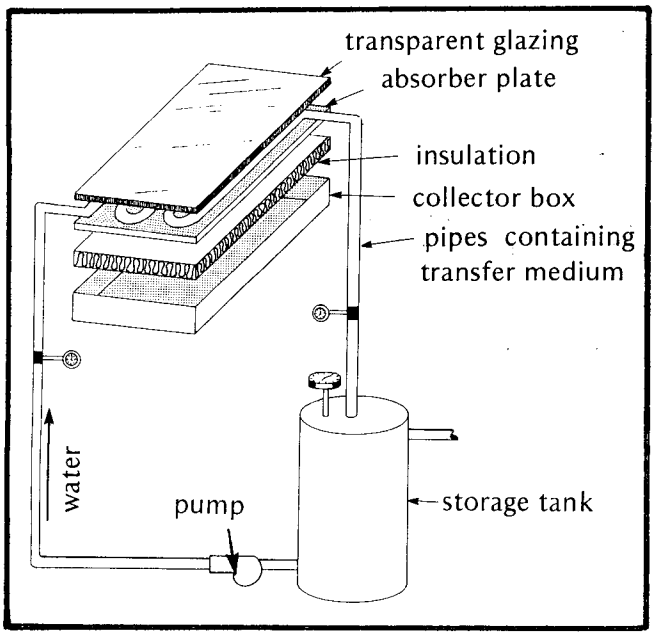
Solar collectors will increase in temperature until the heat they lose equals the heat they absorb.

The calorie is a convenient unit of measurement for the amount of heat absorbed by a collector.

Solar energy may be used to heat the water of individual homes.

## Background

Solar collectors are simply devices that collect the sun's energy and convert it to heat. Any collector has five basic parts: glazing to transmit the solar energy into the collector, a collector plate to absorb the energy transmitted and convert it to heat, insulation to trap this heat within the collector, a transfer medium to distribute the heat collected to storage or to the space to be heated, and a collector box to house the entire apparatus.




The amount of heat absorbed by a collector can be measured in calories, where one calorie is defined as the amount of heat necessary to raise the temperature of one gram of water one degree Celsius.

The solar water heater constructed in this activity illustrates the basic collector parts. The wide-mouth jar serves as both the collector box and the glazing, with the curved aluminum foil on the outside acting as a reflector. The can is the absorber plate, the water is the transfer medium, and the cardboard in the lid is a partial insulator. Although the increases in water temperatures will not be great, solar water heating is easily demonstrated by this activity. The collectors mounted on houses and other buildings to provide domestic hot water or space heating contain the same basic parts and function in the same way as this model collector.

(For additional background on solar collectors, see Activity 1 in this book, "Solar Energy in a Can.")

## Advance Planning

Several weeks before the activity, have students start bringing in jars and cans from home. The school cafeteria or a local restaurant may be another good source. The jar openings must be wide enough to accommodate the cans. All jars and cans should be clean, with labels and glue removed. Remove the tops from the cans.

Use non-water-soluble flat-black spray paint to paint the outsides of the cans. To eliminate fumes in the classroom and to save time, it is recommended that the painting be done by the teacher.

To save additional classroom time, the corrugated cardboard may be pre-cut to fit into the jar lids. You may also want to punch the holes in the lids and cardboard inserts ahead of time.

## Suggested Time Allotment

One class period to construct the collectors

Two or three class periods for the collection and interpretation of data

## Suggested Approach

Divide the class into groups, with two or three students assigned to each collector. To facilitate coordination of the activity, one student can serve as timer for the entire class.

The activity should be done outside or through a window exposed to direct sunlight. Use a relatively sunny day to collect data.

Invite a solar energy systems dealer to talk to the class about solar water heaters. The students should prepare a list of questions ahead of time. The dealer may also be asked to talk about career opportunities in solar energy.

## Precautions

*Students should never look directly at the sun.*

*No stress should be placed on thermometers as they are inserted into the jars and cans.*

*Students should not punch holes in the jar lids themselves.*

## Points for Discussion

When did your solar collector heat up most rapidly?

What factors affect the rate of temperature increase in your collector?

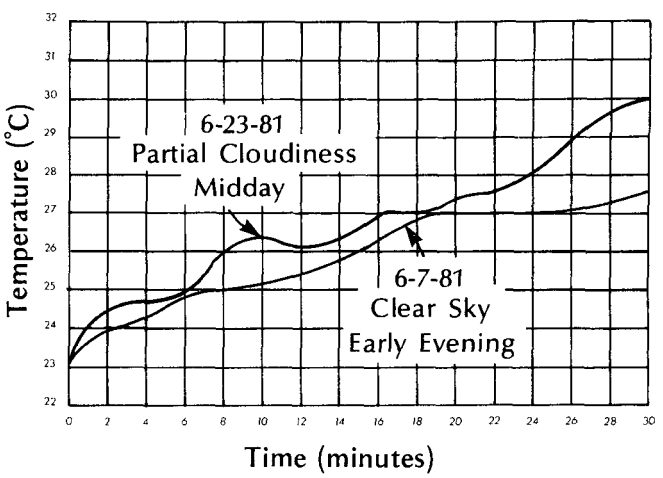
Why does the water in your collector reach a much higher temperature than would the same amount of water left in the sun uncovered?

Would solar collectors be most economical in heating the air (space heating) or providing the hot water for your home? Why?

## Typical Results

Results will vary according to outside temperatures and other weather conditions, the angle the collector is set at, and the amount of water in the can. The temperature increase should level off after 30 to 40 minutes.

Some typical results are given below.




## Evaluation

Inspect the solar water heaters to determine how closely students followed the directions given.

Collect the data sheets and graphs to ascertain if students measured and recorded temperature changes properly. Note if the calculated heat absorption is reasonable and accurate.

Review students' answers to the questions for accuracy and level of inference.

## Modifications

Although standard laboratory thermometers are used in this activity, less expensive metal-backed thermometers can be substituted. Just make sure the tip of the thermometer is in the water and that the thermometer can be read.

If 12-ounce beverage cans are used, the thermometers can be inserted through the tab openings. The holes in the jar lids and cardboard will then have to be punched off-center. Plastic lids to reseal pop-top cans (available in supermarkets) can be used in place of the balloons.

## References


Build Your Own Solar Water Heater, Stu Campbell and Doug Taff.
(Garden Way Publishing Co., Charlotte, VT 05445, 1978, $7.95/paper.)

Home Guide to Solar Heating and Cooling, Jackson Hand.
(Harper and Row Publishers, Inc., Keystone Industrial Park, Scranton, PA 18512, 1978, $3.95/paper.)

Solar Energy, Franklyn Branley.
(Thomas Y. Crowell Co., Harper and Row Publishers, Inc., Keystone Industrial Park, Scranton, PA 18512, 1975, $7.95.)

The Solar Home Book: Heating, Cooling, and Designing with the Sun, Bruce Anderson and Michael Riordan.
(Brick House Publishing Co., 34 Essex St., Andover, MA 01810, 1976, $9.50/paper.)

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.)

# 3 Detecting Solar Energy

Solar energy is energy radiated (given off) by the sun. This energy, in the form of radiation, travels through space away from the sun in all directions. Because the earth is so small and far away from the sun, it receives only a small portion of the total radiation that the sun gives off. Most of the solar radiation that reaches the earth's surface is in the form of visible light or heat (infrared radiation).

How can we detect the presence of solar energy? We know that our skin and clothes feel warm when we stand in sunlight; we also know that our houses tend to be warmer and brighter on sunny days. But the key to detecting solar energy is remembering that energy is defined as THE ABILITY TO DO WORK and that work is defined as MOVING SOMETHING THROUGH A DISTANCE BY APPLYING SOME FORCE. One instrument that allows us to "see" the work done by solar energy is called a radiometer. By using a radiometer similar to the one pictured above, we can detect the presence or absence of solar energy, and we can determine when we have different amounts and different types of it.

# objectives

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

- o describe the appearance of a paddle radiometer,
- o explain the purpose of the radiometer,
- o state the relationship between the amount of sunlight striking the radiometer and the rate at which it spins, and
- o demonstrate that radiation from the sun is a form of energy.

# skills and knowledge you need

The skills of following directions and observing carefully

The skill of drawing a bar graph

A knowledge of the meaning of the terms solar radiation, visible light, and infrared radiation

# materials

a paddle radiometer

pieces of cardboard (or black construction paper) at least 30 cm on a side

a timing device (clock, watch, or electronic timer)

a can or other container large enough to fit over the radiometer

a wax pencil or small piece of tape

an incandescent lamp (one or two per class)

a fluorescent lamp (one or two per class)

a metric ruler

# procedure

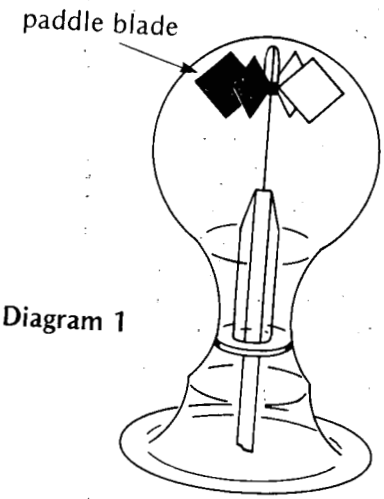



Diagram 1

1. Observe the radiometer carefully to see how it is constructed (Diagram 1). Answer Questions 1 and 2 in the Question section.

2. Place the radiometer on a table in sunlight and observe what happens. Answer Question 3.

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

3. Place the can over the radiometer in the sunlight (Diagram 2). Leave the can in place for about a minute, then remove it quickly, being careful not to disturb the radiometer. Observe the paddles the instant you remove the can. Answer Question 4.

4. Think about how you could use a radiometer to detect the presence of solar energy. Answer Question 5.

5. Use a wax pencil or piece of tape to place a small mark on the side of the radiometer's bulb (Diagram 3). You will use this mark as a reference point to count the number of complete rotations (turns) of the radiometer's paddle wheel.

6. a. Place the radiometer in direct sunlight and count the number of complete rotations the paddle wheel makes in one minute. Record this number in the appropriate space on the Data Table.

   b. Use the cardboard pieces to partly shade the radiometer from the sunlight (Diagram 4). Count the number of complete rotations the paddle wheel makes in one minute. Record this number in the Data Table.

   c. Use the cardboard pieces to completely shade the radiometer from the sunlight (Diagram 4). Count the number of complete rotations the paddle wheel makes in one minute. Record this number in the Data Table.

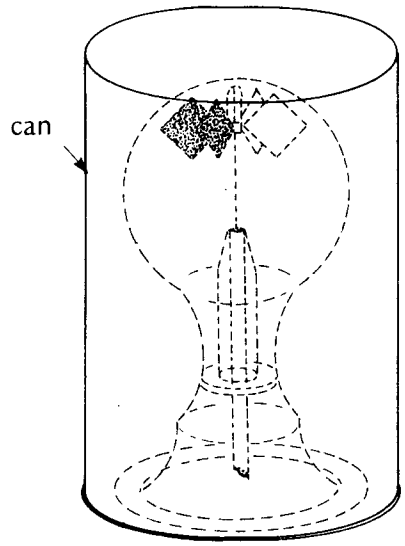



Diagram 2

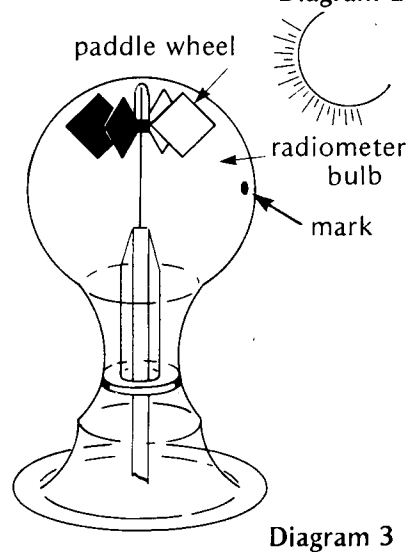



Diagram 3

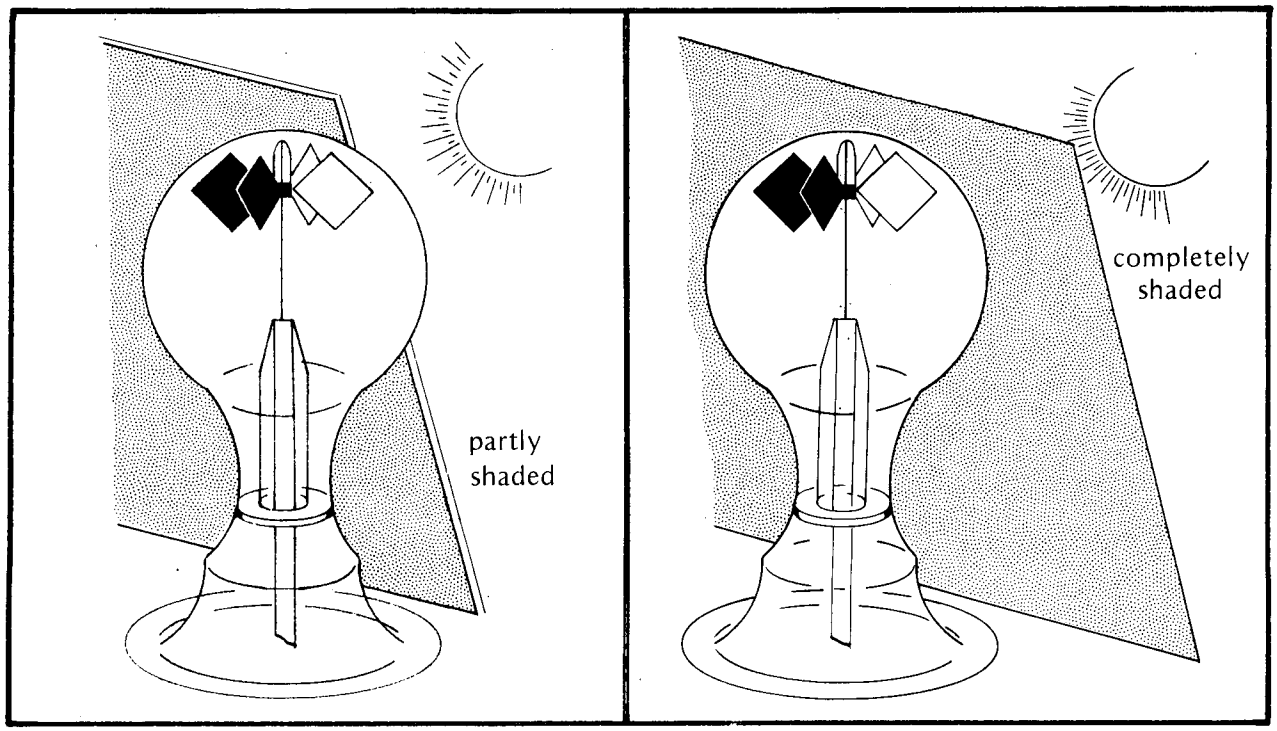



Diagram 4

7. Use the grid provided to construct a bar graph of the data you collected. Answer Question 6.

8. Take your radiometer to the lighted incandescent lamp located somewhere in the classroom. Place your radiometer about 20 cm away from the lamp and position it so that the radiation from the bulb strikes it. Observe what happens and answer Question 7.

*Caution: Do not look directly at the light bulb. Observe the radiometer from behind the lamp.*

9. Now place your radiometer about 20 cm away from the lighted fluorescent lamp. Position the radiometer so that the radiation from the bulb strikes it. Observe what happens and answer Question 8.

# questions

1. How many paddle blades does the radiometer have? Are both sides of each paddle blade the same color?

2. What colors are the opposite sides of each paddle blade? Looking at two blades, do paddle sides of the same color or of unlike colors face each other?

3. What happened when you placed the radiometer in sunlight?

4. What were the paddles doing the <u>instant</u> you removed the can?

5. How can you use a radiometer to detect solar energy?

6. Based on your bar graph, what is the relationship between the amount of sunlight striking the radiometer and the rate at which the paddle wheel turns?

7. What happened when you placed the radiometer next to the incandescent lamp?

8. What happened when you placed the radiometer next to the fluorescent lamp?

9. An incandescent bulb gives off large amounts of visible light <u>and</u> infrared radiation. A fluorescent bulb gives off large amounts of visible light <u>but hardly any</u> infrared radiation. Based on this information, does your radiometer detect primarily visible light, primarily infrared radiation, both, or neither? Explain your answer.

10. From what you observed in this activity, is it possible for a form of solar radiation to strike the radiometer without the paddle wheel turning? Why or why not?

11. When the paddle wheel of the radiometer turned, did the dark or light side of the blades face forward?

12. From what you have learned in this activity, how can a radiometer demonstrate that sunlight is a form of energy? (Hint: Remember the definition for energy.)

# looking back

There are many ways of detecting and measuring solar energy. We can use our eyes and our skin to see the light and feel the warmth of solar radiation. But our eyes and skin don't allow us to measure that radiation very precisely.

The radiometer is a simple instrument that allows us to detect solar energy and, to some degree, measure it. By the rate at which its paddles turn, the radiometer gives us some idea of how much energy is present. The turning paddles also remind us that solar energy is real energy, which can be harnessed to do work.

# going further

You have demonstrated that sunlight can do work. But you may have no idea how this work is done. Based on the differences between the two sides of each blade, can you explain what causes the paddle wheel to turn in the sunlight? Check your answer with your teacher.

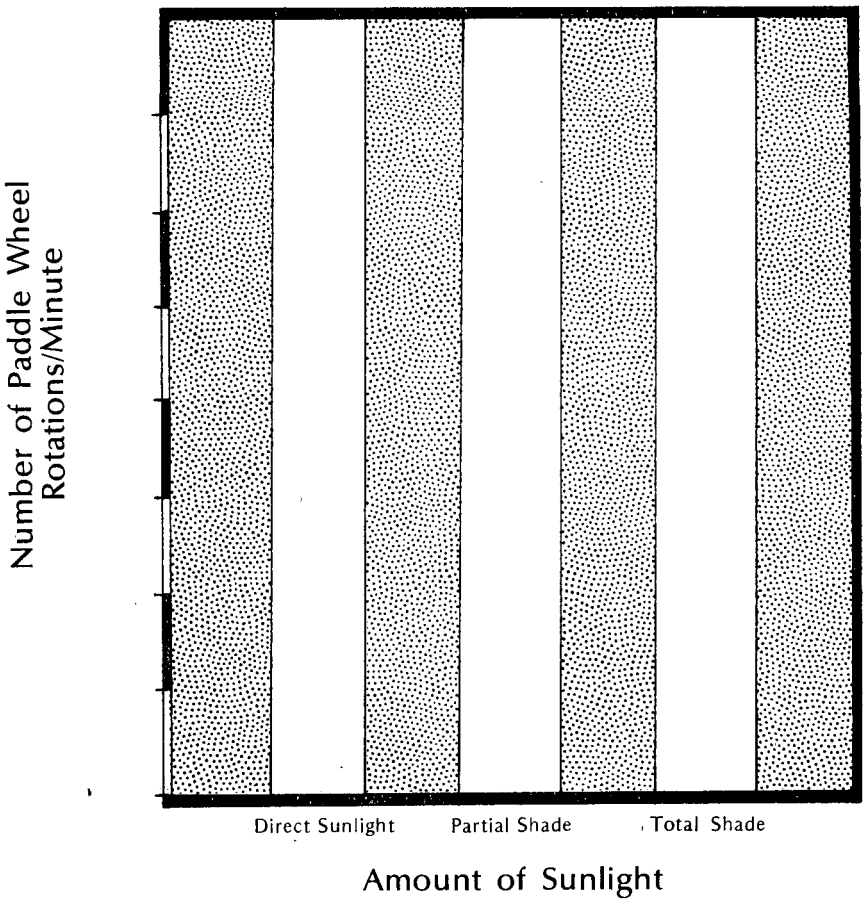
Do you think the radiometer would work if the inside were a perfect vacuum? Why or why not?

If a radiometer is held near an open fireplace or a woodstove, its paddle wheel spins with the dark sides always moving away from the source of radiation. If the radiometer is removed from the source of radiation, the paddle wheel quickly slows, stops, and then begins to spin in the opposite direction. Can you explain why?

## Data Table

| Amount of Sunlight | Number of Paddle Wheel Rotations/Minute |
|---|---|
| Direct Sunlight | |
| Partial Shade | |
| Total Shade | |

## Bar Graph



Teacher Information

# Detecting Solar Energy

## Suggested Grade Level and Discipline

Science, grades 6-8
Physical Science

## Skill Objectives

Making careful observations and inferring from them

Constructing a bar graph

Demonstrating that sunlight is a form of energy

Measuring rotations/minute and determining the relationship between speed of rotation and light intensity

## Major Understandings

A paddle radiometer is a simple instrument that detects solar energy. Its paddle wheel will rotate in sunlight but not in darkness.

The rate of the radiometer's spin is a direct function of the intensity of sunlight striking the radiometer.

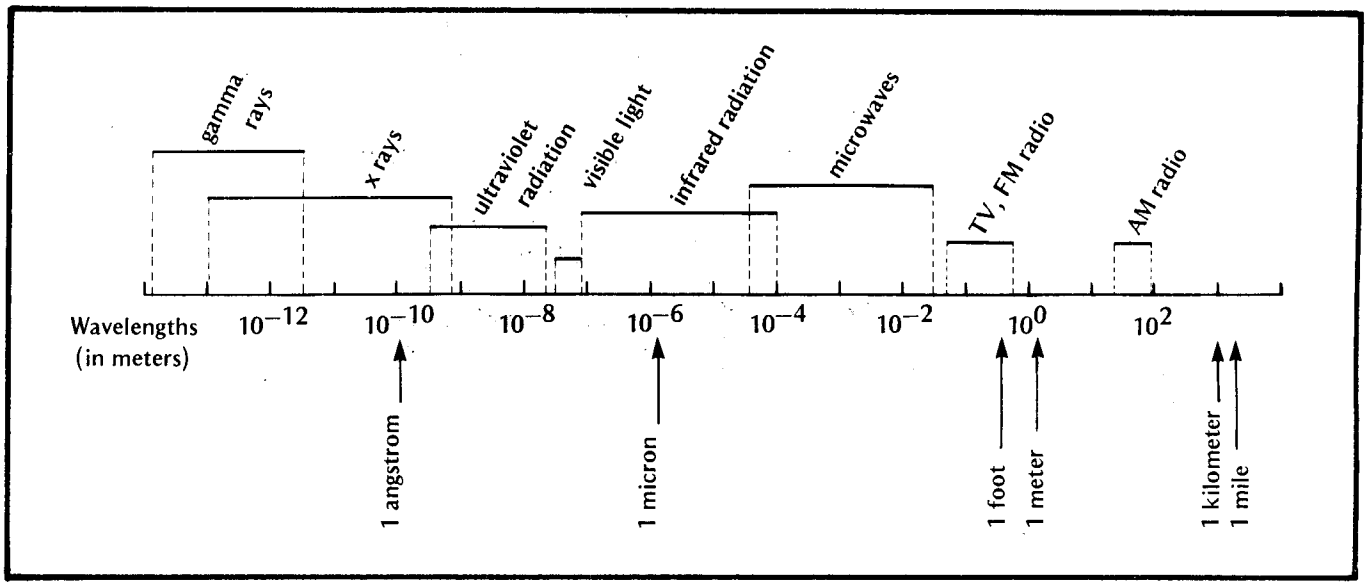
The radiometer is sensitive to infrared radiation, not visible light.

The radiometer detects solar energy because solar energy causes the paddle wheel to turn, therefore doing work on it. Because solar energy can do work on the radiometer, it is demonstrated to be a form of energy.

