# Solar Water Heaters

RENEWABLE ENERGY
THE INFINITE POWER OF TEXAS

## For Grades 6, 7 and 8

## OVERVIEW

Students will discuss the concept of a passive solar water heater system and its components. Students will study how a solar water heater functions by making a simple, passive solar model and taking temperature measurements and recording and graphing their results. The teacher will question why a passive solar system would be desirable, compared to one using other energy sources, such as electricity or gas. Students will discuss the advantages and disadvantages of renewable and non-renewable energy sources.

## OBJECTIVES

See Middle School Teacher Resource Guide for TEKS objectives and additional information regarding this and other middle school units.

## SUGGESTED TIMEFRAME

Teacher will need to determine how many class periods to devote to each activity, based on the suggested timeframe and length of classes.

| Time | Activity | Content Area |
|---|---|---|
| *5 minutes* | **Activity 1** – Teacher Introduction | |
| *15 minutes* | **Activity 2** – Assessment of Current Student Knowledge | Science |
| *45 minutes* | **Activity 3** – Vocabulary and Reading Passage<br>**Homework Assignment** – Vocabulary Definitions | Vocabulary Reading Language Arts |
| *30 minutes* | **Activity 4 –** Pre-Lab<br>**Activity 5 –** Lab | Science |
| *30 minutes* | **Part A:** Constructing the Parabolic Solar Water Heater | |
| *10 minutes* | **Part B:** Performing the Experiment | |
| *30 minutes* | **Activity 6 –** Post-Lab | Science |
| *45 minutes* | **Activity 7 –** Library/Internet Research | Technology & Science |
| *30 minutes* | **Activity 8 –** Assessment | Science |

## REQUIRED MATERIALS

- copy of the Reading Passage and Student Data Sheets (includes reading comprehension questions, vocabulary and Lab Activity) for each student
- copy of the Assessment Questions for each student
- graph paper
- an equipment kit for each group containing the following:
  - 40 cm of aquarium tubing, painted black
  - cardboard paper towel roll
  - 1 small sheet of aluminum foil
  - 1 pair scissors
  - 1 self adhesive fastener for binding holed paper (any office supply store)
  - 2 brass brad fasteners
  - 1 gooseneck lamp with 100 watt bulb (to represent the sun) or access to strong, direct sunlight
  - 1 Styrofoam cup
  - 1 tube of caulk (may be shared among the groups)
  - 1 collecting jar or small beaker
  - 1 pencil
  - goggles

## ADVANCED PREPARATION FOR LAB WORK

The teacher should read the Lab Activity completely and understand the steps involved in constructing the solar water heater. The lab equipment kit should be prepared ahead of time. Some special preparation of materials is required, such as painting the aquarium tubing and cutting

holes in the paper towel rolls for the brass fasteners. At the teacher's discretion, a group of students may be selected to prepare these materials.

## BACKGROUND INFORMATION

There are two basic types of solar water heaters: passive and active. Active systems utilize a circulating pump and some type of temperature control. Passive systems do not have any moving parts and rely on the basic principle of physics—that hot water rises and cold water falls. The teacher should read the Reading Passage contained in this unit about solar water heaters. The Teacher's Resource Guide also contains links to other documents describing solar water heaters.

## SUMMARY OF ACTIVITIES

### Activity 1 – Teacher Introduction (5 minutes)

Explain to the class that for the next unit of study, they will learn how solar water heating systems work and about the different types of systems that are available. Inform students that they will build a simple parabolic solar water heater.

### Activity 2 – Assessment of Current Student Knowledge (15 minutes)

To assess what students already know, prompt a class discussion based on the 2 questions listed below. Based on this discussion, create and display a graphic organizer of the points that were discussed that can be displayed throughout the unit of study. Refer to the Teacher Resource Guide for sample organizers.

1. What is a solar water heater? How could they have been used by people who did not have electricity hundreds of years ago, such as the early American pioneers or Native Americans?
2. What do you think you would need to build a solar water heater for your home?
3. Does heating your water with the sun benefit the environment? Why or why not?

See Teacher Resource Guide for alternative or additional assessment activity.