## Background

The sun radiates many different types of energy, including gamma rays, x-rays, ultraviolet light, visible light, infrared radiation, and radio waves. Collectively, these different wavelengths of light are known as the electromagnetic spectrum, but usually we just simply call them solar radiation. All but visible light and infrared radiation are almost entirely absorbed by the earth's atmosphere, so most of the sun's energy that strikes the earth's surface is in the form of visible or infrared radiation.

The paddle radiometer is a simple instrument that detects solar radiation by responding to infrared radiation. The speed of



rotation of the paddle wheel depends upon the intensity of radiation. How the radiometer actually functions is closely related to the partial vacuum created inside the radiometer bulb. Because of this partial vacuum, air molecules inside the radiometer move about much more freely than they normally would. Each paddle blade has a light-colored and a dark-colored side. When sunlight strikes the radiometer the dark sides absorb more radiation and become warmer than the light sides. The heat is stored as increased energy of motion (kinetic energy) of the molecules. When the freely moving air molecules strike the faster vibrating molecules of the dark side, they take on more energy and bounce away at a higher speed than those striking the more slowly vibrating molecules of the light side. The result is that the paddle wheel begins to move in the partial vacuum as the faster air molecules "kick away" harder from the dark sides. The paddle wheel spins with the light sides facing forward. As the radiation intensity increases, even more energy is absorbed by the dark sides than the light sides. More kinetic energy is transferred to the air molecules hitting the dark sides, these air molecules kick away even faster, and the paddle wheel's rate of rotation increases.

When the paddle wheel turns, a force is being applied through a distance. Therefore, solar radiation is able to do work and meets the definition of energy.

## Advance Planning

Obtain #10 cans from the school cafeteria or have students bring coffee cans, oatmeal containers, or other large containers from home.

Pre-cut the cardboard squares.

Read over the background section so you understand how the radiometer works. You may want to duplicate this section for students.

Set up one or two incandescent lamps and one or two fluorescent lamps. They should have reflectors attached and can be mounted on ringstands. Position the lamps so that students can observe the radiometers from behind them.

If necessary, you may be able to borrow extra radiometers from other science classrooms.

## Suggested Time Allotment

One or two class periods

## Suggested Approach

Discuss the terms solar radiation, infrared radiation, and visible light with the students before the activity begins. Also discuss the concepts of work and energy.

Students should work in pairs so that one student can time while the other counts rotations.

If radiometers are in short supply, consider doing the activity as a teacher demonstration or as one of several solar activities being performed in the classroom at the same time, with student groups rotating from activity to activity.

Since student interest in how the radiometers work will be high, explain this as part of the class discussion.

## Precautions

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

*Caution students never to look directly at the sun.*

*Remind students to observe the radiometers from behind the lamps.*

## Points for Discussion

Why is it important to know that sunlight is a form of energy?

Besides turning the paddle wheel of the radiometer, what other work can sunlight do?

Why does the radiometer's paddle wheel rotate faster under high light intensities?

Why do the light-colored sides face forward when the paddle wheel spins?

## Typical Results

The radiometer will rotate in the presence of sunlight, but not in darkness. As the intensity of radiation increases, the rate of rotation increases. The radiometer will rotate under the incandescent lamp but not under the fluorescent lamp.

## Evaluation

Check students' data tables and bar graphs for accuracy, neatness, and completeness.

Observe the students' ability to follow directions and to make observations. Observe whether the students adhere to safety rules.

Ask students to describe the radiometer and to explain its purpose.

Give students sample speeds of rotation for the radiometer and ask them to order these according to intensity of radiation.

Ask students to demonstrate that sunlight is a form of energy.

## Modifications

If weather conditions are unfavorable, an incandescent lamp can be substituted for sunlight. However, the effectiveness of the activity with younger students may be reduced.

It can be demonstrated further that the radiometer responds to infrared radiation rather than visible light by placing a flat bottle of water between a lighted incandescent bulb and a radiometer. The water, although transparent to visible light, absorbs most of the infrared. Replace the water with a solution of carbon disulfide and iodine; this liquid is transparent to infrared but opaque to visible light. Have students compare the effects on the speed of rotation of the radiometer's paddle wheel.

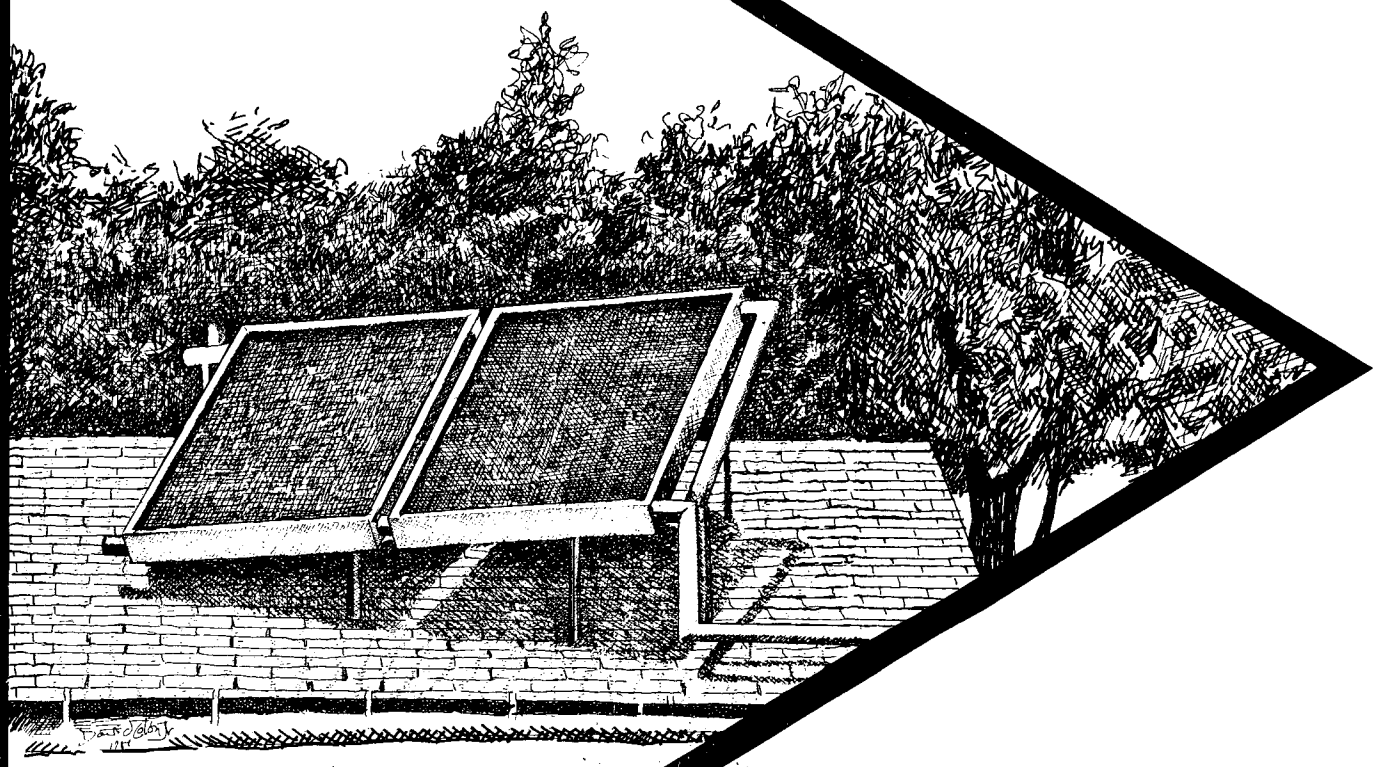
## References

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

The Radiometer: What Makes it Work?
(Windsor Electronics, Inc., P.O. Box 662, Wheaton, IL, 60187, free.)

Teaching High School Science: A Source Book for the Physical Sciences, Alexander Joseph et al.
(Harcourt Brace Jovanovich, Inc., 757 Third Ave., New York, NY 10017, 1961, out of print.)

# 4 Aiming at the Sun



People sometimes make the misleading statement, "The sun is overhead." In reality the sun is never directly overhead at most latitudes of the earth's surface. It is usually at some altitude less than 90° above the horizon, and its altitude changes with the time of day and the time of year.

To collect the most possible solar energy, you have to know the altitude of the sun and aim your solar collector so that the sunlight falls on it directly.

# objectives

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

- set a solar meter at various angles of inclination from the ground,
- estimate the altitude of the sun,
- use two methods to determine the angle at which to set the solar meter to obtain the maximum reading, and
- predict the best angle at which to set a solar collector at a particular time of day.

# skills and knowledge you need

Using a protractor

Graphing data

# materials

a solar meter or photoelectric light meter

a protractor

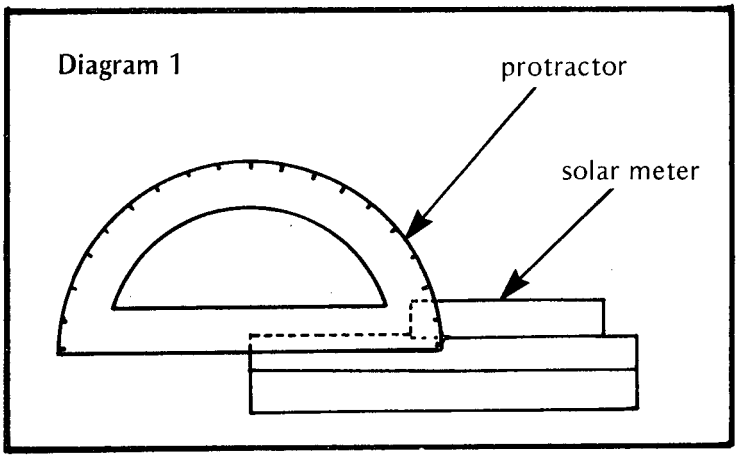
# procedure

1. Take the materials outside to a sunny spot. If possible, find a location with a picnic table or a bench.

2. Place the solar meter flat on a level spot so that the surface of the solar cell is aimed straight up. Record on the Data Table, under Day 1 and next to $0^{\circ}$, the reading of the solar meter.

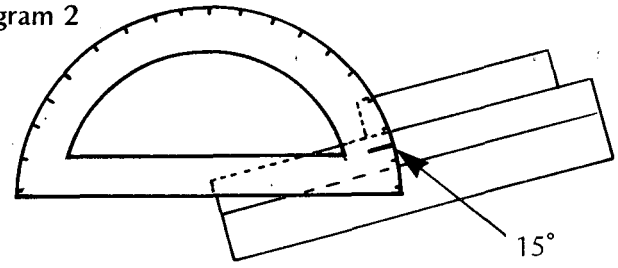
3. Place the protractor so that the bottom edge aligns with the solar meter's surface. (See Dia-

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



gram 1.) Turn the protractor and the meter so that they point toward the sun. Lift the solar meter so that its surface is parallel to $15^{\circ}$ on the protractor. In this position the solar cell surface forms an angle of $15^{\circ}$ with the ground. Record the solar meter reading next to $15^{\circ}$ on the Data Table.

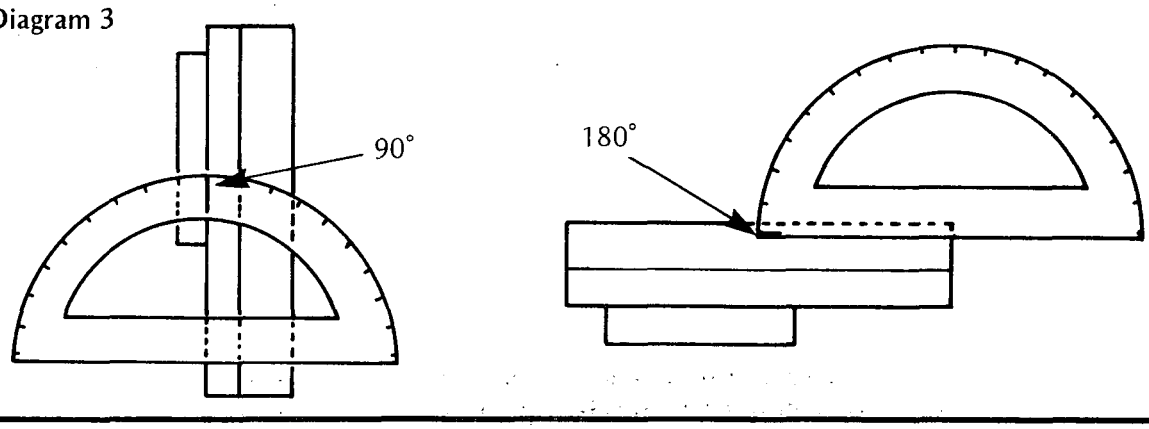
Diagram 2




4. Lift the solar meter until its surface is parallel to $30^{\circ}$ on the protractor. Record the solar meter reading.

5. Repeat Step 4 for the following angles: $45^{\circ}$, $60^{\circ}$, $75^{\circ}$, $90^{\circ}$ (the solar cell should face the horizon), $105^{\circ}$, $120^{\circ}$, $135^{\circ}$, $150^{\circ}$, $165^{\circ}$, and $180^{\circ}$ (the solar cell should face the ground).

Diagram 3

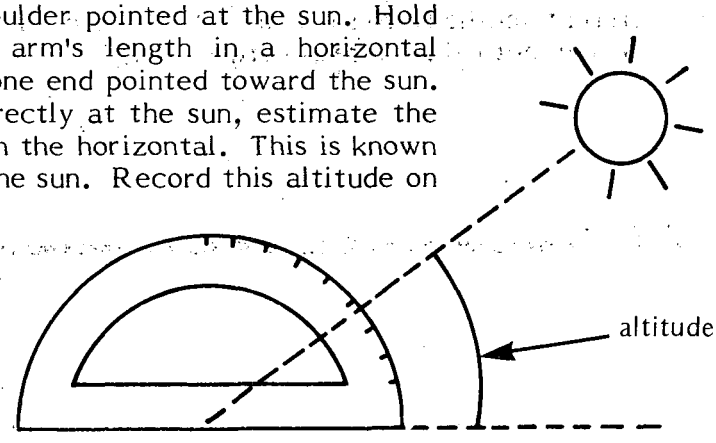



6. Record the general cloud conditions over the course of this activity. Also record the time of day.

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

7. Stand with one shoulder pointed at the sun. Hold the protractor at arm's length in a horizontal position and with one end pointed toward the sun. Without looking directly at the sun, estimate the angle it makes with the horizontal. This is known as the altitude of the sun. Record this altitude on the Data Table.

Diagram 4



8. Subtract the altitude of the sun from $90^{\circ}$. Place the solar meter at this resulting angle. At this angle of inclination from the ground, the sun's rays will strike the solar cell directly (on the perpendicular). Record the solar meter's angle of inclination and its reading on the Data Table.

9. Repeat this entire activity at the same time on another day when the cloud conditions are different. Record your results under Day 2 on the Data Table.

10. Plot each set of data on the graph provided. Be sure to label the lines Day 1 or Day 2.

# questions

1. At which angle of inclination did the maximum amount of light energy strike the solar meter on Day 1? On Day 2?

2. Were these angles the same? Should they have been the same? Why or why not?

3. Compare the maximum reading you obtained (Question 1) with the reading when the meter was set at $90^{\circ}$ minus the altitude. How similar are the readings? How similar should they be?

4. How did the altitude of the sun relate to the angle of the maximum solar meter reading? Explain these results.

5. Did your solar meter ever read zero? Why or why not?

6. How did the cloud cover affect the amount of light energy received from the sun?

7. Based on the data you collected, what would be the best angle of inclination at which to position a solar collector on the day and time of each reading?

8. Think about the path of the sun through the sky over an entire day and an entire year. Would your answer to Question 7 always be the best angle at which to place a collector? Why or why not?

9. Describe two different methods you can use to find the angle at which to place a solar collector. Which method is more accurate? Why?

# looking back

The data you collected in this activity should indicate that the angle a solar collector is mounted at is important. A properly oriented collector will heat up quickly in sunlight, but one that is angled the wrong way may collect so little heat that you will think the collector doesn't work. You have to aim at the sun.

However, keeping the collector aimed at the sun all day would be a difficult job. You'd probably have to mount the collector on a complicated (and expensive) sun-tracking mechanism. The answer is to choose the orientation that will work best on a daily average.

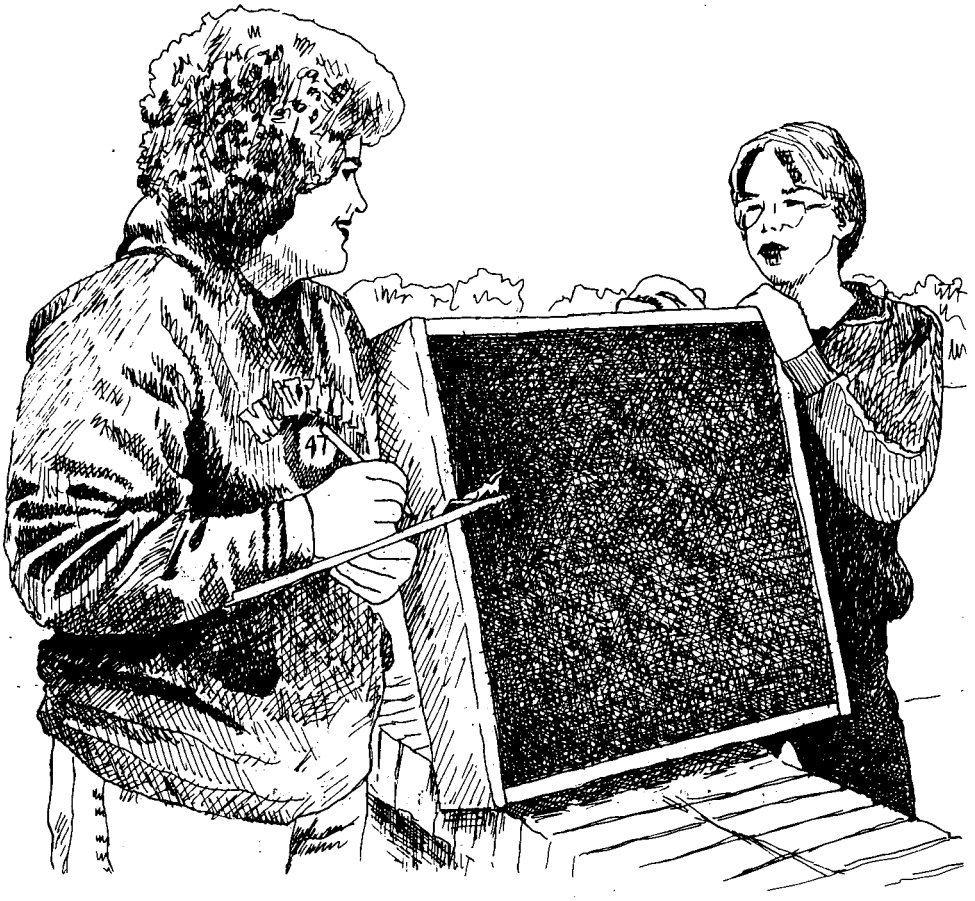
## going further

Repeat the activity at 3 or 4 different times of day; for example, 8:00 A.M., noon, 4:00 P.M. How do the results change?

Plot the altitude of the sun every hour from sunrise to sunset. Graph the results and then interpret them.

Plot the altitude of the sun at noon once a month for a year. Graph the results and then interpret them.

Try Activity 4 in the Industrial Arts Activities book or Activity 3 in the Earth Science Activities book. Both of these activities will further explain solar altitude and angle of inclination.



# Data Table

## Solar Meter Reading

| Angle (°) | Day 1 | Day 2 |
|---|---|---|
| 0 | | |
| 15 | | |
| 30 | | |
| 45 | | |
| 60 | | |
| 75 | | |
| 90 | | |
| 105 | | |
| 120 | | |
| 135 | | |
| 150 | | |
| 165 | | |
| 180 | | |
| Cloud Conditions | | |
| Time of Day | | |

Day 1

Altitude of the sun at the time of the readings _____

Angle of inclination of solar meter ($90^{\circ}$- altitude) _____

Solar meter reading at this angle _____

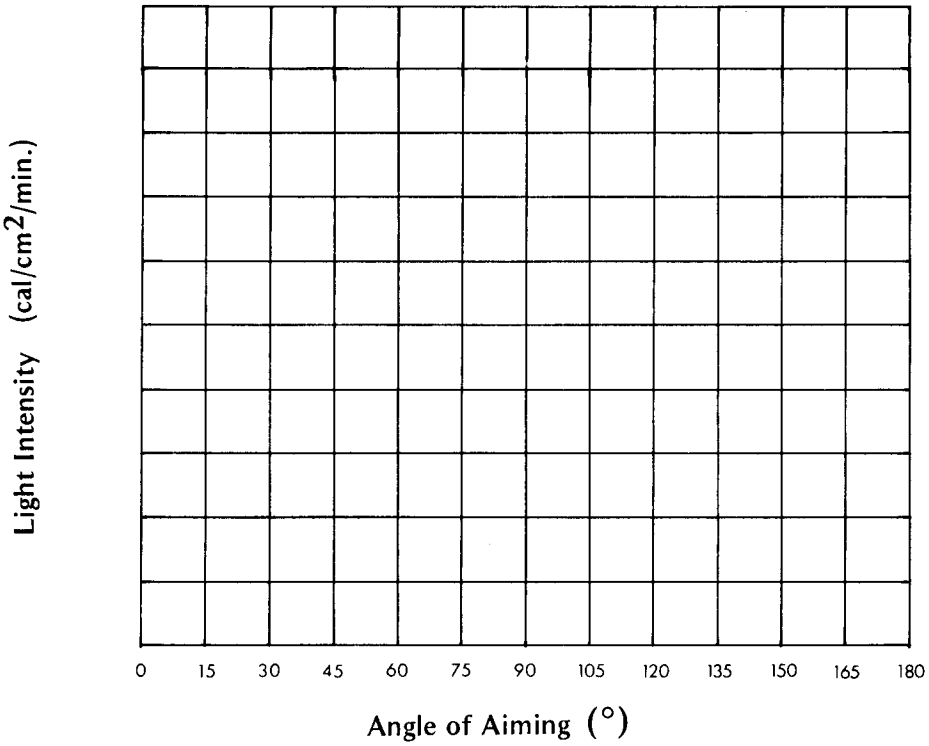
Day 2

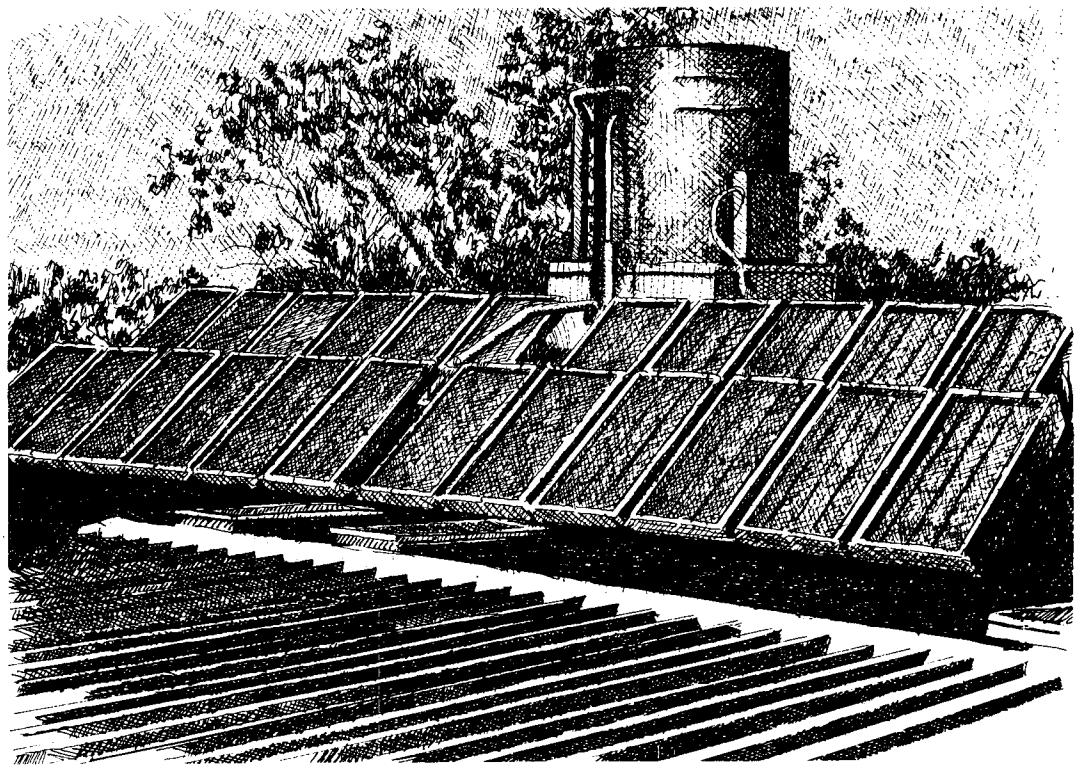
Altitude of the sun at the time of the readings _____

Angle of inclination of solar meter ($90^{\circ}$- altitude) _____

Solar meter reading at this angle _____

# Graph


Light Intensity (cal/cm2/min.)
0
15
30
45
60
75
90
105
120
135
150
165
180
Angle of Aiming (°)



Teacher Information

# Aiming at the Sun

## Suggested Grade Level and Discipline

Science, grades 7-9
General Science
Physical Science

## Skill Objectives

Using a solar meter to measure the intensity of solar radiation

Estimating the altitude of the sun

Using two methods to determine the most effective angle at which to aim a solar collector at a particular time of day and year

## Major Understandings

The level of solar intensity depends upon the degree of cloud cover, the sun's altitude, and the time of year.

The most effective angle of inclination at which to aim a solar collector is the complement of the solar altitude at a particular time of day. This orientation will be perpendicular to the sun's rays.

The most effective angle of inclination for a fixed collector is one that allows the most heat collection on a daily average.

Atmospheric scattering of sunlight results in some indirect solar radiation on a surface aimed at any angle with the ground.

## Background

Energy from the sun takes the form of electromagnetic radiation, much of it in the range of visible light. Solar radiation arriving at the outside of the earth's atmosphere is scattered and diffused by the atmosphere. About 28% is reflected back into space while another 25% is absorbed by ozone, carbon dioxide, and clouds in the upper atmosphere. Only about 47% of incoming solar radiation actually arrives at the earth's surface.

A photovoltaic or solar cell measures the intensity of this radiation. It is a thin disc or rectangle composed of two layers of a semiconductor, 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 place the solar meter at various angles of inclination from the ground. They will discover that solar radiation will be most intense when the surface of the solar meter is perpendicular to the sun's rays. From this, they are able to predict the optimum angle at which to place a solar collector.

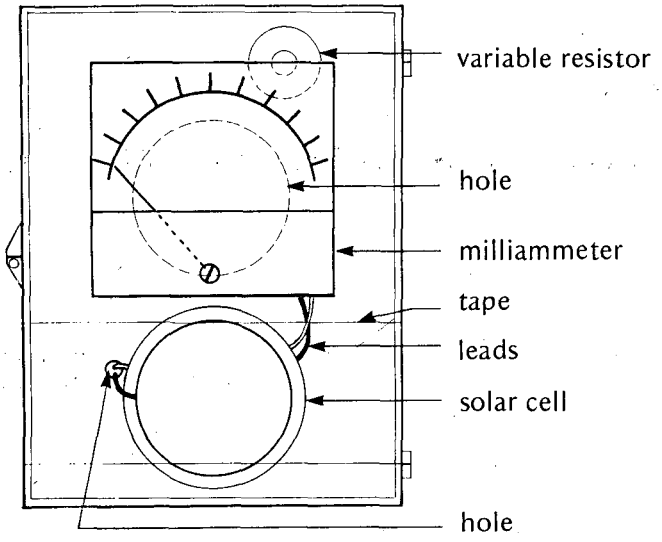
## Advance Planning

If your school does not have pyranometers or other solar meters, they can be made easily by wiring together a solar cell, a milliammeter, and a shunt resistor, 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.

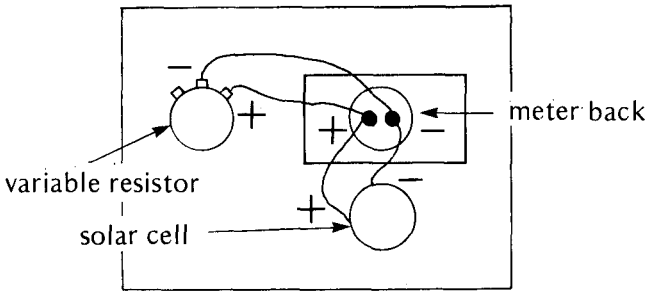
### Building the Solar Meter

Materials

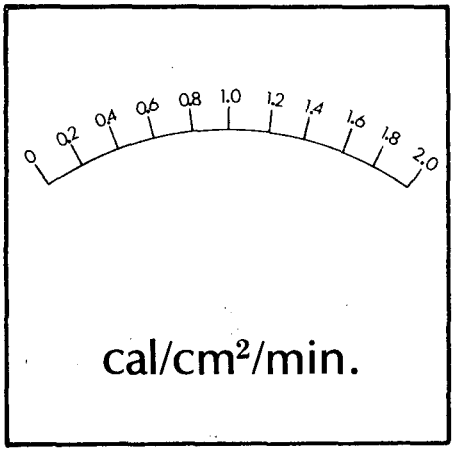
photovoltaic cell (at least 1 $cm^2$)
milliammeter (Radio Shack #270-1752, 0-1 mA)
variable resistor (0-1000 ohm potentiometer)
plastic case (about 9 x 12 cm with clear plastic top)
wire




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$^\circ$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.*

To save your own time and effort, you may want to have students help calibrate the solar meters.

Photoelectric light meters are usually available from the photography classroom. For this activity the light meters may be too sensitive and may need filters.

## Suggested Time Allotment

Two class periods to take readings

One class period to graph and interpret data

## Suggested Approach

First acquaint students with the equipment. Stress the delicacy of the solar meter. Explain how it was built, how it operates, and its function. Indicate the unit in which it is calibrated.

Demonstate how to use the protractor in determining the angle of inclination of the solar meter.

If there is insufficient equipment for the entire class, it may be necessary to send a different group of students outdoors each day to take readings. This procedure will provide a greater amount of data to interpret.

After discussing the most effective angle at which to aim a solar collector, students may wish to confirm this prediction by setting up solar collectors they have already designed for other activities.

## Precautions

*Warn students not to look directly at the sun when estimating its altitude. You may want to perform this portion of the activity yourself to ensure student safety.*

*Solar cells are extremely fragile. Remind students to treat them very gently.*

*Never use a lens or mirror to focus sunlight on a solar cell. The heat produced will damage the cell.*

*With moving cloud cover, radiation values may fluctuate and lead to ambiguous results. Try to do the activity on a clear or evenly overcast day.*

## Points for Discussion

Why is the angle at which a surface is aimed toward the sun related to the amount of energy it receives?

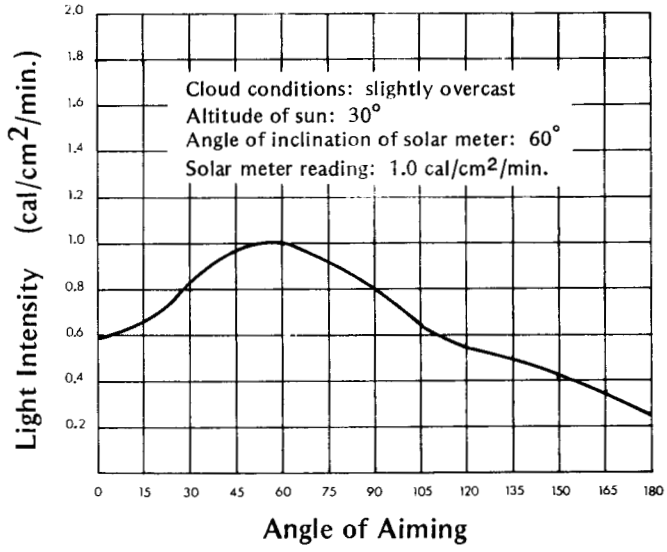
Why will there be differences in the amounts of solar radiation recorded at the same times and locations on different days?

How would you determine the optimal orientation for a solar collector in order to ensure it captured the maximum radiation available throughout the year?

## Typical Results

As the angle of inclination approaches the complement of the sun's altitude, the solar meter reading will approach its maximum value.

Sample data are displayed below.




## Evaluation

Observe students' use of the instruments.

Collect and review data tables and graphs for accuracy and completeness.

Check students' answers to questions.

Ask students to determine the most effective angle of collector inclination for a given solar altitude.

## Modifications

Substitute an astrolabe or sextant for the protractor when estimating solar altitude.

## References

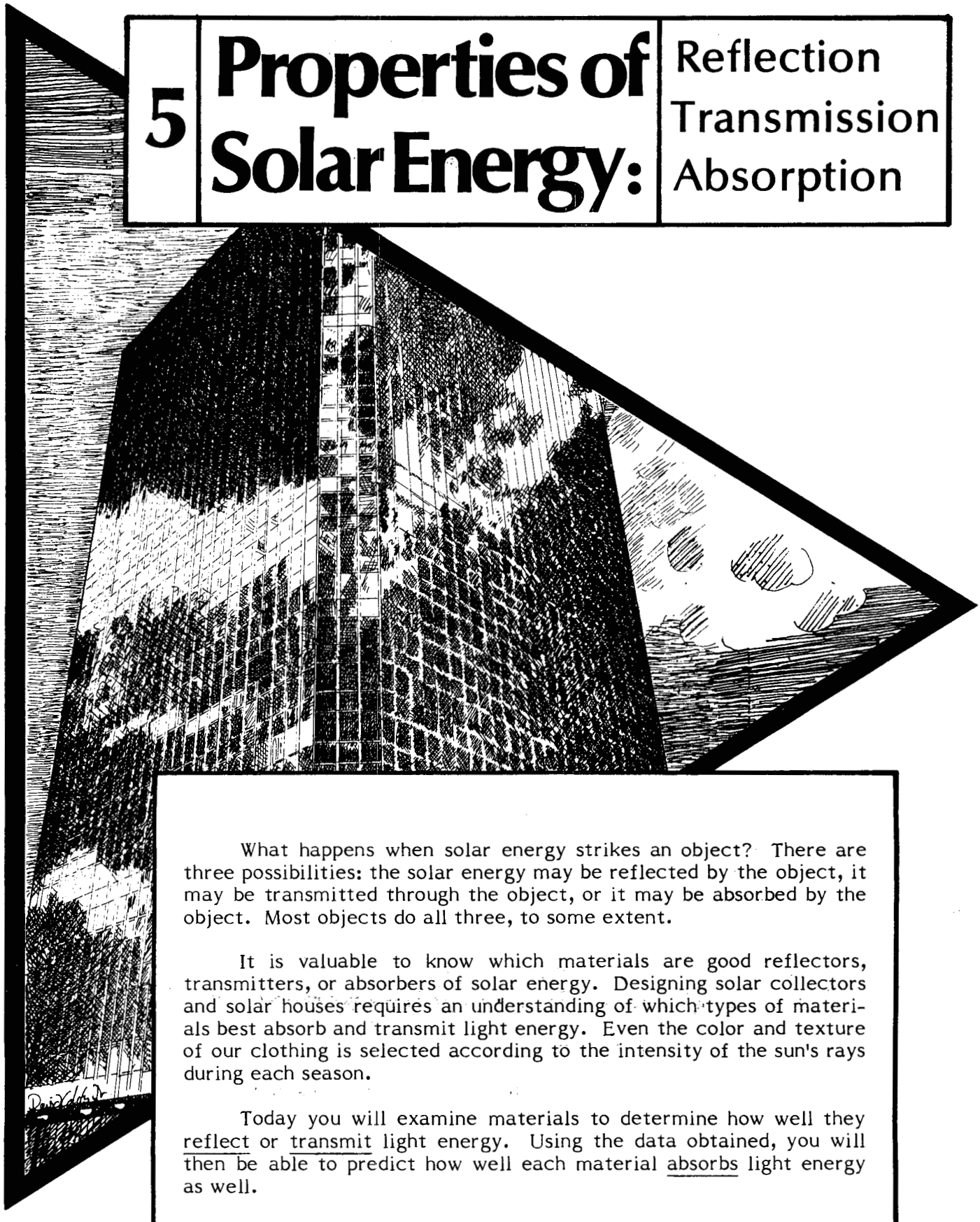

Direct Use of the Sun's Energy, Farrington Daniels.
(Ballantine Books, Inc., 400 Hahn Rd., Westminster, MD 21157, 1974, $1.95/paper.)

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

Solar Energy Experiments, Thomas W. Norton.
(Rodale Press, Inc., 33 E. Minor St., Emmaus, PA 18049, 1977, $5.95/paper.)

The Solar Home Book: Heating, Cooling, and Designing with the Sun, Bruce Anderson and Michael Riordan.
(Brick House Publishing Co., 34 Essex St., Andover, MA 01810, 1976, $9.50/paper.)

# 5 Properties of Solar Energy: Reflection Transmission Absorption



What happens when solar energy strikes an object? There are three possibilities: the solar energy may be reflected by the object, it may be transmitted through the object, or it may be absorbed by the object. Most objects do all three, to some extent.

It is valuable to know which materials are good reflectors, transmitters, or absorbers of solar energy. Designing solar collectors and solar houses requires an understanding of which types of materials best absorb and transmit light energy. Even the color and texture of our clothing is selected according to the intensity of the sun's rays during each season.

Today you will examine materials to determine how well they reflect or transmit light energy. Using the data obtained, you will then be able to predict how well each material absorbs light energy as well.

# objectives

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

- o demonstrate that solar energy can be reflected and transmitted,
- o compare the amounts of solar energy reflected and transmitted by different materials,
- o predict how well different materials will absorb solar energy, and
- o select those materials most effective for transmitting and absorbing energy in a solar collector.

# skills and knowledge you need

The skill of reading a meter

The skill of recording data

A knowledge of the functions of a solar collector's parts

# materials

a solar meter

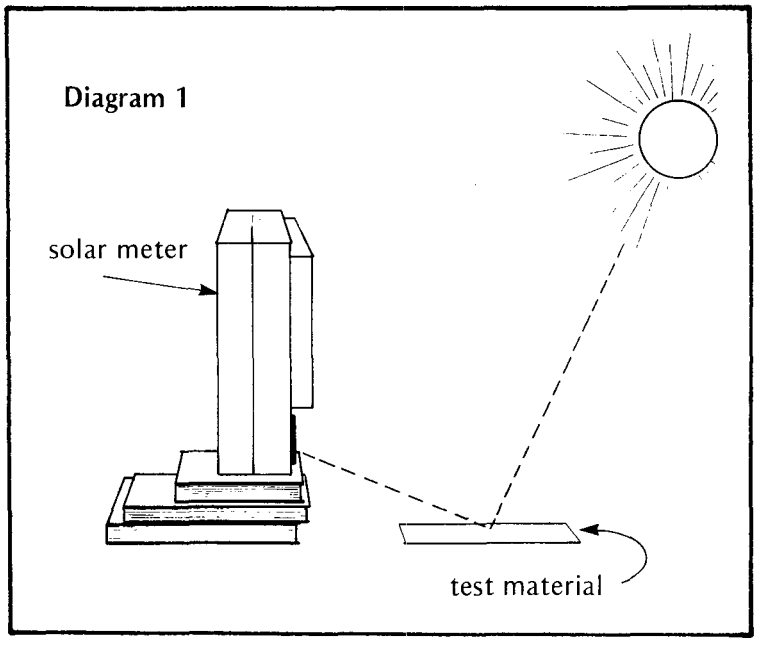
squares, 5 cm on a side, of

- mirror
- window glass
- frosted glass
- aluminum foil
- unpainted copper sheeting
- black-painted copper sheeting
- wood
- waxed paper
- clear plastic wrap
- cellophane (clear, yellow, red, blue, green)
- construction paper (black, yellow, red, blue, green)

# procedure

## Reflection

1. Place the first item to be tested (the mirror) flat on a table top in the sun. Place the solar meter on the opposite side of the item from the sun. Position the solar meter so that it receives as much reflected light as possible from the test material, but as little direct light as possible. (See Diagram 1.) You may have to stack some books under the solar meter.




2. Leave the solar meter in this position for the rest of the measurements involving reflection.

3. Record the solar meter reading in the Data Table under "reflection." Then remove the test sample and replace it in turn with each remaining test material. Make sure each test material is placed in exactly the same position as the original test item. Record the reading for each test material in the Data Table.

4. Based upon your readings, describe each test material's ability to reflect light. Place one of the following descriptions in the Data Table: excellent, good, fair, poor, or no ability.

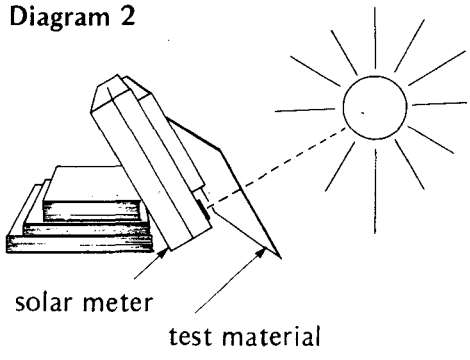
## Transmission

5. Aim the solar meter into the sun so that the meter shows the highest possible reading. Record this reading as the initial one under "transmission" in the Data Table.

6. Prop the solar meter in this position for the rest of the measurements.

7. Hold each piece of material in turn over the cell of the solar meter, keeping it as close to the cell as possible. Always keep each material at the same distance from the meter. (See Diagram 2.) Record the reading for each test material in the Data Table.

8. Based upon your readings, describe each test material's ability to transmit light. Place one of the following descriptions in the Data Table: excellent, good, fair, poor, or no ability.



### Absorption

9. Now inspect your descriptions of each test material's ability to reflect and transmit light. From these data, predict each test material's ability to absorb light. Place one of the following conclusions in the Data Table: excellent, good, fair, or poor.

# questions

1. Which materials were the best reflectors of light? Which were the poorest?

2. Which materials were the best transmitters of light? Which were the poorest?

3. Which materials did you predict were the best absorbers of light? Which were the poorest?

4. On what basis did you make the predictions?

5. Based upon your data, what materials would you use as the cover material, or glazing, for a solar collector?

6. Based upon your data, what color and material would you use in a solar collector to absorb the greatest amount of sunlight? Why?

7. How could you use what you've learned about reflection to increase the absorption of solar energy by a collector?

# looking back

Different materials reflect, transmit, and absorb different amounts of light energy. The color, texture, and chemical composition of a material are important in determining how much energy it can reflect, transmit, or absorb. Once we understand such properties, we can decide how to build an efficient solar collector or passive solar home. You should remember that the degree to which an object reflects, transmits, or absorbs light energy helps to indicate its usefulness in collecting and storing solar energy.

# going further

Repeat this activity using materials other than those given. Are there more effective reflectors, transmitters, or absorbers of light energy than the ones you first tested?

Design the exterior and interior of an automobile for greatest passenger comfort during the summer. Design another automobile for greatest passenger comfort during the winter. What properties of solar energy did you apply in each plan? Why?

Why are leaves green rather than some other color (like black)?

To find out more about the absorption of solar energy, try the next activity, "More on Absorption."

## Data Table

| Material | As a Reflector | | As a Transmitter | | As an Absorber |
|---|---|---|---|---|---|
| | Reading | Description | Reading (Initial:_____) | Description | Conclusion |
| Mirror | | | | | |
| Window Glass | | | | | |
| Frosted Glass | | | | | |
| Aluminum Foil | | | | | |
| Unpainted Copper Sheeting | | | | | |
| Black-painted Copper Sheeting | | | | | |
| Wood | | | | | |
| Waxed Paper | | | | | |
| Clear Plastic Wrap | | | | | |
| Cellophane Clear | | | | | |
| Yellow | | | | | |
| Red | | | | | |
| Blue | | | | | |
| Green | | | | | |
| Construction Paper Black | | | | | |
| Yellow | | | | | |
| Red | | | | | |
| Blue | | | | | |
| Green | | | | | |

Teacher Information

# Properties of Solar Energy: Reflection, Transmission, and Absorption

## Suggested Grade Level and Discipline

Science, grades 6-9
Earth Science
Physical Science

## Skill Objectives

Using a solar meter to record reflected and transmitted light energy

Determining which materials are the best reflectors and which are the best transmitters of light energy

Predicting the absorption capacities of different materials from their abilities to reflect and transmit light

Applying the results of the activity to the design of solar collectors

## Major Understandings

Color, texture, and chemical composition affect the amount of solar energy that a given material will reflect, transmit, and absorb.

The amount of energy absorbed, transmitted, and reflected by a given material must be equal to the energy incident upon it.

The best absorbers are materials which poorly reflect or transmit light energy.

Darker surfaces absorb more solar energy than lighter surfaces.

Window glass and clear plastic sheeting are effective glazings for a solar collector, while black-painted metals are effective absorber plates.

## Background

In this activity, students are asked to compare the relative amounts of solar energy reflected and transmitted by various test materials and to determine which are the best and poorest reflectors and transmitters. They are also asked to use their data to infer which materials are the best absorbers. This can be determined by finding out which materials are the poorest reflectors and transmitters, since, according to the law of conservation of energy, the total amount of energy reflected, absorbed, and transmitted by a single material must be equal to the energy incident upon it.

Understanding these three properties (reflection, transmission, and absorption) of solar energy will help students understand the fundamentals of solar design. Flat plate solar collectors are covered with glazings that transmit the greatest possible amount of sunlight into the collector, where it becomes trapped. Absorber plates usually are made of black-painted metal, which absorbs the greatest amount of this trapped sunlight and converts it to heat. The objective is to convert the greatest amount of sunlight possible into heat energy, thus achieving maximum efficiency of conversion. Concentrating collectors can achieve greater efficiency than flat plate collectors because they also employ the property of reflection: they concentrate the amount of solar energy striking an absorber by using mirrors to reflect more light onto the absorber.

A solar meter is made by connecting a solar cell to a milliammeter or to a galvanometer. Since the main purpose of this activity is to compare relative amounts of energy reflected and transmitted rather than to measure these amounts, there is no need to calibrate such a "home-made" instrument. (Perhaps it would be better named a solar

"comparometer.") Since the same meter is used to take all of the readings, and since the readings are used only to compare the solar energy reflected or transmitted by different samples, the numbers alone will tell the story. The higher the reading on the meter, the greater the amount of light energy reflected or transmitted, while the lower the reading, the smaller the amount reflected or transmitted.

(For additional information on these three properties of solar energy, see the next activity's background section.)

## Advance Planning

If your school does not have a pyranometer to use as the solar meter, one can be made easily from the following:

a solar cell, 1 cm x 1 cm, delivering 22 mA at .45 V. (This will probably have to be ordered, so allow time for delivery.)

a milliammeter, range 0-15 milliamperes d.c., or a galvanometer. (These items are probably available from the supply cabinet.)

a shunt resistor (0-100 ohm potentiometer). (This will keep the meter within scale and will allow calibration.)

To construct the solar meter, simply connect the leads from the solar cell to the terminals of the milliammeter or the galvanometer. Wire the potentiometer in parallel with the meter. You may want to tape the cell and its wires to the meter or a flat board, since the wires attached to solar cells are easily separated from them.

To construct the more permanent instrument shown in the diagrams, see the instructions in Activity 4, "Aiming at the Sun."

You may want to assemble and cut the test materials ahead of time. Students can help with this task outside of class time.

## Suggested Time Allotment

One class period to perform the activity

One class period to answer the questions and discuss the activity

## Suggested Approach

Define and then discuss the properties of reflection, transmission, and absorption. Use the introductory drawing as a basis for discussion. Does the office building reflect, transmit, and absorb solar energy?

Discuss the relationships between reflection, transmission, and absorption. (Incident solar radiation = reflection + transmission + absorption.)

If students have not worked with solar meters before, explain how photovoltaic cells operate and how to read the solar meter.

If enough solar meters are available, then students should work in small groups (3 to 4 students). Otherwise, this activity can be done as a teacher demonstration or as one of several solar activities being performed in the classroom at the same time.

If time for the activity is limited, groups can run either the reflection or transmission tests, then share their data prior to predicting the absorption capacities of the materials.

Demonstrations of homemade or commercial solar collectors or field trips to collector sites will reinforce the applications required of students in the activity.

## Precautions

*The solar cells are delicate, especially where the leads attach to the cell proper. Resoldering the leads can be difficult if they are broken off. Ask students to handle the solar meters gently.*

*Caution students to be careful in handling glass and metal. Sand or tape the edges if necessary.*

*Caution students not to reflect sunlight into their eyes.*

*Do not use the mirror to focus sunlight on the solar meter. The heat generated may damage the meter.*

*If you are using a galvanometer as the solar meter, it may be too sensitive to angle the solar cell directly into the sun during the transmission tests. If the meter reads more*

*than a full-scale deflection during any of the tests, turn the solar cell away from the sun just enough to give a full-scale deflection with the best transmitters.*

## Points for Discussion

What steps did you take to make sure that the material being tested was the only factor influencing the meter readings? (What variables did you control?)

What types of material would you suggest for the construction of a passive solar house or a greenhouse?

If you wished to use reflected solar energy to cook food in a solar oven, what types of material would you suggest using?

How might you use materials which show themselves to be good solar absorbers?

## Typical Results

The values obtained for reflection and transmission of light energy will vary from group to group as a result of several variables, especially the lack of a calibrated scale.

The best reflectors will be mirror and aluminum foil. The best transmitters will be window glass and clear plastic sheeting. The construction paper, mirror, foil, copper sheeting, and wood will be opaque, transmitting virtually no light energy.

Students should predict that the darker-colored construction papers, black-painted copper sheeting, and wood would be the best absorbers of light energy.

## Evaluation

Observe students' skills in manipulating the equipment, in making observations, in recording, classifying, and interpreting data, and in identifying and controlling variables.

Inspect data tables for reasonable readings and accurate descriptions and conclusions.

Check the quality of the answers to questions that ask the students to apply their findings to the design of solar collectors.

Show students sample data from additional test materials and ask them to predict the best absorbers.

## Modifications

Because weather conditions may be unsuitable, this activity has been designed to be carried out in artificial light if necessary. A 200-watt incandescent lamp with a reflector, mounted on a ring stand, will serve as an effective alternative to sunlight.

To prevent or reduce the possibility of any direct light striking the solar cell during the light reflection tests, mount a 20 cm x 20 cm piece of black construction paper as a curtain between the energy source and the solar cell. At the same time, black construction paper can be placed on the area around the meter and the test materials to minimize any unwanted reflection.

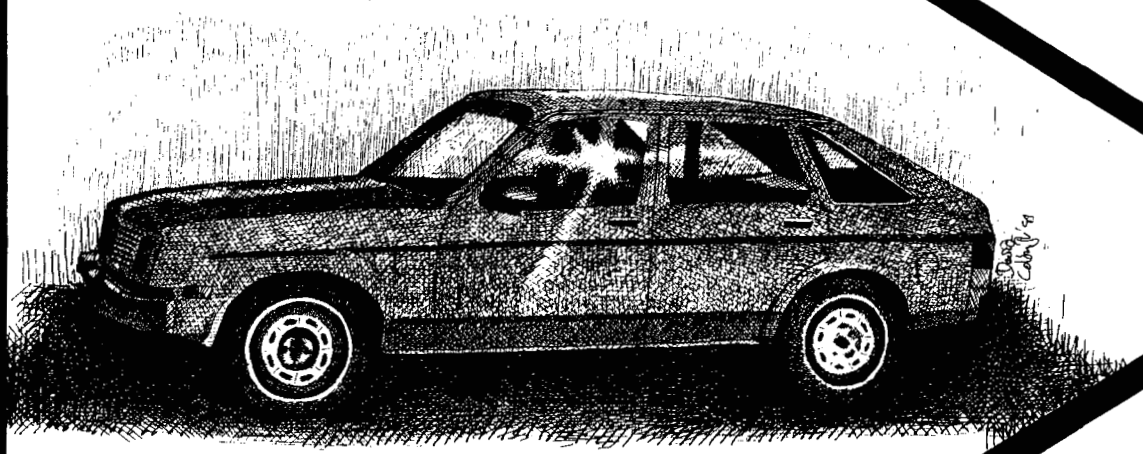
## References


Catch a Sunbeam: A Book of Solar Study and Experiments, Florence Adams.
(Harcourt Brace Jovanovich, Inc., 757 Third Avenue., New York, NY 10017, 1978, $7.95, for student reading.)

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 More on Absorption



Look at a car sitting in a bright glare of sunlight. Three things are happening to the light that is striking it. Some of the light is reflected. We can see that from the bright spots on the chrome, the body, and the windows. Some is being transmitted through the windows. We can see the interior of the car by that transmitted light.

Finally, some of the light is being absorbed. When an object absorbs light it heats up. It is this absorption of light that sometimes makes the body or the seats of a car too hot to touch on a sunny day.

Any object placed in the sunlight absorbs some light. But objects of different kinds and colors absorb different amounts of light.

# objectives

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

- o demonstrate that solar energy can be absorbed by objects and changed to heat energy,
- o determine which colors absorb the greatest amount of solar energy and which absorb the least, and
- o explain why these results occur.

# skills and knowledge you need

Reading a thermometer

Recording and graphing data

# materials

6 large test tubes

6 single-hole rubber stoppers fitted with Celsius thermometers

a piece of corrugated cardboard (16 cm x 16 cm) or a large test tube rack

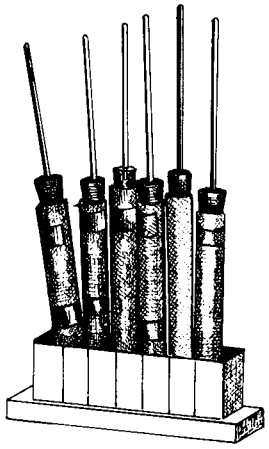
aluminum foil (10 cm x 15 cm)

pieces of construction paper (each 10 cm x 15 cm)
- white
- red
- yellow
- green
- black

scissors

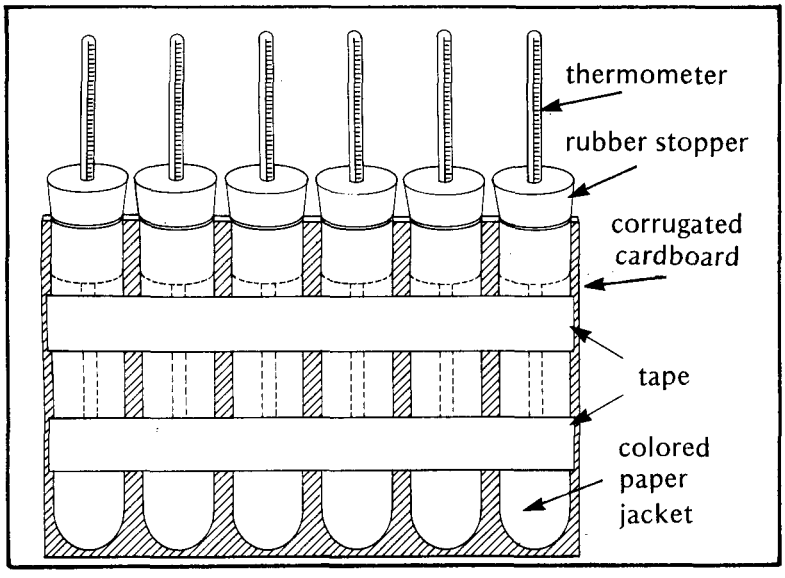
masking tape

a watch or clock with second hand



# procedure

1. Obtain all the needed materials. Wrap each of the first five test tubes in a different colored paper jacket. Wrap the remaining test tube with aluminum foil. Trim and tape the jackets as needed.




2. Insert the stoppers into the test tubes. Place all six test tubes on the cardboard (or in the test tube rack) in the following order: white, red, yellow, green, black, and aluminum foil. Turn the test tubes so that each thermometer scale faces up. Tape the test tubes in place as shown in the diagram.

3. Answer Question 1 in the Question section by predicting which test tubes will absorb the most and which the least solar energy.

4. Place the apparatus in sunlight so that the sun's rays strike the test tubes directly (on the perpendicular). Prop the apparatus in this position for the rest of the activity.

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

5. Immediately read the temperature of each test tube and record it in the proper column of the Data Table. Always read the thermometers and record the data in the same order, starting with white.

6. Record the temperature of each test tube every two minutes for 20 minutes.

7. Use the graph provided to plot the data you collected. Be sure to use a key or to label each line with the correct color. (You may want to draw each line with a different colored pencil.)

## questions

1. Which test tubes do you predict will absorb the most solar energy? The least? Explain your predictions.

2. Which test tube actually absorbed the most solar energy? How do you know? Was your prediction correct?

3. Which test tube actually absorbed the least solar energy? How do you know? Was your prediction correct?

4. List the test tubes in order from the one which absorbed the most solar energy to the one which absorbed the least solar energy.

5. How do you account for the results obtained from the aluminum foil?

6. Why do some colors absorb more solar energy than others? Base your answer on what you know about both absorption and reflection of solar energy.

7. Why do people usually wear light-colored clothes in summer and dark-colored clothes in winter?

8. Suppose you are building a house in Alaska and you want to use solar energy to help heat it. What color roof should you choose? Why? Would you use the same color roof if you were building the house in a hot desert? Why or why not?

9. If you performed the previous activity in this book, check back to see if your predictions concerning the absorption of solar energy by the colored construction papers and the foil were correct. Explain why your predictions were or were not correct.

# looking back

Different colors absorb different amounts of radiation. Generally, darker colors absorb more than lighter colors, and lighter colors reflect more than darker colors.

The radiation striking an object may be absorbed, reflected, transmitted, and, in some cases, all three. The color, texture, and chemical composition of the object will determine what happens to the light that strikes it. In any case, the total amount absorbed, reflected, and transmitted will equal the amount received by the object from the sun.

# going further

Investigate how fast the different colors cool. Take the test tubes out of the sun and again record their temperature every two minutes for 20 minutes. Graph the results. Which colors cooled the most? The least? Explain your results.

Repeat the activity using an uncovered test tube. Graph the results. How do they compare to your original results? Explain the differences.

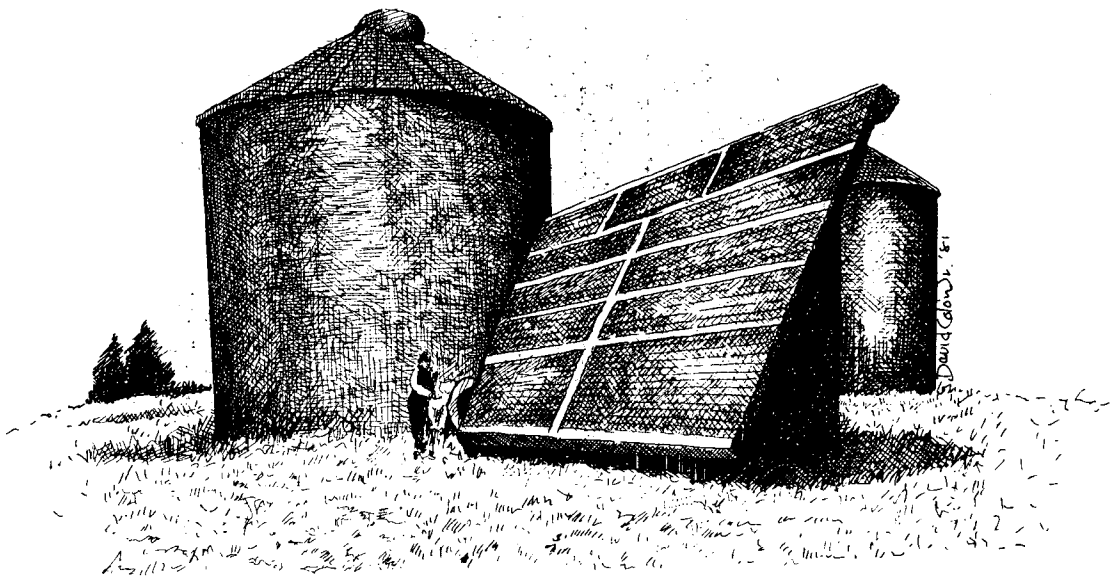
Repeat the activity using flat black and shiny black paper to cover two test tubes. Explain any differences in results between the two papers.

Place the colored construction papers inside the test tubes. What other property of solar energy now has to be considered? Repeat the activity and explain any changes in results by referring to the properties of solar energy.

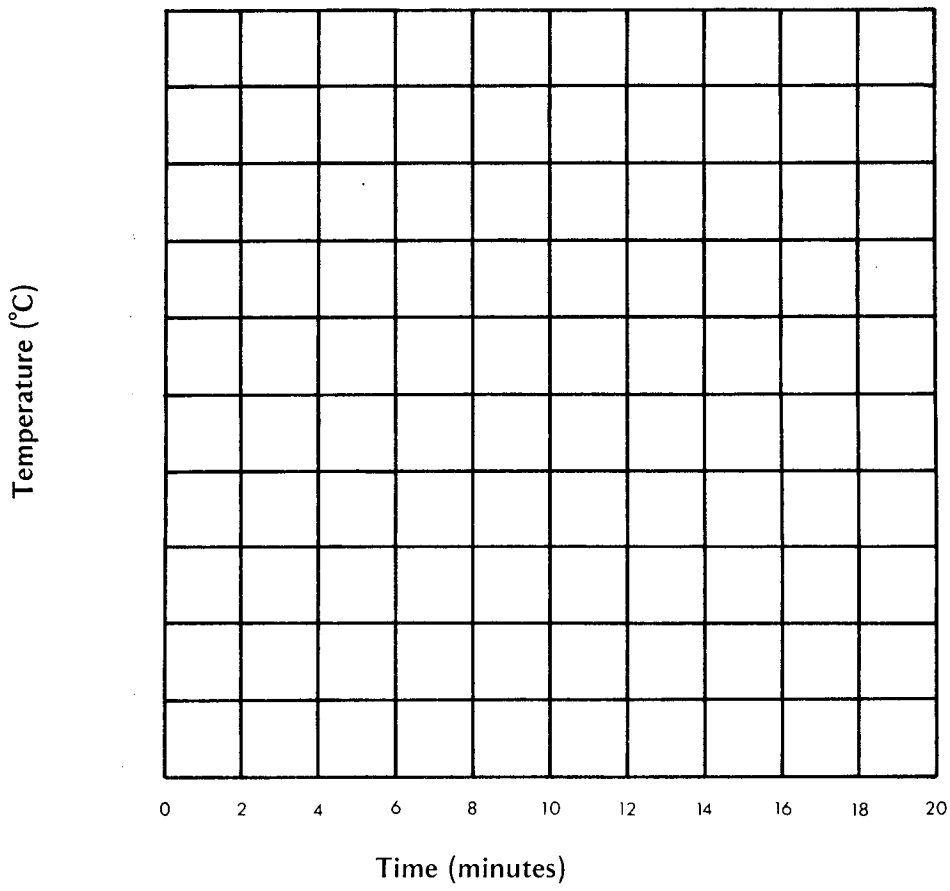
Place containers of dry black sand and dry white sand in direct sunlight. Record the temperature of each at one minute intervals for 30 minutes. Graph the results. How do you explain the differences in the heating curves of the sands? Which type of material would store heat most effectively? Why?

# Data Table

| Time (minutes) | Temperature (°C) | | | | | |
|---|---|---|---|---|---|---|
| | White | Red | Yellow | Green | Black | Aluminum Foil |
| 0 | | | | | | |
| 2 | | | | | | |
| 4 | | | | | | |
| 6 | | | | | | |
| 8 | | | | | | |
| 10 | | | | | | |
| 12 | | | | | | |
| 14 | | | | | | |
| 16 | | | | | | |
| 18 | | | | | | |
| 20 | | | | | | |



# Graph



Teacher Information

# More on Absorption

## Suggested Grade Level and Discipline

Science, grades 6-9
Physical Science
Earth Science

## Skill Objectives

Constructing a simple apparatus to measure the temperature change as different colors of the same material absorb solar energy

Determining which colors best absorb solar energy

Recording observations and interpreting results

Applying results to the solution of practical problems

## Major Understandings

Different colors absorb solar radiation in varying amounts.

If the solar radiation striking an object is not absorbed, then it is either reflected or transmitted by the object.

Darker colors absorb more and reflect less solar radiation than lighter colors.

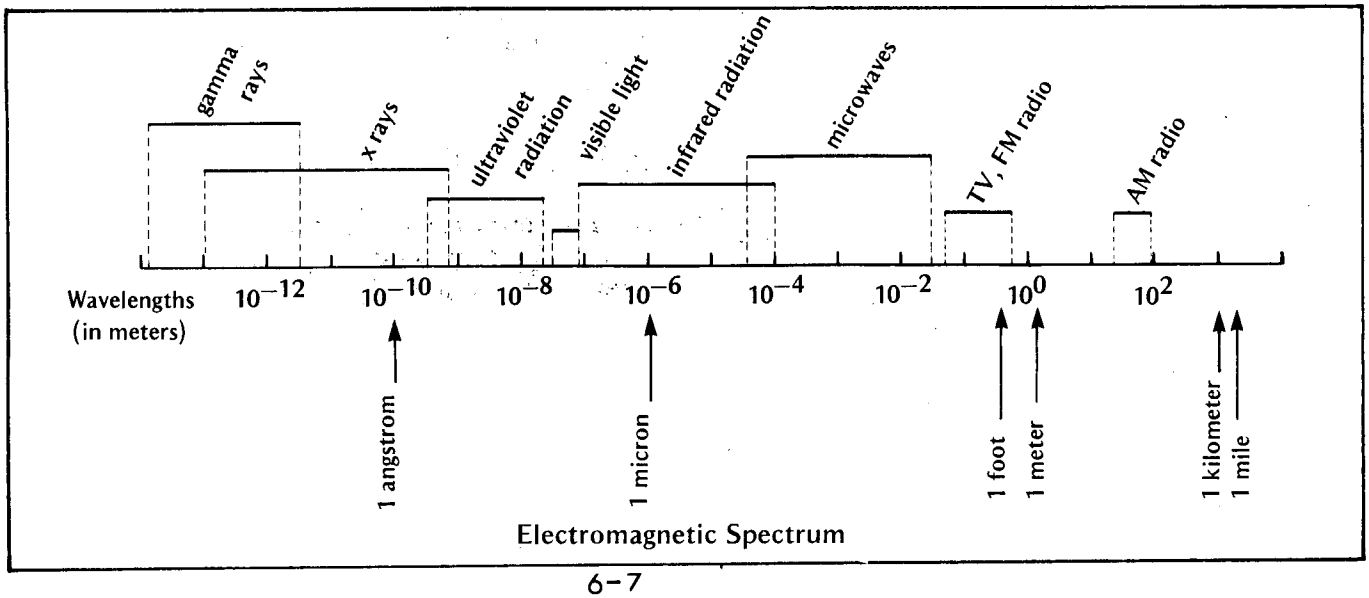
Lighter colors and smooth, polished materials reflect more and absorb less solar radiation than darker colors.

## Background

In the previous activity students inferred how much solar energy was absorbed by various objects by studying reflection and transmission data from these objects. In this activity they have an opportunity to test their inferences by obtaining actual absorption data.

The radiation emanating from the sun is known as electromagnetic radiation. This radiation has many different wavelengths grouped into characteristic bands of the spectrum. Visible light, for example, is that small portion of the spectrum to which our eyes are sensitive.

The phenomenon of absorption occurs every time electromagnetic radiation strikes a surface. The radiation penetrates the surface and is scattered about inside the object, losing energy and causing the object's atoms to gain energy. This increase in the atoms'



Electromagnetic Spectrum

kinetic energy (or energy of motion) can be seen empirically as an increase in the temperature of the object.

Although only a small portion of the electromagnetic spectrum consists of visible light, it is this portion which accounts for over half of the sun's radiated energy. As a result, it is visible light which can cause the greatest temperature increases in objects. And the color of the object affects greatly the amount of solar energy absorbed. An object is red, for example, because it absorbs all wavelengths of visible light but red, which it reflects and which causes its color. White objects reflect all the wavelengths of visible light; therefore, little solar energy is absorbed. Black objects absorb all the wavelengths of visible light and reflect none; much solar energy is absorbed and the objects increase greatly in temperature.

But an object reflects and transmits radiation as well as absorbs it. In fact, according to the law of conservation of energy, the amount of energy absorbed, transmitted, and reflected by an object must equal the incident energy. So the surface of the object also affects solar absorption. A smooth surface will cause high reflectivity and low absorption. A rough surface will trap radiation in its cavities and depressions, where it has a greater chance to be absorbed before it re-emerges as reflected radiation. Radiation which scatters through an object and emerges on the other side is the transmitted portion of the radiation.

The air inside the test tubes becomes heated primarily by conduction. The construction paper absorbs the solar energy and converts it to heat. This heat then travels by conduction through the glass of the test tube and into the trapped air.

## Advance Planning

The rubber stoppers have to be fitted with Celsius thermometers. We suggest that you yourself do this, rather than the students, as a safety measure and to prevent breakage. Use glycerin to coat the thermometers. Adjust the thermometers so that each bulb is approximately one-third of the way into the test tube.

You may want to cut all of the covering materials ahead of time. Don't forget that students can help with this task during study halls or after school.

Duplicate the data table and graph for student use.

## Suggested Time Allotment

One class period to set up apparatus and gather data

One class period to graph and discuss results

## Suggested Approach

Discuss the relationships between reflection, absorption, and transmission. (Incident solar radiation = reflection + absorption + transmission.)

Describe the electromagnetic spectrum. Use a prism to break a filmstrip projector's white light into colored bands.

Students can work in groups of three to cut down on the number of set-ups needed.

If thermometers and test tubes are in extremely short supply, each student can be assigned one test tube to monitor. However, make certain all test tubes are propped at the same angle and have the same incident energy.

Make sure students predict the answers to Question 1 before doing the activity.

## Precautions

*Remind students never to look directly at the sun.*

*Caution students to treat thermometers and test tubes gently. They are extremely fragile.*

## Points for Discussion

In what situations could you make use of the knowledge that white objects absorb less heat energy than black objects?

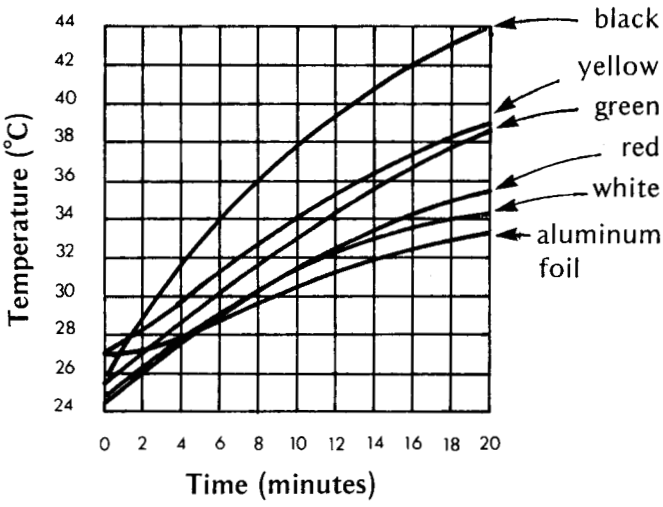
How might aluminum foil be used in capturing the sun's radiation?

According to your findings, what color would be an acceptable coating for a solar collector plate? Why?

Do the temperature curves on your graph level off? Why or why not?

## Typical Results

The graph below indicates typical results using a flood lamp. (See modifications.)




## Evaluation

Inspect data tables and graphs for accuracy and completeness.

Check students' answers to questions.

Give students a list of colors. Ask them to name the colors which absorb the greatest and the least amounts of solar energy. Ask them to explain why this is so.

## Modifications

Because weather conditions may be unsuitable, this activity has been designed to be carried out in artificial light if necessary. A 200-watt incandescent lamp or a flood lamp, with a reflector and mounted on a ring stand, will serve as an effective alternative to sunlight.

If laboratory thermometers are not available, inexpensive metal-backed thermometers can be substituted. Use small jars instead of the test tubes. Plastic wrap with a slit cut for the thermometers can be placed over the tops of the jars.

## References


Catch a Sunbeam: A Book of Solar Study & Experiments, Florence Adams.
(Harcourt Brace Jovanovich, Inc., 757 Third Ave., New York, NY 10017, 1978, $7.95, for student reading.)

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

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.)

# 7 Sun Tea.... or Solar Chocolate

Nowadays we have appliances and machines to do even the simplest jobs. In earlier times this wasn't so, but people then knew how to make the most of the energy resources they had. The sun dried the wash, the windmill pumped the water, the river drove the mill wheels to cut lumber and grind grain. Food and clothing came from growing things, not from chemicals, and cooking was fueled with wood. On land horses and oxen provided transportation; on the sea, wind-driven sailing ships.

Today we live at a faster pace, and we like the convenience of electric appliances and gasoline engines. But the energy of the sun can still be used to do work for us.

# objectives

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

- o describe a simple flat plate solar collector;
- o determine whether the sun's energy will change the physical appearance and temperature of chocolate bars, plain water, and water containing tea bags;
- o explain how the sun's energy caused any of these changes; and
- o apply what you have learned to preparing foods and saving energy in your own home.

# skills and knowledge you need

The skills of recording and graphing data

The skill of performing a controlled experiment

A basic knowledge of heat absorption

# materials

a large piece of cardboard or tagboard (30 x 45 cm)

a large cardboard box, with the inside painted black

plastic sheeting or plastic wrap cut to cover the top of the box

six small jars or beakers (250 ml)

six Celsius thermometers

two tea bags

two small bars of chocolate

water

a watch, clock, or timer

masking tape

colored pencils (optional)

# procedure

1. Label the six beakers with masking tape as follows.

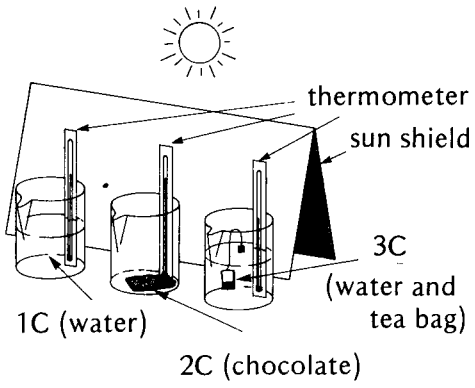
| | |
|---|---|
| 1 | 1C |
| 2 | 2C |
| 3 | 3C |

2. Place the following into the beakers.

   1 and 1C: 100 ml of water
   2 and 2C: a bar of chocolate
   3 and 3C: 100 ml of water and a tea bag

   Record in the first column of Data Table 1 the physical appearance of the substances in each beaker.

Diagram 1




3. Fold the large piece of cardboard in half as shown in Diagram 1. This will be used as a sun shield.

4. Carry the beakers and other needed materials to a spot in direct sunlight.

5. Set up the sun shield so that it creates a shaded area. Place beakers 1C, 2C, and 3C in this shade.

6. Set the large box in direct sunlight. Place beakers 1, 2, and 3 into it.

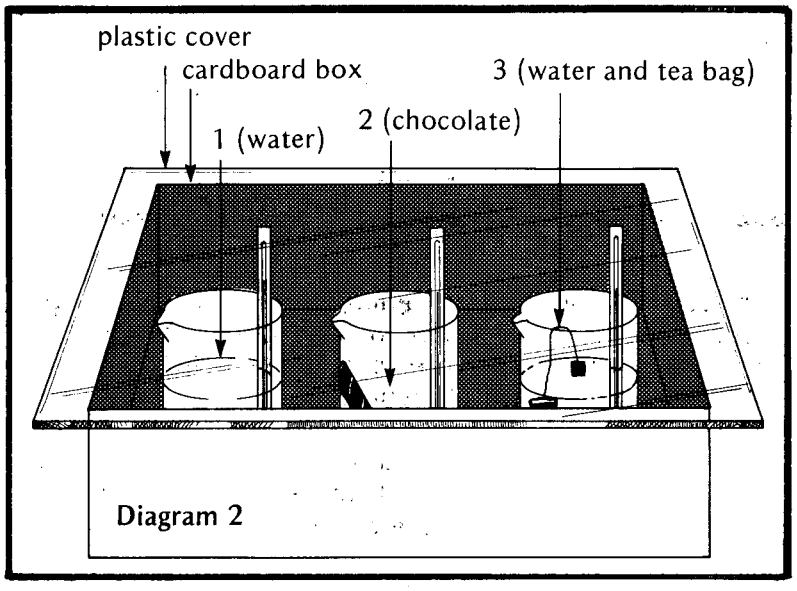



Diagram 2

7. Place a thermometer in each of the six beakers. (Make sure you press the thermometer bulbs into the chocolate bars.) Place the plastic over the cardboard box.

8. Read the temperature of each beaker and record it under "0" in Data Table 2.

9. Read and record the temperatures every half hour for two hours.

10. After two hours, again observe the physical appearance of the substances in each beaker. Record in Data Table 1.

11. On the graph provided, plot the data from Data Table 2. Draw a separate line for the temperature of each beaker. Label each line correctly. (You may want to use a different colored pencil to draw each line.)

# questions

1. What general conclusions can you draw from your graph?

2. What was the purpose of beakers 1C, 2C, and 3C?

3. What were the purposes of the sun shield and the covered box? In solar terms, what would the covered box be called?

4. By how many degrees did the temperature in each beaker change?

5. Which changed temperature more, beaker 1 or 1C? 2 or 2C? 3 or 3C?

6. List beakers 1, 2, and 3 in order from the greatest temperature change to the least temperature change.

7. Explain the results you reported in Questions 5 and 6.

8. Compare the difference in appearance between beakers 1 and 1C, between 2 and 2C, and between 3 and 3C. How did these differences in appearance (if any) occur?

9. How might you use what you have learned in this activity in preparing foods or beverages in your own home? Would this save fossil fuel energy? How much?

# looking back

You have just seen the sun do some small tasks that we usually do with an appliance: making tea and melting chocolate. It did the tasks rather slowly, of course, because sunlight is diffuse, not concentrated like a gas flame or a hot electric burner.

Perhaps with time and thought you can devise other ways to substitute the energy of nature for some of the electric and fossil fuel energy that is becoming more expensive every day.

# going further

If you were to use styrofoam cups instead of glass beakers, what differences would you expect in results? Test your hypothesis. Then repeat the activity once more using styrofoam cups painted black.

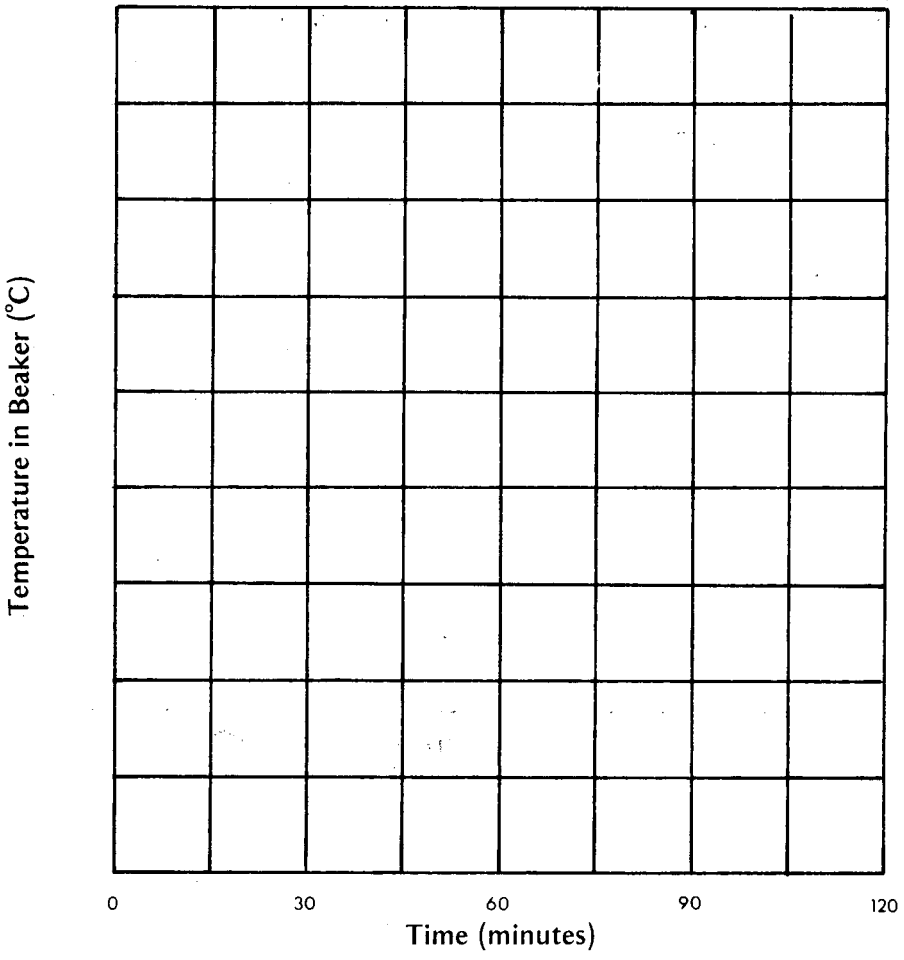
Can tea be made without hot water or sunshine? Place a beaker of cold water containing a tea bag in a dark place overnight. Compare this tea to your solar tea.

Research the kinds of apparatus that use solar energy to cook foods. Design and build your own solar cooker or oven.

Try some of the suggestions you made in answer to Question 9. For example, save fossil fuel energy at home by using the sun's energy to melt butter or chocolate, to make bread rise, or to prepare tea.

For more information on absorption of solar energy, try Activities 5 and 6 in this book, and Activity 2 in the Earth Science Activities book.

# Graph


Temperature in Beaker (°C)
0
30
60
90
120
Time (minutes)

tea
sun tea

## Data Table 1

| Beaker | Initial Observations | Final Observations |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 1C | | |
| 2C | | |
| 3C | | |

## Data Table 2

| Time (minutes) | Temperature in Beakers (°C) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1C | 2C | 3C |
| 0 | | | | | | |
| 30 | | | | | | |
| 60 | | | | | | |
| 90 | | | | | | |
| 120 | | | | | | |

Teacher Information

# Sun Tea . . . or Solar Chocolate

## Suggested Grade Level and Discipline

Science, grades 6-8
Physical Science
Home Economics

## Skill Objectives

Setting up a controlled experiment

Making qualitative observations and drawing inferences from them

Making quantitative observations, preparing graphs, and interpreting them

## Major Understandings

A flat plate solar collector consists basically of an enclosed box with a transparent cover (glazing) and an absorbing material.

Solar energy, when absorbed and converted to heat energy, can cause both physical and chemical changes in substances.

Darker colored substances will absorb more solar energy than lighter colored substances.

Solar energy is a possible energy source for preparing some foods and beverages in the home.

## Background

The radiation reaching the earth from the sun has enough energy to cause both physical and chemical changes. In this activity, students observe both. When heated by energy from the sun, the chocolate undergoes a physical change of state, from a solid to a liquid, while the tea undergoes chemical reaction, becomes more soluble, and diffuses into the water at a greater rate.

Since darker colors absorb and convert more solar energy to heat, the chocolate should show the greatest change in temperature over time. The tea should show a smaller overall temperature change but an increasing rate of change. As the tea begins to diffuse and the surrounding water becomes darker, more solar energy is absorbed and the temperature increases more rapidly. The water, being transparent to sunlight, will absorb the smallest amount of heat energy and will show the smallest temperature change.

Making tea or melting chocolate normally requires an expenditure of nonrenewable fossil fuel energy. In the case of iced tea, the expenditure is doubled: the water is boiled, then ice (which requires energy to make) is added. In both these cases, a stove is turned on at the least. But placing a jug of water containing tea bags in the sun or chocolate in a bowl in the sun will produce the same result with no fossil energy consumed (although it will take more time). There are other ways we prepare foods that are amenable to this treatment. While in any one case the fossil energy saved is infinitesimally small in comparison to this country's total energy use, the amount saved by many such preparations over time and over a large number of households could be significant.

Many people prefer solar tea. They claim it tastes less bitter; contains less tannic acid, caffeine, and oils; and retains more of the flavor and aroma of the tea leaves.

## Advance Planning

Obtain cardboard boxes from the cafeteria or custodial staff. Spray paint the inside of the boxes with flat black paint. Obtain and cut the plastic sheeting or wrap. A few students can help with this latter task outside of class time.

If beakers are not available, have students bring small glass jars from home. Baby food jars would work well.

Use the least expensive chocolate obtainable. Single 1-ounce squares from unsweetened chocolate cooking bars or chocolate chips will work well. Devise a way to place the thermometer bulb into the unmelted chocolate. Make sure the melted chocolate will still cover the bulb.

Duplicate the data tables and graph.

## Suggested Time Allotment

One class period to set up the activity and make initial observations

Two hours to collect data and make final observations

One to two class periods to graph data, answer questions, and discuss results

## Suggested Approach

Since this activity requires two hours to record data, it is often difficult for students to return to their apparatus from other classes to take temperature readings. We suggest three possible solutions:

obtain permission from other instructors for students to check their apparatus every half hour,
ask students to stop back and record data between classes, or
have several consecutive science classes record data for the same set-ups.

If you choose the last alternative, place all data for each set-up on the blackboard or on a sheet to be duplicated, then allow students time to copy the data onto their own data tables.

Students can work in groups of two or three if there is enough equipment.

Discuss how solar energy emanates from the sun and how it reaches the earth. Demonstrate how the covered cardboard box serves as a simple flat plate collector.

Perform the activity, then discuss the physical and chemical changes which occur. Discuss the familiar practical applications of this activity to energy conservation. Explain how many small contributions yield a large aggregate of energy savings.

You may want to make a gallon of solar tea for students to taste.

## Precautions

*Unless the glassware and thermometers are sterile, students should not taste the tea or chocolate.*

*Water vapor may condense on the inside of the plastic cover. Students can remove the cover to take their readings.*

*Make sure the thermometer bulbs are covered by the chocolate, in both its solid and melted states.*

## Points for Discussion

Why were you asked to record temperatures for as long as two hours?

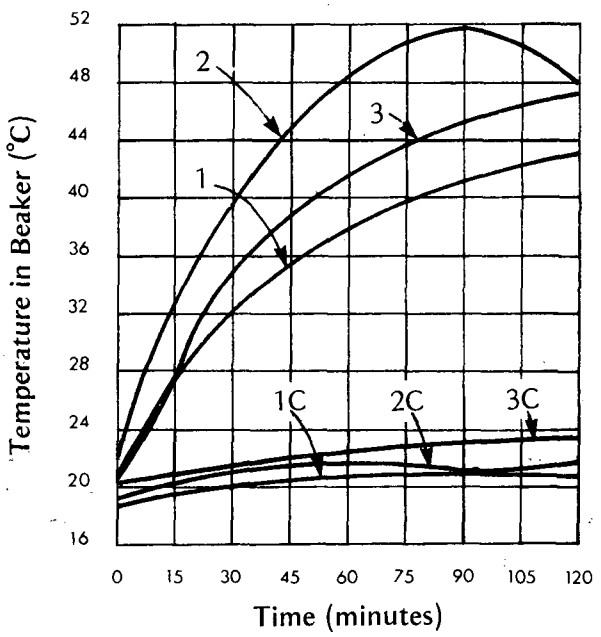
What additional parts do more efficient flat plate collectors have?

How might solar energy be captured and used in your own home?

What are the advantages and disadvantages of using solar energy in the preparation of foods?

## Typical Results

A sample student graph is shown below.



## Evaluation

Review data tables and graphs for accuracy and neatness. Review students' answers to questions.

Ask students to describe or draw a simple flat plate solar collector.

Ask students to write a short paragraph describing the physical and temperature changes which occurred in the activity and explaining the reasons why they occurred.

Ask students to list ways they could substitute solar energy for fossil fuel energy in their own homes.

## Modifications

Although this activity is designed to use inexpensive metal-backed thermometers, short laboratory thermometers can be used.

Glass may be used in place of plastic sheeting. Tape the edges of the glass to protect students.

This activity can be performed indoors or outdoors as long as the apparatus is in direct sunlight for two hours.

## References

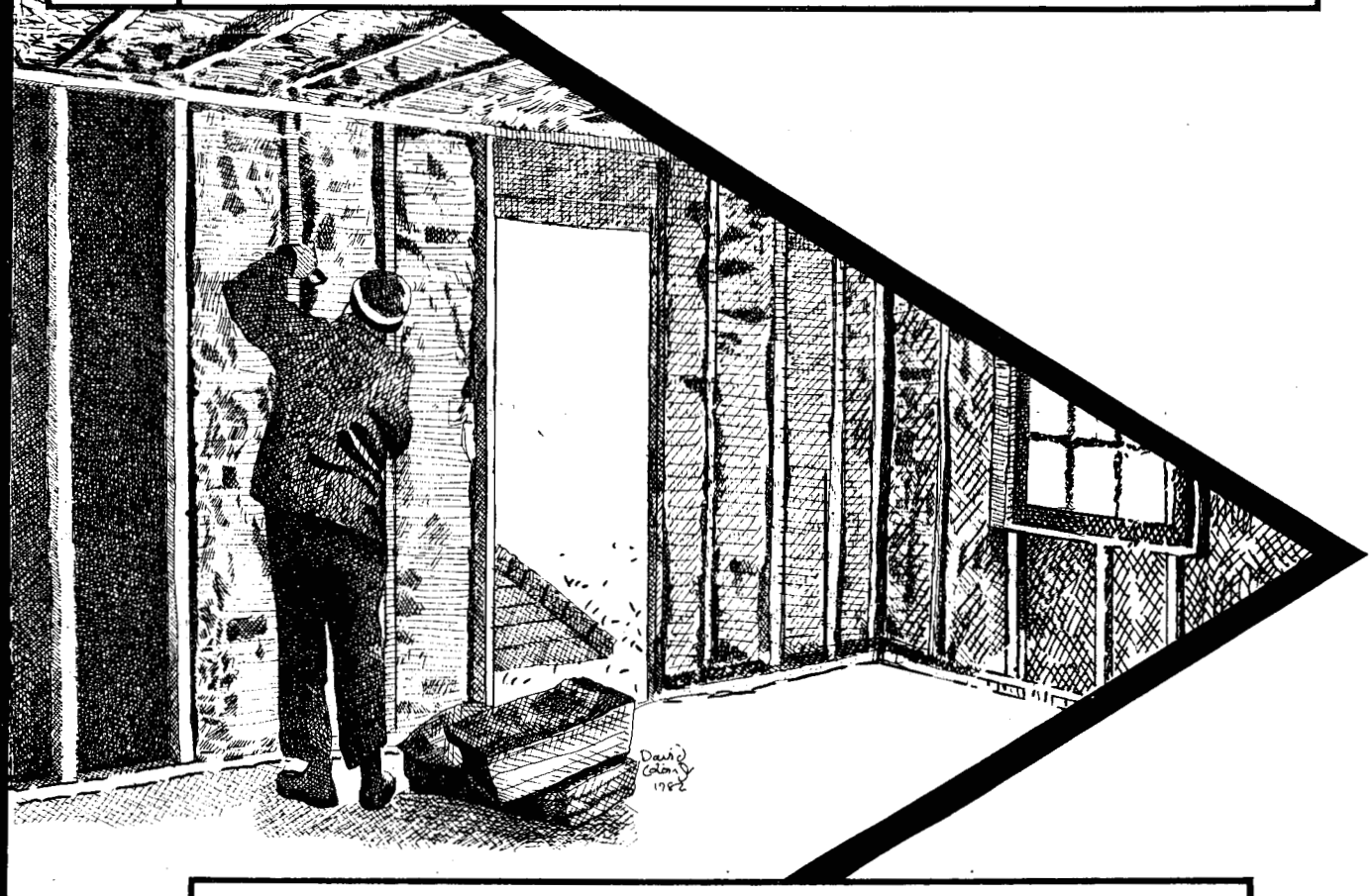

Solar Energy Education Reader
Part I: "The Transition to a Post-Petroleum World," p. 10.
Part IV: "Solar Stoves Teach Energy Awareness," p. 398.
(Solar Energy Education Project, NYS Education Department, Albany, NY 12234, 1981, contact the project for price.)

Catch a Sunbeam: A Book of Solar Study and Experiments, Florence Adams.
(Harcourt Brace Jovanovich, Inc., 757 Third Ave., New York, NY 10017, 1978, $7.95, for student reading.)

Solar Energy Education Packet for Elementary and Secondary Students.
(Center for Renewable Resources, 1001 Connecticut Ave., NW, Suite 510, Washington, DC 20036.)

"Brewing Solar Tea," John W. Hill and Cynthia S. Hill.
(The Science Teacher, National Science Teachers Association, 1742 Connecticut Ave., NW, Washington, DC 20009, January 1980.)

# 8 Insulation: Keeping Heat In or Out



Many parts of the country experience large changes in temperature from season to season. But human comfort demands a fairly constant temperature in homes and work places throughout the year. In cold weather, this means preventing the escape of heat to the outdoors. In hot weather, it means blocking the invasion of heat from the outdoors.

Insulation helps maintain human comfort by blocking heat flow. Some materials are more effective insulators than others. The best insulating material for the home will be one which keeps the most heat in during cold weather and the most heat out during hot weather.

Solar energy collectors also must contain insulation to prevent the collected heat from flowing back into the atmosphere. Hot water tanks and pipes need insulation, too, so that the water they contain doesn't lose its heat.

# objectives

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

- compare different insulating materials for their abilities to keep heat in and to keep heat out,
- determine the best material for insulating against heat loss and against heat gain,
- explain why insulation is an important part of a solar energy collector, and
- explain the importance of insulating homes to reduce heat loss from the inside in cold weather and heat gain from the outside in hot weather.

# skills and knowledge you need

Reading a thermometer

Recording and graphing data

# materials

three identical soda cans

three Celsius thermometers

a clock, watch, or timer to measure minutes

a 200-watt incandescent lamp or flood lamp (with reflector and mounted on a ringstand)

hot water (50°C)

insulating materials: fiberglass, wool, styrofoam, newspaper, aluminum foil

rubber bands

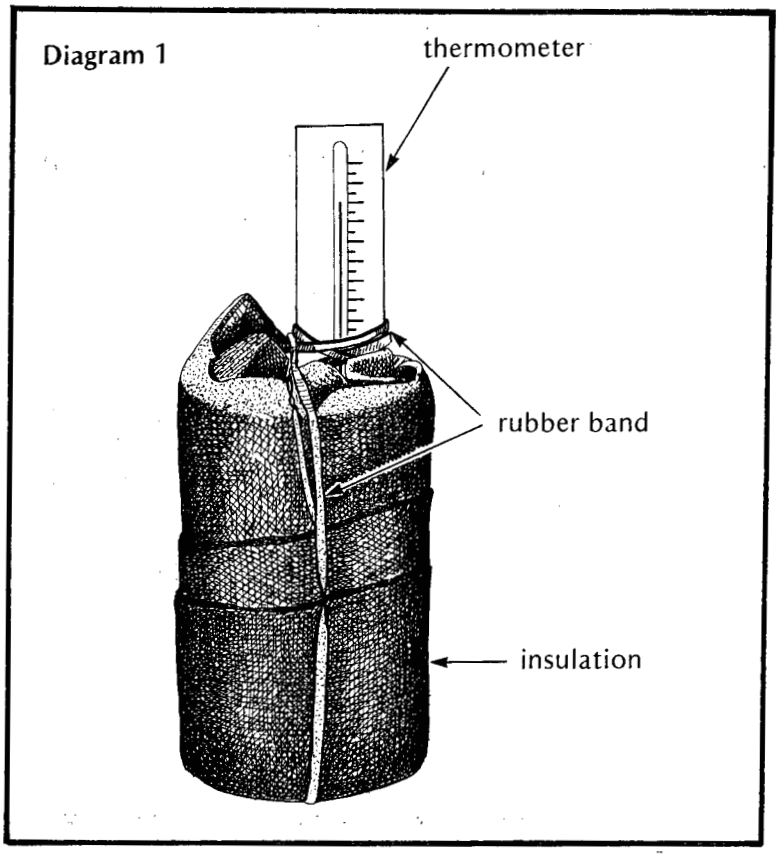
metric ruler

# procedure

## Part 1: Keeping Heat In

1. Fill the three soda cans to within 1 cm of the top with the hot water.

2. Obtain two of the insulating materials. Carefully and completely wrap one can with one insulation and a second can with the other. Make sure you wrap the can tops, but leave a small hole above the pop-top opening for the thermometer. (See Diagram 1.) Hold the insulation in place with rubber bands.




*Caution: Do not spill any water on the insulations when wrapping the cans. If you choose fiberglass as the insulation, wear safety glasses and gloves when handling it.*

3. Leave the third can unwrapped.

4. Wrap rubber bands around the tops of the three thermometers. Insert the thermometers through the insulation and pop-top opening into the cans. Adjust the rubber bands so that the thermometers are at equal depths (about halfway) in the cans and do not touch any part of the cans.

5. Label the first two columns of Data Table 1 with the kinds of insulation you are using.

6. Read and record in Data Table 1 the temperature of the water in each can.

7. Continue to record the water temperature in each can every minute for 20 minutes.

8. On Graph 1, plot your data for each can. Be sure to label each line.

## Part 2: Keeping Heat Out

9. Remove the thermometers and insulations and empty the cans.

10. Replace the same insulations and the thermometers. Position them just as you did in Part 1.

11. Place each can the same distance (about 30 cm) from the heat source (the lamp), as shown in Diagram 2.

12. Label the first two columns of Data Table 2 in the same way as you labeled Data Table 1.

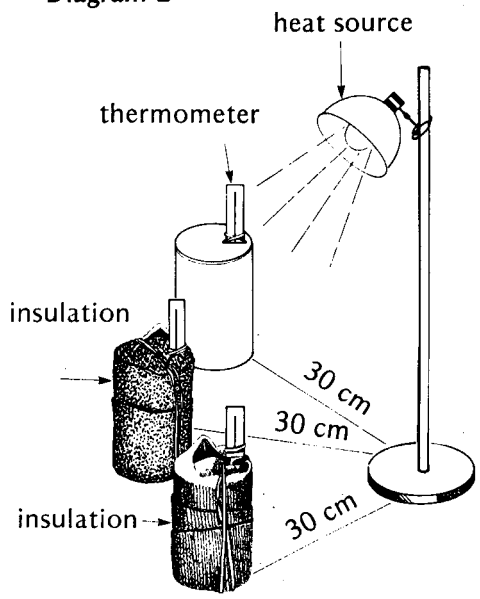
13. Read and record in Data Table 2 the temperature of each can.

14. Turn on the heat source. Record the temperature in each can every minute for 15 minutes.

> *Caution: Do not look directly at the lamp. Read the thermometers from behind the lamp.*

15. Turn off the heat source. On Graph 2, plot your data for each can. Be sure to label each line.

**Diagram 2**




# questions

1. What general conclusions can you draw from the graphs?

2. What was the total change in temperature for each can in Part 1? In Part 2?

3. Why did you use the third can in this activity?

4. Of the materials you tested, which was better at keeping heat in? How do you know?

5. Which material was better at keeping heat out? How do you know?

6. Was the same material the better insulator in both cases?

7. Compare your results with those obtained by the rest of the class. Which material would best insulate against heat loss (keep the heat in)?

8. Which material would best insulate against heat gain (keep the heat out)?

9. Based on your results, why do you think insulation is an important part of a solar energy collector?

10. Why should a house be insulated to reduce both heat loss and heat gain?

# looking back

A good insulation reduces heat flow from warm areas to cold areas. In this activity you simulated cold weather conditions by insulating cans filled with hot water to try to keep the heat in. You also simulated hot weather conditions by insulating empty cans to try to keep heat out.

The best insulations are the ones that allowed the smallest temperature change inside the insulated can. In choosing an insulation for a house or a solar collector, you would also consider other factors like cost and safety.

Insulation makes an important contribution to saving energy and maintaining human comfort.

## going further

Repeat the activity using other sources of heat energy, including the sun. Compare these results to your original results and explain any differences.

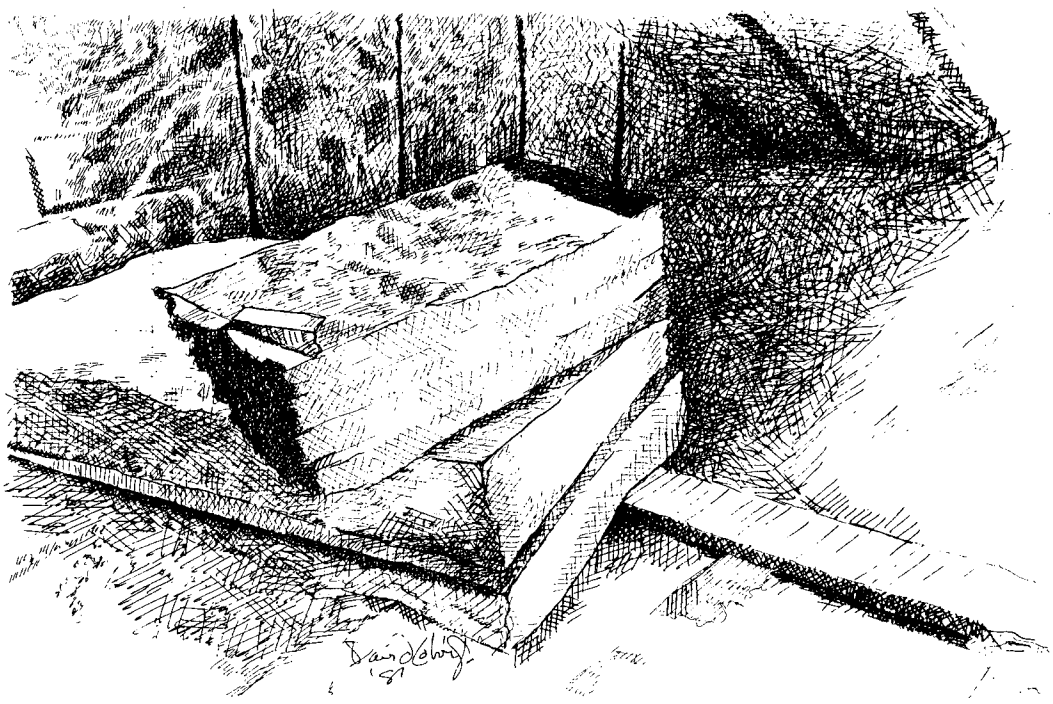
Find out the R-values of the insulations you tested. Write a paragraph explaining R-values, then compare your results in this activity to the R-values of the insulations you tested. Do they agree? Why or why not?

Visit a lumber yard and insulation contractor to find out as much as you can about insulations. Gather information on R-values and costs, then recommend an insulation based on these factors.

Find out the kind, amount, and location of insulation in your home. Determine its R-value. Find out the recommended R-values for walls, ceilings, floors, and basements in your area of the country. If you find your home is not adequately insulated, develop a list of recommendations for improving its insulation.

Research how homes are kept cool in summer. List as many ways to prevent heat gain as you can.

Hold a "cool cube" contest. Design a container that will keep an ice cube from melting for the longest time. Which container wins? Why? (The best containers may hold ice for as long as 15 hours!)



## Data Table 1
## Keeping Heat In

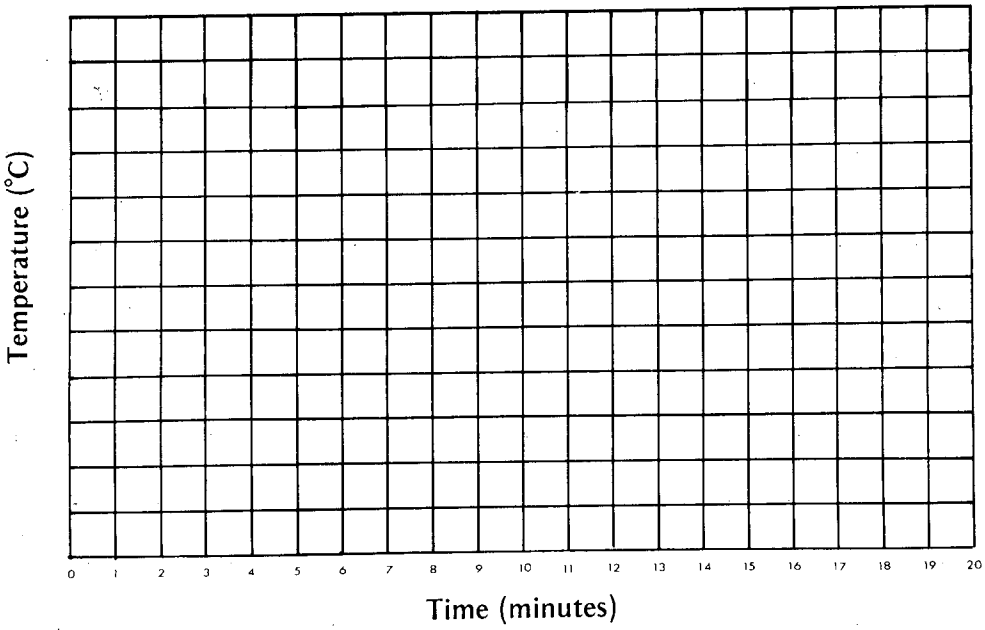
| Time (minutes) | Temperature (°C) | | |
|---|---|---|---|
| | First Can (Insulating Material: _____) | Second Can (Insulating Material: _____) | Third Can (No Insulating Material) |
| 0 | | | |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |
| 16 | | | |
| 17 | | | |
| 18 | | | |
| 19 | | | |
| 20 | | | |

## Data Table 2
## Keeping Heat Out

| Time (minutes) | Temperature (°C) | | |
|---|---|---|---|
| | First Can (Insulating Material: _____) | Second Can (Insulating Material: _____) | Third Can (No Insulating Material) |
| 0 | | | |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |

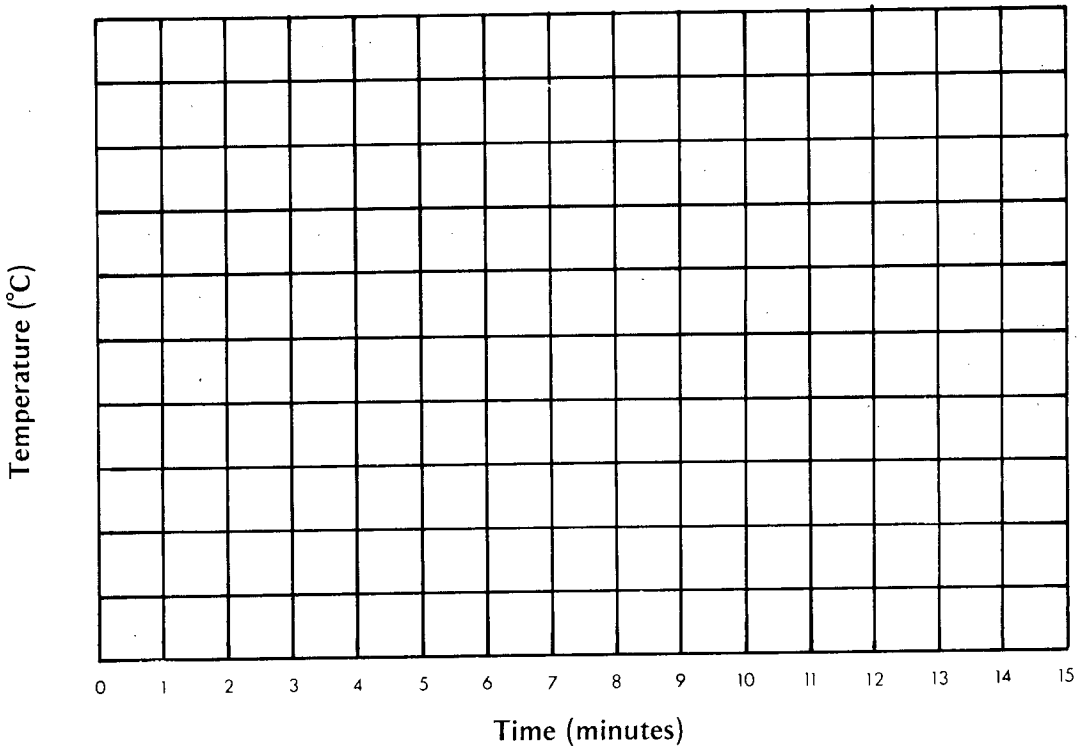
## Graph 1

## Keeping Heat In




## Graph 2

## Keeping Heat Out



Teacher Information

# Insulation: Keeping Heat In or Out

## Suggested Grade Level and Discipline

Science, grades 6-9
Physical Science

## Skill Objectives

Recording temperature data at equal time intervals

Graphing data and interpreting heating and cooling curves

Drawing inferences from graphed data

Applying results to everyday situations

## Major Understandings

The best insulation against heat loss is that which allows the smallest change in the interior temperature of a container when the container is exposed to a cooler external environment.

The best insulation against heat gain is that which allows the smallest change in the interior temperature of a container when the container is exposed to a constant source of heat energy.

Some materials are good insulators against both heat gain and heat loss and thus are good insulation materials in home construction.

Because of the diffuse nature of solar energy, insulation is needed in a solar collector to trap and concentrate heat energy.

Adequate home insulation for keeping heat in during cold weather and heat out during hot weather is an important factor in conserving energy and decreasing fuel costs.

## Background

Insulation is any material used to slow heat transfer. The important component of most good insulators is air because air is a poor conductor of heat. Most insulation contains millions of tiny air spaces which slow heat conduction through it. Thus the heat is "kept in" or "kept out," as this activity demonstrates.

Insulations are rated for their resistance to heat flow. This resistance is known as the insulation's R-value. The greater an insulation's R-value, the greater is its resistance. Some sample R-values are listed in the table.

Home insulation is intended to serve two purposes. In winter the insulation should keep heat in, while in summer it should keep

INSULATION MATERIALS, R-VALUES, AND USES

| Material | "R" per inch thickness* |
|---|---|
| **Flexible** | |
| Cellulose fiber with vapor barrier | 3.20-4.00** |
| Glass fiber or mineral wool | 3.00-3.40** |
| **Loose Fill** | |
| Glass fiber and mineral wool | 2.80-3.40 |
| Cellulose | 3.50-3.70 |
| Vermiculite, expanded | 2.13 |
| **Rigid Board** | |
| Polystyrene, extruded | 5.26 |
| Expanded urethane, preformed | 5.80-6.25 |
| Glass fiberboard | 4.00 |
| Polystyrene, molded beads | 3.57 |
| **Foamed-in-Place** | |
| Expanded urethane, sprayed | 6.25 |

* Determined from ASHRAE Handbook, 1972
** Varies according to density and fiber diameter

heat out. Virtually all insulations slow heat transfer through the material in both directions since this is just a result of poor heat conduction through those tiny air spaces. However, foils are often added to commercial insulations to gain an additional energy-saving factor: the reflection of heat energy, either back into the living spaces in winter, or back to the outside in summer.

Adequate insulation of homes and buildings is an important factor in energy conservation and reduced energy costs. According to a recent American Institute of Architects study, by 1990 we could save one-third of our current total U.S. energy use through improved design of new buildings and retrofitting of old ones. A good portion of this saving would come from improved insulation. And just think of the saving in dollars.

Insulation is an extremely important factor in a solar collector, too. Without insulation to trap the heat collected, a solar collector could never attain the temperatures necessary to provide domestic hot water or space heating.

## Advance Planning

Begin collecting soda cans and insulations several weeks ahead. Students can help by bringing cans and scrap insulation from home. Home centers, lumber yards, or insulation contractors may provide you with insulation samples or scrap. The home economics teacher may be able to provide wool scraps.

Attach the lamps to the ringstands so that the light will strike the cans on the tops and sides. Be careful to keep the lamps from shining directly in students' eyes. The best set-up is to place the lamps low to the table so that students stand above them.

Make preparations to provide 50°C water. Often a hot plate and an old coffee pot works best.

You may want to cut scrap insulations to size before the activity. Students can help with this task outside of class time.

## Suggested Time Allotment

Two class periods to set up and perform the activity

One class period to graph data and compare and discuss results

## Suggested Approach

Students can work in groups of three. One can be the timer, and the other two can read and record the temperatures.

After the students have collected and interpreted their data, discuss the importance of insulation in home energy conservation and in solar collectors.

If necessary, give students help with graphing, labeling lines, and drawing general conclusions from the graphs.

If there are not enough lamps for several small groups of students, perform this activity in conjunction with other solar activities. Rotate groups from activity to activity over the course of several days.

## Precautions

*Students should not look directly at the lamps. Remind them to stand behind the lamps as they collect data.*

*Students should wear safety glasses and gloves when handling fiberglass insulation.*

*If the water is hotter than 50°C, consider pouring it into the cans yourself. Provide students with mitts or gloves to handle hot glassware and cans.*

*Do not use shiny cans as the control cans. In Part 2 they will reflect too much heat. You may want to spray the control cans with flat black paint.*

## Points for Discussion

How rapidly did the control can lose heat in comparison to your insulated cans? Gain heat? Why?

Which insulation slowed heat flow the least? The most? Of the materials tested by your class, which would you recommend as the best home insulation? Why?

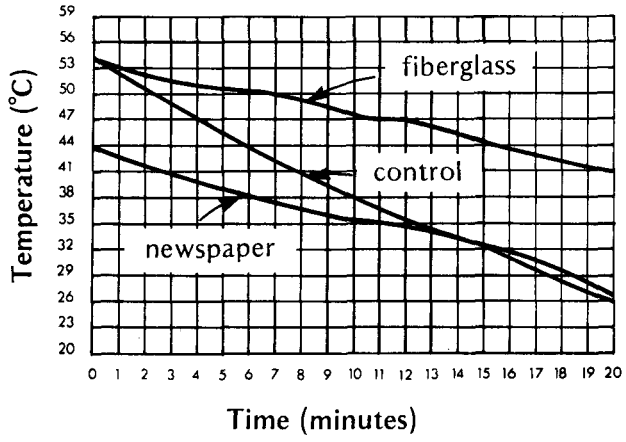
How might you use insulation in active and passive solar heating and cooling?

By what processes does heat flow from one object to another or to the surrounding air?

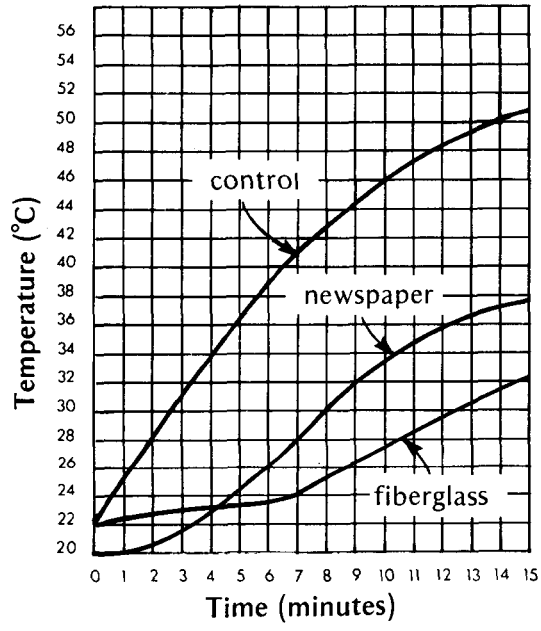
## Typical Results

The following graphs represent sample results obtained using newspaper and fiberglass as insulations.

Keeping Heat In




Keeping Heat Out




## Evaluation

Inspect students' data tables and graphs for accuracy, clarity, and attention to detail.

Review students' answers to the questions to determine if they have made supportable inferences from the data collected.

Ask students to explain why insulation is important in a solar collector.

Request students to discuss in writing one application of their findings to home energy conservation. Inspect their work to see if the suggestion is logical and conforms with the data from this activity.

## Modifications

Although this activity is designed to use low-cost metal-backed thermometers, short laboratory thermometers can be substituted.

This activity could also be performed using the sun as a source of energy.

## References


All Through the House: A Guide to Home Weatherization, Thomas Blandy and Denis Lamoureaux.
(McGraw-Hill Book Co., 1221 Avenue of the Americas, New York, NY 10020, 1980, $6.95/paper.)

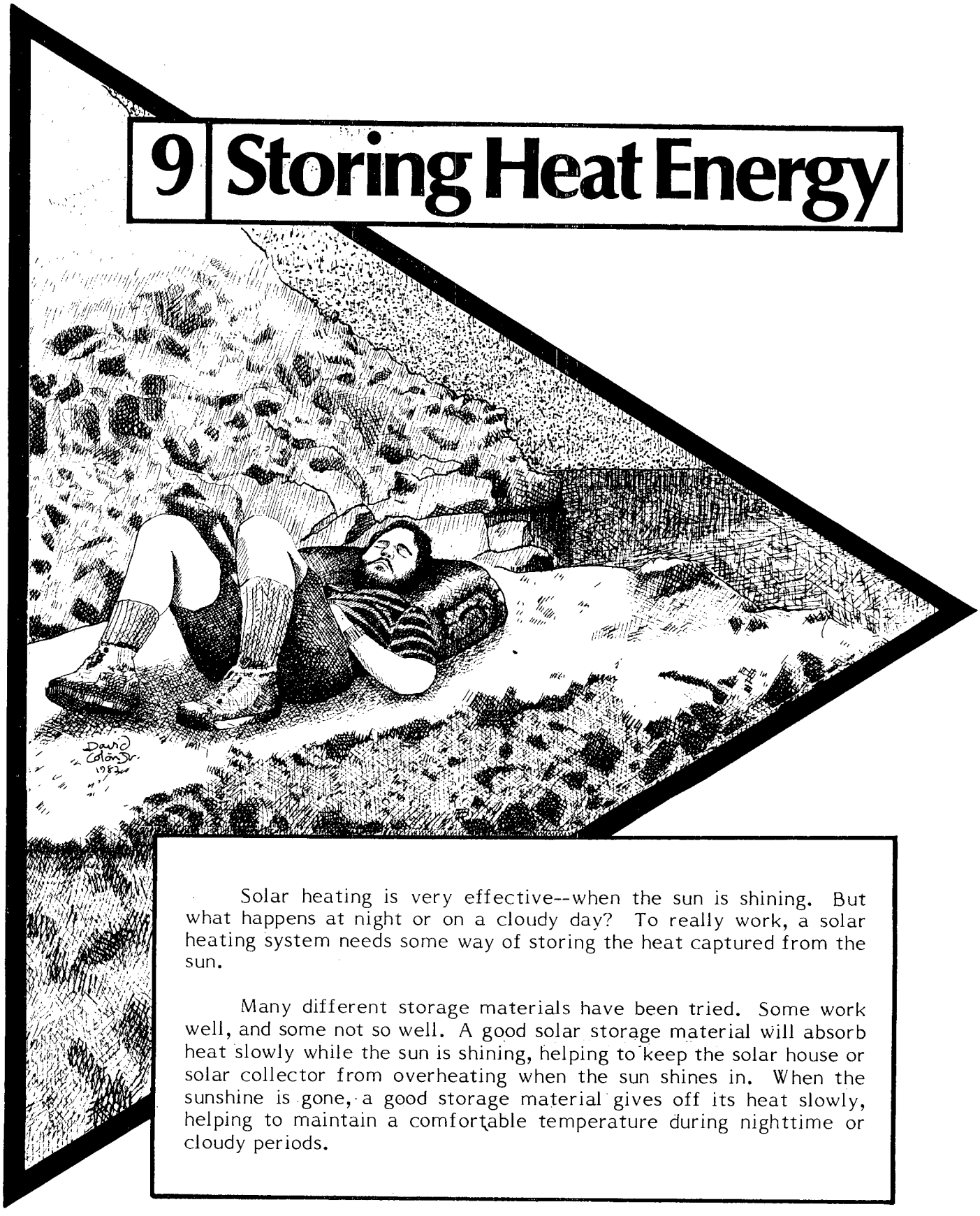
Energy Conservation: Experiments You Can Do . . . from Edison.
(Thomas Alva Edison Foundation, Cambridge Office Plaza, Suite 143, 18280 West Ten Mile Rd., Southfield, MI 48075, 1974.)

547 Easy Ways to Save Energy in Your Home, Roger Albright.
(Garden Way Publishing Co., Charlotte, VT 05445, 1978, $4.95/paper.)

"Insulation," Solar Factsheet 103.
(Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS), P.O. Box 8900, Silver Spring, MD 20907, 1980, single copies free.)

"Tips for Energy Savers: In and Around the Home, On the Road, In the Marketplace."
(Energy Conservation Now, Pueblo, CO 81009, 1978, single copies free.)

# 9 Storing Heat Energy




Solar heating is very effective--when the sun is shining. But what happens at night or on a cloudy day? To really work, a solar heating system needs some way of storing the heat captured from the sun.

Many different storage materials have been tried. Some work well, and some not so well. A good solar storage material will absorb heat slowly while the sun is shining, helping to keep the solar house or solar collector from overheating when the sun shines in. When the sunshine is gone, a good storage material gives off its heat slowly, helping to maintain a comfortable temperature during nighttime or cloudy periods.

# objectives

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

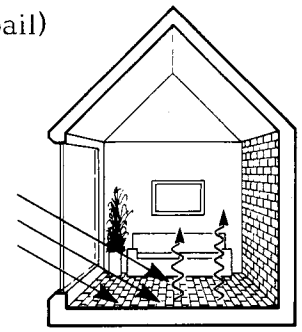
- o demonstrate how heat energy can be stored,
- o indicate whether air or rocks heat more rapidly,
- o indicate whether air or rocks release heat more rapidly, and
- o determine which material is better able to store heat energy and explain why.

# skills and knowledge you need

Using electrical appliances safely
Reading a thermometer
Recording and graphing data

# materials

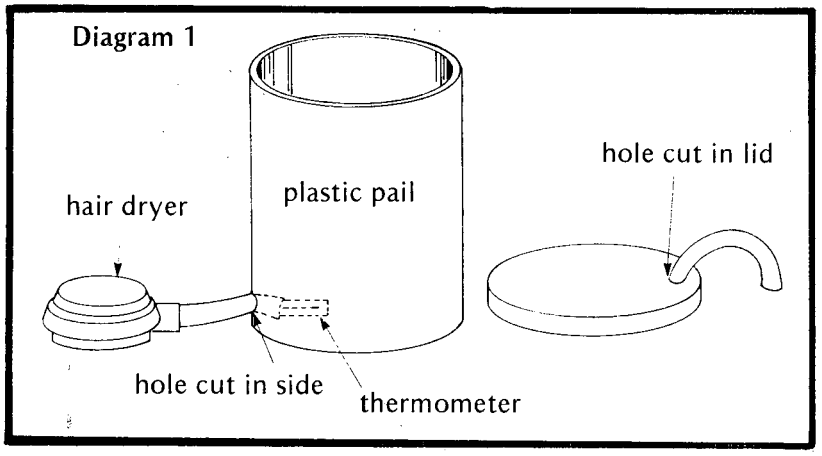
a 5-gallon plastic pail (with a lid)
a discarded bonnet-type hair dryer
a colander or small-mesh wire screen to fit snugly inside the pail
clean gravel, 1-2 cm in diameter (enough to two-thirds fill the pail)
a Celsius thermometer
a watch, clock, or timer to measure minutes
a knife



# procedure

1. Cut the hair dryer hose into two sections, as shown in Diagram 1.

2. About 2 cm up from the bottom of the plastic pail, cut a hole the same size as the diameter of the hose. Cut another hole the same size in the pail's lid. (See Diagram 1.)

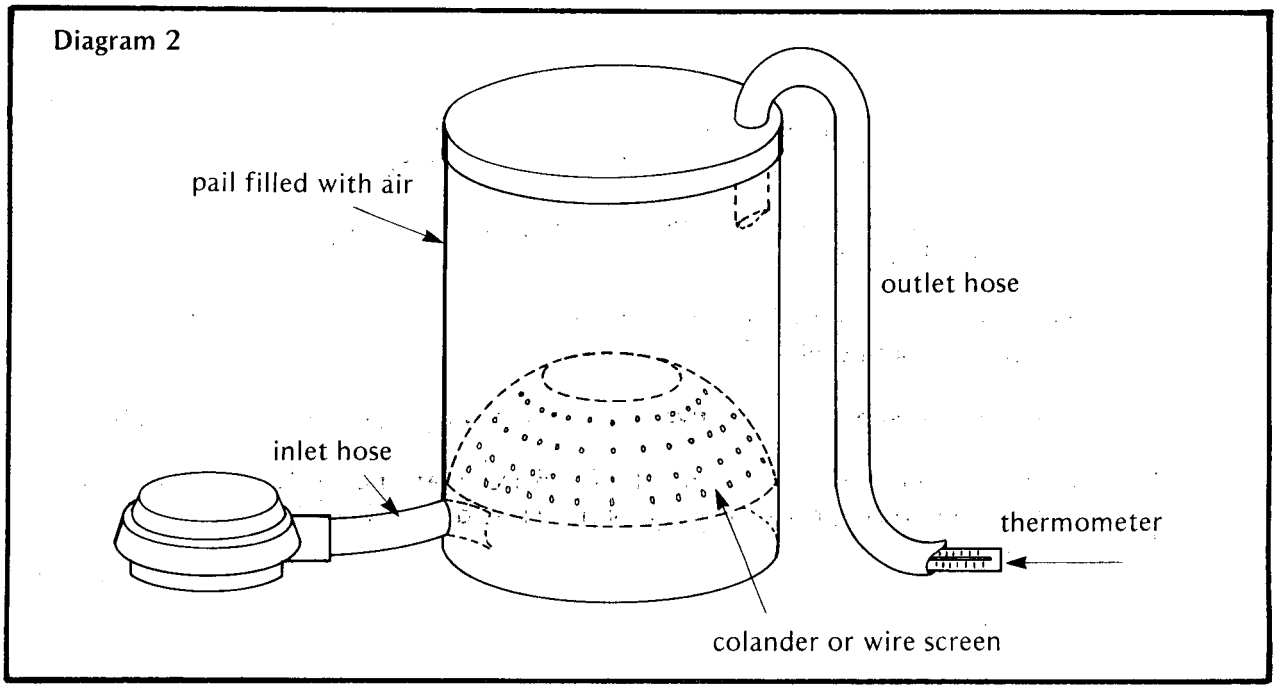



3. Attach the hair dryer to the lower hole with one section of hose. Attach the second section of hose to the hole in the pail's lid.

4. Place a thermometer in the inlet hose, as shown in Diagram 1. Plug the dryer into an electrical outlet and set it on "hot." When the temperature of the incoming air stops changing, record it in the Data Table. Turn the dryer to "cool" and again record the temperature when it stops changing. Turn the dryer off.

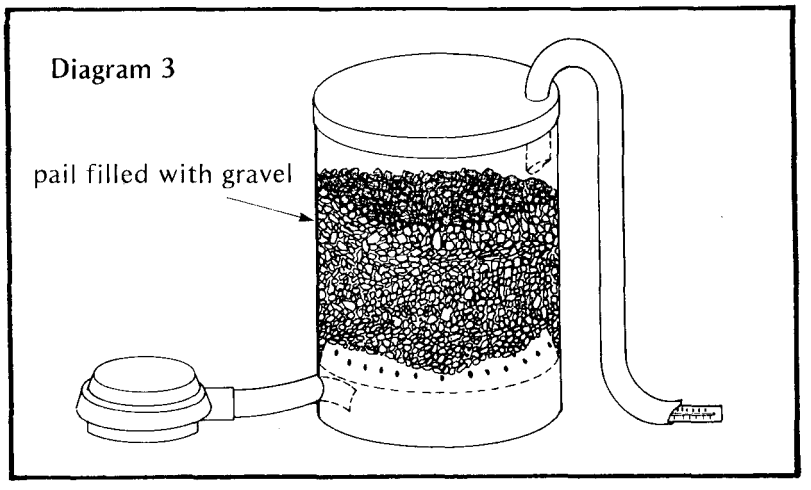
5. Remove the thermometer. Place the colander upside down in the pail. Attach the pail's lid.

6. Place the thermometer in the outlet hose, as shown in Diagram 2. Record the temperature next to zero in the "Pail Filled with Air" column of the Data Table. Set the dryer on hot. Record the air temperature every minute for 10 minutes.




7. Turn the dryer to cool. Continue to record the temperature for another ten minutes. Turn the dryer off.

8. Fill the pail with the clean gravel, as shown in Diagram 3. (Leave the colander in place to provide an air space below the gravel.) Replace the lid and record in the "Pail Filled with Gravel" column of the Data Table the beginning temperature of the outlet air. Turn the dryer to hot and record the temperature every minute for 10 minutes.




9. Turn the dryer to cool and continue to record the temperature for another ten minutes. Turn the dryer off and unplug it.

10. On the graph provided, plot both sets of data. Be sure to label each line correctly.

# questions

1. When the pail was filled with air, what was the change in the outlet air temperature during the heating phase? During the cooling phase?

2. When the pail was filled with gravel, what was the change in the outlet air temperature during the heating phase? During the cooling phase?

3. As shown by the outlet air temperature, which substance, air or gravel, heated more rapidly? Which cooled more rapidly?

4. Which substance provided the higher temperature at the outlet during the heating phase? During the cooling phase?

5. What differences are shown by the two sets of data when plotted on the graph?

6. Which substance is better able to absorb and store heat energy for later use, rather than passing it right through the storage pail? How do you know?

7. Which substance can release the greater amount of heat during the cooling phase? How do you know?

8. Which substance releases its heat more slowly? How do you know?

9. If you were designing a solar heating system for your own home, would you choose air or gravel as your storage material? Why?

## looking back

In this activity you experimented with two very different materials to decide how well they would store heat. You found that one of them is just not dense enough to store much heat. It heats up quickly, but when the heat source is removed it cools off quickly.

The other material is much more dense and stores a lot more heat. When heat is being supplied it absorbs a lot of it. When the heat source is turned off, this storage material continues to give off heat slowly for some time.

## going further

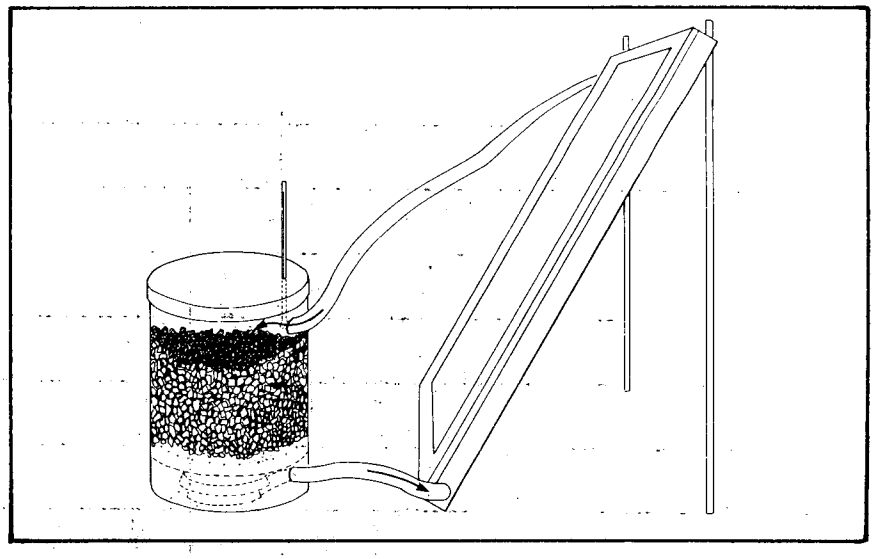
Repeat the activity using one hour as the time interval for the heating phase and one hour for the cooling phase. Compare these new data to your original results.

Repeat the activity, this time placing a smaller pail filled with water inside the plastic pail. Compare these new results to your original data.

*Caution: Water and electricity do not mix. Be extremely careful not to spill any water while the dryer is plugged in.*

Repeat the activity using several different sizes and kinds of gravel, from sand to a few large rocks. Compare results and explain any differences.

Adapt the apparatus for connection to a flat plate solar collector. Place the dryer in the bottom of the pail with the colander over it. Connect the hoses to the collector. Operate the dryer at the cool setting. Monitor the heating phase with the collector connected to the pail, then monitor the cooling phase with the collector disconnected. (See Activity 3 in the Chemistry and Physics Activities book for more information.)



Adapt the apparatus for heat storage through the melting of a solid such as paraffin (wax). Select a paraffin with a melting point in the same range as your dryer's temperature range. Experiment with various ways of placing the paraffin in the pail. Compare any new results to your original data.

Research other materials and methods for storing heat energy in solar heating systems. Write a report of your findings.

# Data Table

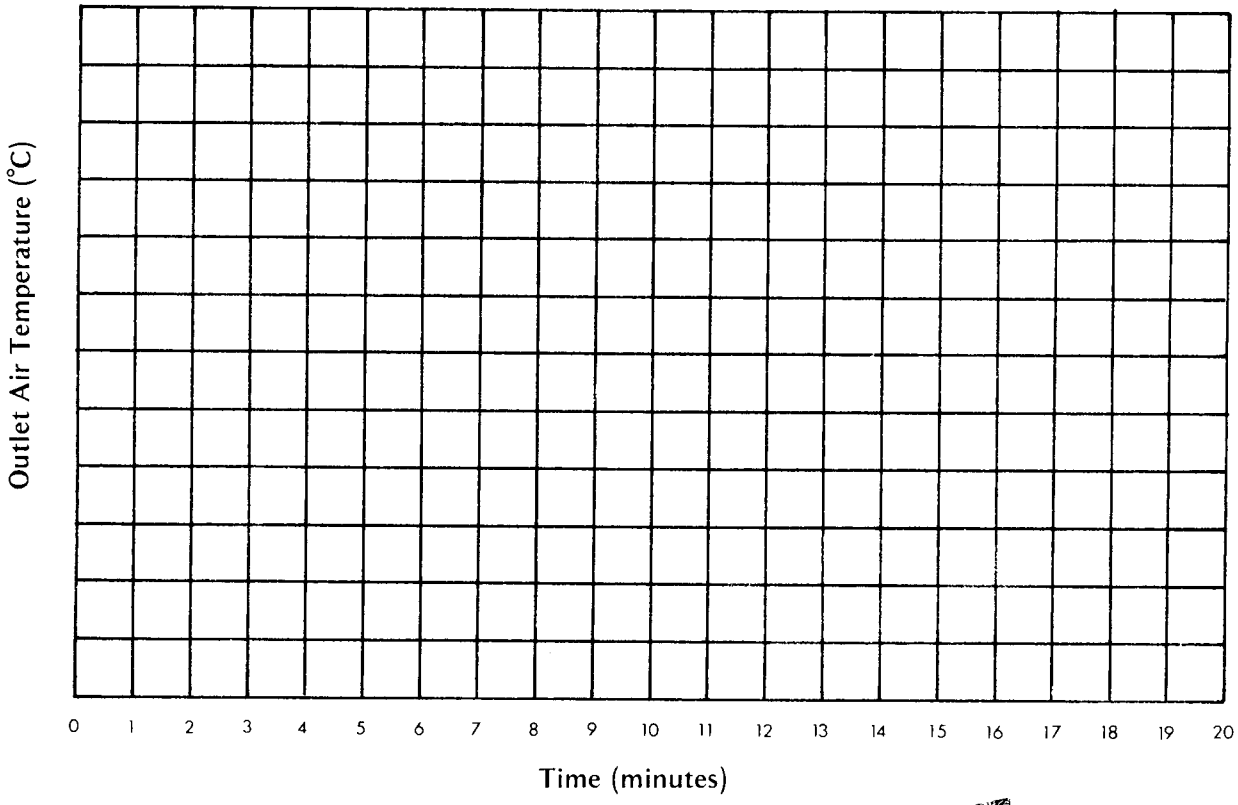
Temperature at Inlet

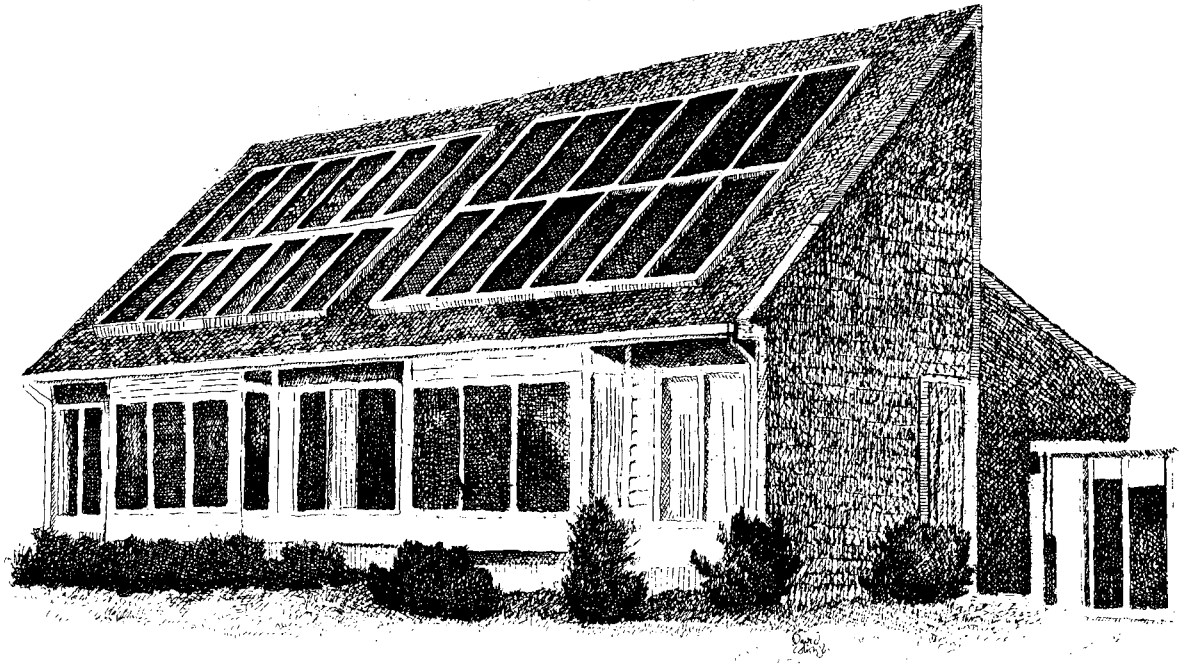
Dryer set on hot: _____ °C

Dryer set on cool: _____ °C

| Time Elapsed (minutes) | | Air Temperature at Outlet (°C) | |
|---|---|---|---|
| | | Pail Filled with Air | Pail Filled with Gravel |
| Heating Phase | 0 | | |
| | 1 | | |
| | 2 | | |
| | 3 | | |
| | 4 | | |
| | 5 | | |
| | 6 | | |
| | 7 | | |
| | 8 | | |
| | 9 | | |
| | 10 | | |
| Cooling Phase | 11 | | |
| | 12 | | |
| | 13 | | |
| | 14 | | |
| | 15 | | |
| | 16 | | |
| | 17 | | |
| | 18 | | |
| | 19 | | |
| | 20 | | |

# Graph


Outlet Air Temperature (°C)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time (minutes)



Teacher Information

# Storing Heat Energy

## Suggested Grade Level and Discipline

Science, grades 6-9
Physical Science
Earth Science

## Skill Objectives

Constructing a heat storage system

Preparing and interpreting heating and cooling curves for heat storage materials

Applying results to practical situations

## Major Understandings

Rocks can store far more heat energy per unit volume than air.

Air will heat rapidly during the heating phase and cool rapidly during the cooling phase of heat storage.

Rock will cause the heating and cooling curves to moderate. Outlet air temperatures will increase less during the heating phase as heat is absorbed and stored by the rock. Also, outlet air temperatures will decrease less during the cooling phase as the stored heat energy in the rock is slowly released to its surroundings.

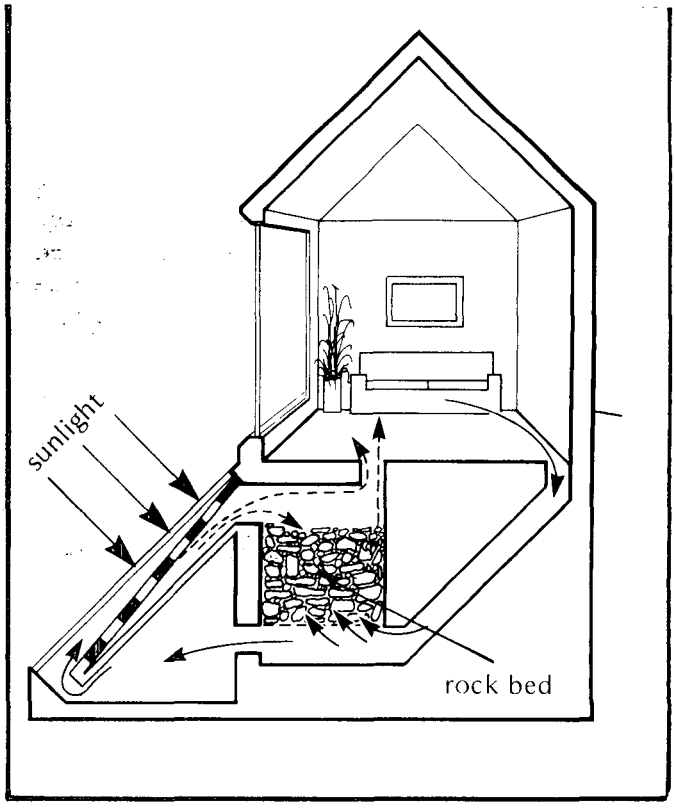
The higher heat capacity of rock is largely due to its much greater density.

Rock is a good absorber and conductor of heat energy. It is thus a suitable material for storage of solar-derived heat energy.

## Background

As other activities in this book have demonstrated, solar energy is easily captured. But for this energy to be useful in heating our homes, it must also be stored. This storage is usually accomplished by using rock-like solids or water. Passive solar homes, for example, often have masonry floors, back walls, or fireplaces (known as thermal masses) to absorb and store solar energy for nighttime use. Sand, rock, or earth beds below grade absorb heat from hot air pumped through them. Water walls and large tanks of water are yet other ways to store solar energy.

In this activity students investigate the storage capacities of two materials, air and rock. The pail serves as a heat storage unit and functions as a storage bed in a solar house would function. Heated air is blown through the pail storage, just as a rock bed would be "charged." In a solar system, heated air from collectors would be blown into the top of the bed and cold air drawn from



the bottom in a closed loop. Then, when heat is needed in the living space, a second cycle would be added: heated air is drawn from the top of the rock bed, circulated through the space to be heated, and returned to the bottom. In the activity, this heat-removal phase of the cycle is simulated by blowing cool air through the pail and monitoring (as changes in temperature) the heat given off.

Students will readily see why rock or sand is a preferred choice for thermal storage. The key is the heat capacity of rock as compared to air. Heat capacity is related to specific heat, which is defined as the number of calories needed to raise one gram of a material by one degree Celsius. But to compare how much heat a given volume of different materials can store, one needs to know their densities. Rock, for example, is much denser than air. Multiplying the density by the specific heat will give the heat capacity, the amount of heat that can be stored in a given volume of material ($cal/cm^3{}^oC$). Rock can store over 2000 times as much heat as the same volume of air, while water can store 2.6 times as much heat as rock.

| SUBSTANCE | Specific Heat ($cal/g^oC$) | Density ($g/cm^3$) | Heat Capacity ($cal/cm^3{}^oC$) |
|---|---|---|---|
| Air | .24 | .001 | 0.00024 |
| Water | 1.00 | 1.00 | 1.00 |
| Rock | .21 | 2.64 | 0.55 |
| Brick | .20 | 1.97 | 0.39 |
| Concrete | .156 | 2.24 | 0.35 |
| Sand | .19 | 1.52 | 0.29 |

In practice, thermal mass is sized to solar collector systems. If heat is being stored in water, than 60-120 liters/sq. meter (2-4 gallons/sq. ft.) of collector surface are needed. For rock or sand, the amount is 500-900 kilograms/sq. meter (100-200 lbs/sq. ft.).

## Advance Planning

The plastic pails are available from both your custodial and cafeteria staffs.

Students will often have discarded bonnet-type hair dryers at home. Just make sure they understand the hose will be cut. These hair dryers are also often available at garage or yard sales.

The colanders can be obtained inexpensively from discount stores or kitchen supply stores. Stores may be willing to donate them. Wire mesh is readily available and makes a good substitute.

Gravel is obtainable from lumber yards, hardware stores, pet supply stores, or sand and gravel companies. Gravel is very inexpensive and gravel companies will probably be willing to donate it to you.

The holes in the pail can be cut with any sharp but stout-edged knife. A heavy exacto knife is recommended. You may want to cut the holes yourself.

## Suggested Time Allotment

One period to assemble apparatus and conduct the air storage phase of the activity

One period to conduct the gravel storage phase of the activity and graph results

One period to answer questions and discuss results

## Suggested Approach

The number of set-ups available will determine how this activity is conducted. If you have access to several hair dryers, allow students to work in groups of two or three. Otherwise, consider conducting this activity as a teacher or student demonstration or in conjunction with several other solar activities. In the latter case, groups of students can rotate from activity to activity over the course of several days. (You will still need two or three set-ups.)

After students have obtained and graphed their data, explain the concept of heat capacity. Discuss the heat capacities of air and rock.

Discuss the importance of heat storage to the success of solar heating.

If class time is in short supply, some groups can perform the air phase of the activity while others perform the rock phase. However, if the hair dryers don't provide equivalent temperatures, be sure to point it out during the discussion of results. Provide time for sharing of data.

## Precautions

*Make sure students use the knives carefully. Collect them immediately after use.*

*Remind students that the dryer is an electrical appliance and that all electrical safety procedures should be followed.*

## Points for Discussion

What results might you obtain if you extended the heating and cooling phases of the activity to one hour each?

What would happen if you doubled the amount of gravel?

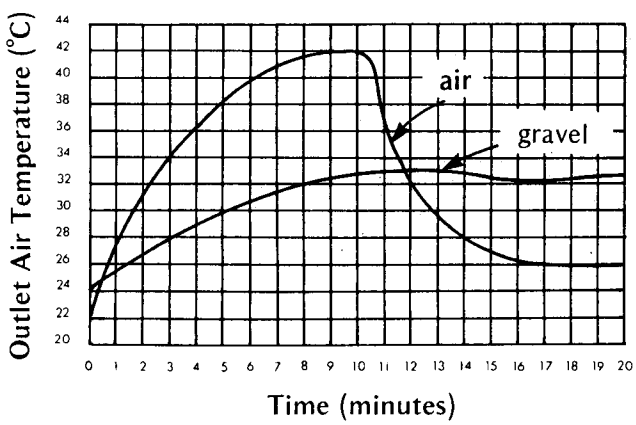
Why is the necessity of storing heat energy central to the success of any solar heating system?

What materials could be used to store solar energy? What materials are commonly used?

## Typical Results

A graph of sample data is given below. The incoming air temperature was 57°C when the dryer was set at hot and 25°C when the dryer was set at cool. Gravel used was 1.6 cm (5/8") washed river gravel.

When the gravel was allowed to store heat for an indefinite period of time, the outlet air temperature leveled off after one hour at 40°C. The gravel itself reached 50°C. After cooling for one hour the outlet air temperature dropped to 26°C and the gravel to 27°C.




## Evaluation

Inspect students' tables and graphs for accuracy and completeness.

Review students' answers to questions to determine if they comprehend the heat storage properties of air and rock.

Ask students to explain why rock is a better heat storage material than air.

Ask students to draw typical heating and cooling curves for air and rock.

## References

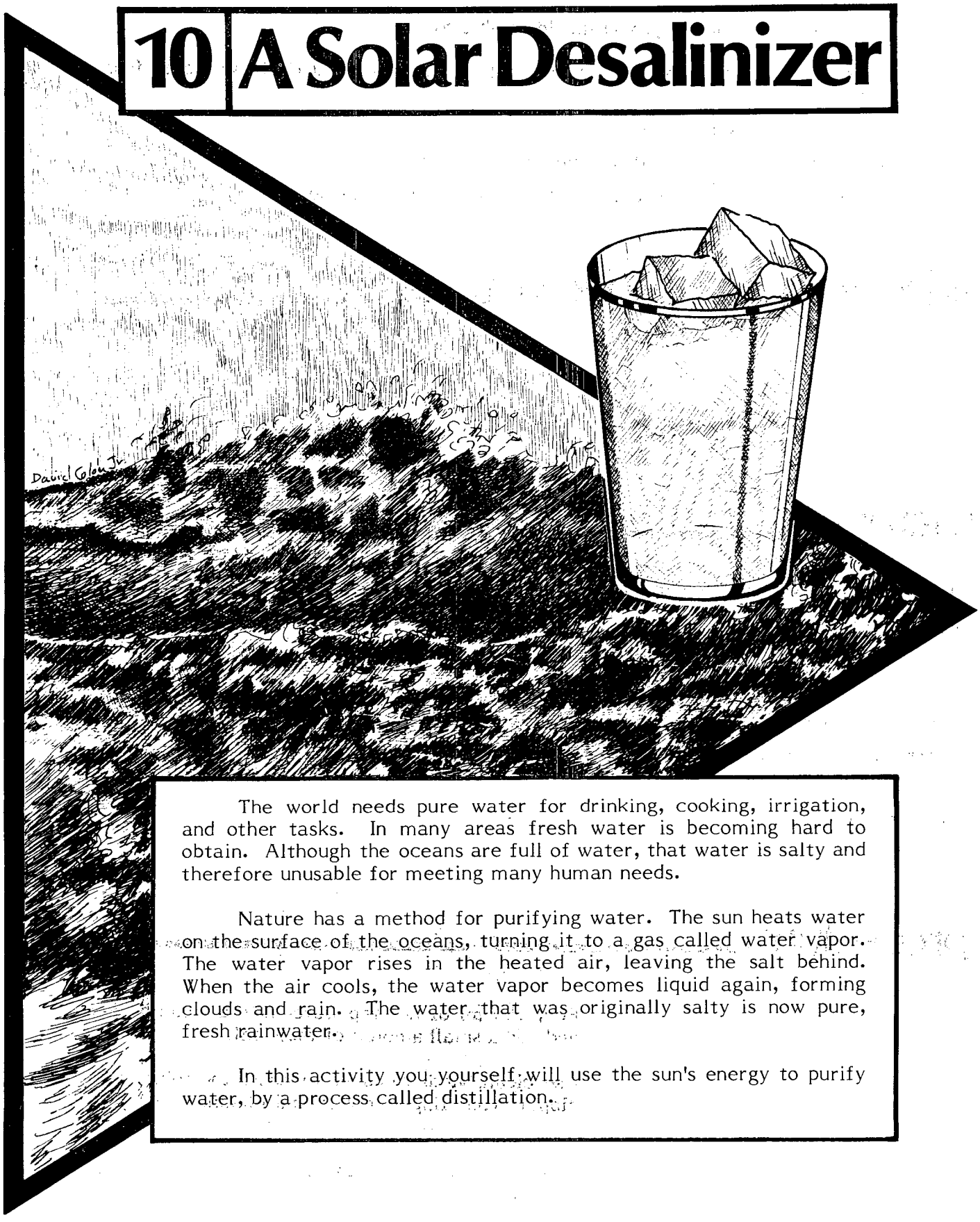

Engineer's Guide to Solar Energy, Yvonne Howell and Justin Bereny.
(Solar Energy Information Services, Second Ave., P.O. Box 204, San Mateo, CA 94401, 1979, $29.50/paper.)

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

Sun Up to Sun Down: Understanding Solar Energy, Shawn Buckley.
(McGraw-Hill Book Co., 1221 Avenue of the Americas, New York, NY 10020, 1979, $6.95/paper.)

Solar Age (April 1978).
(Solar Vision, Inc., Church Hill, Harrisville, N.H. 03450.)

# 10 A Solar Desalinizer




The world needs pure water for drinking, cooking, irrigation, and other tasks. In many areas fresh water is becoming hard to obtain. Although the oceans are full of water, that water is salty and therefore unusable for meeting many human needs.

Nature has a method for purifying water. The sun heats water on the surface of the oceans, turning it to a gas called water vapor. The water vapor rises in the heated air, leaving the salt behind. When the air cools, the water vapor becomes liquid again, forming clouds and rain. The water that was originally salty is now pure, fresh rainwater.

In this activity you yourself will use the sun's energy to purify water, by a process called distillation.

# objectives

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

- o construct a model desalinizer that uses solar energy to produce fresh water from salt water;
- o explain how this desalinizer works;
- o define evaporation, condensation, and distillation; and
- o compare the operation of a solar desalinizer to the water cycle.

# skills and knowledge you need

Following directions

Measuring metric volume

Collecting and interpreting data

# materials

a plastic shoebox or similar-sized plastic container

plastic wrap

a small paper cup, a small jar, or a 50 ml beaker

salt

a large rubber band

a marble or rounded stone

black construction paper

a 500 ml beaker

tape

# procedure

1. Pour 500 ml of hot tap water into a clean beaker and add a small amount of table salt.

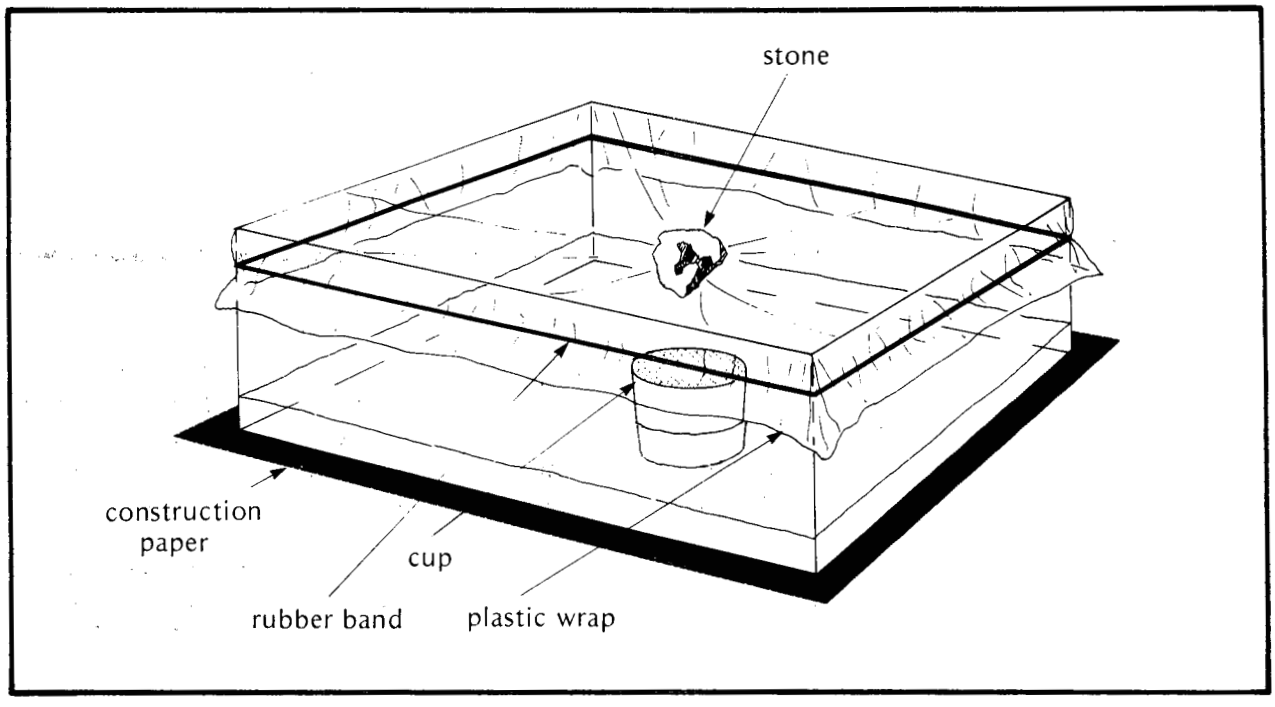
2. Use clean hands to carefully taste the solution by dipping your finger into it and placing it on your tongue. How does the solution taste?

3. Tape the cup or jar into the center of the plastic shoebox.

4. Carefully pour the salt water solution into the shoebox. Be sure not to get any in the cup.

5. Cover the shoebox with the plastic wrap. Hold it in place with the rubber band.

6. Place the marble or stone in the center of the plastic wrap, directly above the cup. Press down on the marble and loosen the wrap so that the marble sits in a depression, but not so far down that the plastic wrap touches the rim of the cup.




7. Carry the equipment to a level spot in direct sunlight, being careful not to slosh salt water into the cup. Set the black construction paper down first, then place the shoebox on top. Predict what you think will happen in your solar desalinizer.

8. Observe your solar desalinizer at intervals during the day. What is happening?

9. When your teacher directs you to, uncover the shoebox and carefully remove the cup. Dry the outside. Be sure not to get any salt solution into the cup. What does the cup contain? Taste the contents using the method already described. Again, taste the solution in the shoebox.

## questions

1. Look up the following terms in a dictionary or science book: water cycle, evaporation, condensation, and distillation. Write out the definitions.

2. What did you predict would happen when your desalinizer was placed in the sun?

3. What actually did happen inside your desalinizer? What is this process called? Was your prediction correct?

4. What did the solution in the shoebox taste like before distillation? After distillation?

5. Did a liquid accumulate in the cup? If so, what did it taste like?

6. Why was black paper placed beneath the shoebox?

7. Energy was required to remove the salt from the saltwater solution. Where did this energy come from?

8. Compare the operation of your desalinizer to the water cycle. Make sure you use the terms you defined in Question 1.

# looking back

In this activity you constructed an apparatus called a solar still or solar desalinizer, which produced fresh water from salt water. Just as in the natural cycle of evaporation and condensation, the sun supplied the energy to separate fresh water from salt water. You helped the process by setting up your solar desalinizer so as to catch the fresh water and keep it separate from the salt water.

In nature this solar water purification process goes on every day, as clouds form and rain falls. People can take advantage of the same solar distillation process to meet some of the demand for pure water.

# going further

Do research on large-scale solar desalinization of sea water. What countries desalinize sea water? Why do they do it? Are there regions of the world where solar desalinization could not be accomplished? Why?

In what other ways can sea water be desalinized? What are the advantages and disadvantages of each of the ways, including solar desalinization?

Research some of the more recent ideas for obtaining pure drinking water, such as seeding clouds, chemically treating water, or towing icebergs from Antartica. List the advantages and disadvantages of each. How likely is it that any will become accepted methods of producing drinking water?

To find out about another kind of solar distiller, try Activity 5 in the Earth Science Activities book.

Teacher Information

# A Solar Desalinizer

## Suggested Grade Level and Discipline

Science, grades 6-8
Physical Science
Earth Science
Ecology

## Skill Objectives

Constructing a model solar still

Measuring metric volume

Predicting and observing

## Major Understandings

Solar energy can be used to remove impurities from sea water by evaporating the water and leaving salts and other minerals behind.

Upon cooling, evaporated water will condense into liquid form and is suitable for human use.

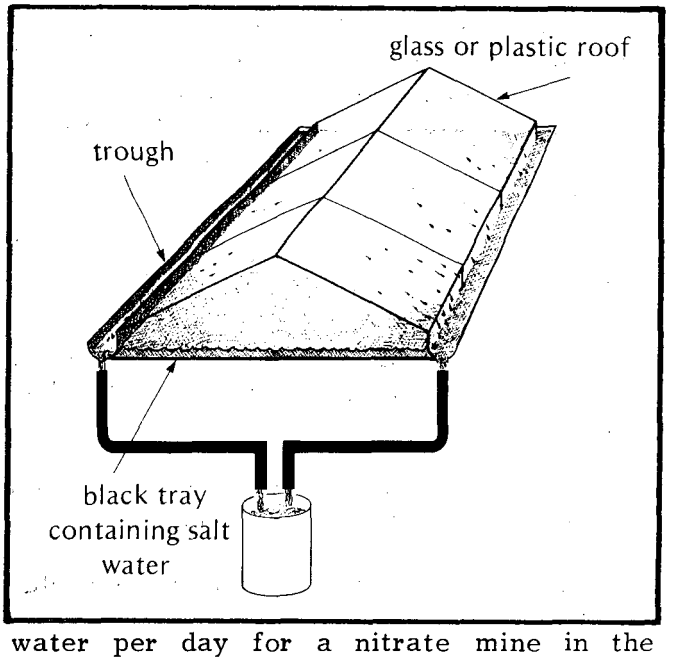
Solar desalinizers operate on the same principle as the hydrologic cycle, in which water is evaporated from the surface of the earth, condenses into clouds in the air, and precipitates as rain or snow.

## Background

Water is becoming an increasingly precious commodity. If demand for non-saline water continues to grow at its present rate, severe water shortages may occur before the year 2000 in many regions of the world. Even now, areas in the United States such as southern Florida, the northeast, and Arizona are experiencing water shortages as a result of drought, lowered water tables, and increased demand.

Current water use is estimated to be 800 metric tons/person/year, worldwide. This includes energy production, industry, and municipal and domestic use, as well as use in irrigated agriculture (which accounts for over half of all water use). Meeting increased future demands for water may require the desalinization of sea water on a massive scale.

Solar desalinization of water is not a new technique. Beginning in 1872 and continuing for 40 years, a large-scale solar distillation plant produced over 5000 gallons of water per day for a nitrate mine in the Chilean desert. Solar distillation is also technically simple, as this activity illustrates. In most commercial stills, a blackened tray (which increases solar energy absorption) holds a layer of salt water and is covered by a glass or plastic tent which slopes to a trough at each side of the tray.



As the water is heated by the sun's rays passing through the clear tent, its vapor pressure increases and it evaporates, leaving brine behind. The vapor then condenses on the undersides of the cooler tent and runs into the troughs where it is conducted to a reservoir. A typical still can achieve a production of 4.1 liters of water/$m^2$/day.

Solar distillation is commercially feasible in small quantities and in remote areas where pure water is difficult to obtain. Small family stills, producing a few gallons a day, are economically competitive, especially in developing countries. These stills are inexpensive to build and have a low operating cost. Massive solar distillation for agricultural irrigation, however, is not now economically attractive, as it requires a high capital investment and very large tracts of land. There is also the associated environmental problem of the disposal of the brine.

## Advance Planning

Plastic shoeboxes may be purchased inexpensively at discount houses and hardware stores. Tote trays or other plastic containers can easily be substituted for shoeboxes if necessary.

Try out the size of the collecting cup before students perform the activity. It should be small enough so that the plastic wrap, when weighted down by the marble, does not touch the edges. If small jars are used, students should bring them to class ahead of time.

## Suggested Time Allotment

One class period to construct the desalinizer, place it in sunlight, and observe what is happening

Several hours for an appreciable amount of condensate to collect in the cup

One class period to interpret and discuss results

## Suggested Approach

Since the stills must operate for several hours before fresh water accumulates in the cups, it is suggested that the stills be left in place and examined on the next class day. If they have been placed outside, students can help you bring them inside at the end of the school day. Overnight cooling of the stills may actually cause more condensation, resulting in a greater amount of pure water being collected.

Students can work in groups of two or three to construct the desalinizer.

Help the students to understand the similarity of distillation to the cycling of water in nature.

## Precautions

*Make sure all equipment is clean, as students will be tasting solutions. Remind students that they should never taste chemicals unless directed to do so by the teacher.*

*Make sure students do not accidentally contaminate the distilled water with salt water.*

*Make sure the plastic wrap does not touch the edges of the cup or the condensate will not drop into the cup.*

## Points for Discussion

When and where would the process demonstrated be useful to humans?

How could a more effective solar desalinizer be designed?

## Typical Results

On a variably cloudy afternoon in mid-September, with air temperature about 18°C, the desalinizer collected approximately 25 ml of water over three hours.

## Evaluation

Inspect students' desalinizers to determine how well they have followed directions.

Check answers to questions.

Ask students to write a paragraph comparing the operation of a solar still to the water cycle.

## Modifications

If necessary, a heat or flood lamp can be substituted for sunlight.

You may wish to make a stock salt solution rather than having students make their own solutions, especially if the classroom does not contain hot tap water.

## References


Catch a Sunbeam: A Book of Solar Study and Experiments, Florence Adams.
(Harcourt Brace Jovanovich, Inc., 757 Third Ave., New York, N.Y. 10017, 1978, $7.95, for student reading.)

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

Energy for Survival: The Alternative to Extinction, Wilson Clark.
(Doubleday & Co., Inc., 501 Franklin Ave., Garden City, NY 11530, 1974, $12.50.)

Global 2000 Report to the President of the U.S., Vol. 1, Executive Summary, Gerald O. Barney.
(Superintendent of Documents, Government Printing Office, Washington, D.C. 20402, 1979, $3.50.)

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 | 2.54 | centimeters | cm |
| | feet | 30.0 | centimeters | cm |
| | feet | 0.3 | meters | m |
| | yards | 0.91 | meters | m |
| | miles | 1.61 | kilometers | km |
| Area | square inches | 6.5 | square centimeters | $cm^2$ |
| | square feet | 0.09 | square meters | $m^2$ |
| | square yards | 0.8 | square meters | $m^2$ |
| Mass (Weight) | ounces | 28 | grams | g |
| | pounds | 0.45 | kilograms | kg |
| Volume | gallons | 3.8 | liters | l |
| | cubic feet | 0.03 | cubic meters | $m^3$ |
| 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, $5.8 \times 10^9$ joules or $5.5 \times 10^6$ Btu or $1.39 \times 10^6$ 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.