### Activity 3 – Vocabulary and Reading Passage (45 minutes)

Distribute to each student a copy of the Reading Passage and the Student Data Sheets, which include vocabulary words and reading comprehension questions. (As an alternative to making copies, the Student Data Sheets can be displayed so the entire class can view and copy them into their science notebooks.) Instruct students to study the Reading Passage and complete the questions and vocabulary. This activity will help them learn about the basic concepts involved in solar water heating systems. Key vocabulary words in the Reading Passage will assist them in understanding the Lab Activity instructions. For students who wish to learn more of the detailed principles behind the operation of solar water heaters, direct them to the appropriate resources suggested in the Teacher Resource Guide.

#### Homework Assignment – Key Vocabulary List

1. Instruct students to create in their science notebooks meaningful sentences that reflect an understanding of the definition of each vocabulary word. Students should have written the definition of the words in their science notebooks during class. See Teacher Resource Guide for alternative vocabulary homework.
2. Collect and grade this assignment the next day.

### Activity 4 – Pre- Lab (30 minutes)

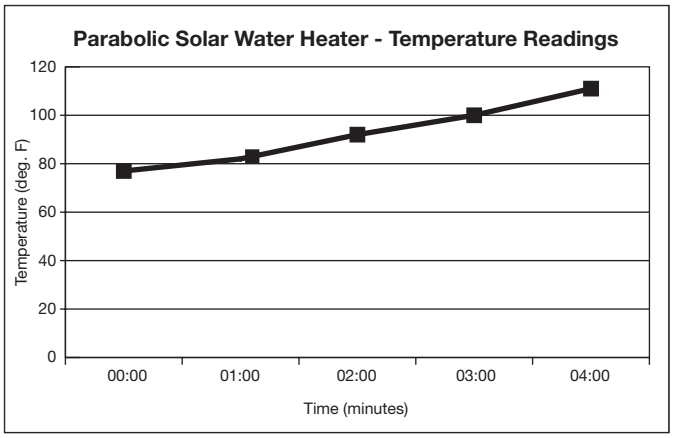
1. Explain to the class that the purpose of the Lab Activity is to enhance their understanding of passive solar water heaters by building a simple parabolic water heater and demonstrating the concept of heating water with light. For teachers interested in exploring the scientific method more fully as it applies to this Lab, see the Teacher Resource Guide for guidelines. Before performing the lab, students can be given the lab instructions to read and summarize the steps involved. The summary can be in the form of a brief chart. Review safety guidelines before students conduct the lab. See Teacher Resource Guide for general safety guidelines. Demonstrate proper use and care of thermometers and use of equipment. Discuss with students how they plan to create their graph including which variables will be graphed on the two axes.
2. Divide the class into small groups to build their parabolic solar water heaters.

#### Expected Observations

The small amount of water used in this experiment will gain about 3 to 5°C and upon standing several minutes will lose heat, indicating a need for an insulated storage tank in the home. If natural sunlight is used as the heating mechanism rather than a lamp, the timeframe will be altered.

## Activity 5 – Lab – Building a Parabolic Solar Water Heater (40 minutes)

1. Instruct students to follow the directions outlined in the Lab Activity. To ensure that all students participate, instruct the groups to assign who will be responsible for each step in the activity before beginning.
2. Confirm that the students have recorded their time and temperature measurements and observations on their Lab Report Form, as well as answers to the lab questions.
3. Distribute graph paper to each student. Instruct students to graph their results on the graph paper. A sample graph is provided below with time plotted on the x-axis and temperature plotted on the y-axis. Although students worked in teams to obtain the data measurements, each student should complete his or her own graph.




**Sample graph (actual results will vary)**

## Activity 6 – Post-Lab (30 minutes)

After students have completed their Lab Report Forms and their graphs, discuss their results. You may ask each group to summarize to the class its results.

## Activity 7 – Internet Research Using Solar Energy in the Home (45 minutes)

1. Arrange for time in your school computer lab for the class to investigate solar energy usage in the U.S. and around the world. Students should focus on solar thermal energy usage (such as solar water heating) rather than solar electric usage (photovoltaics). Suggested Internet resources are listed in the Teacher Resource Guide.
2. Divide the students into pairs or small groups. Assign the student groups different areas of the world – either geographic (continents or countries) or economic (industrialized or developing nations).
3. Instruct students to research solar energy usage in the U.S. and throughout the world and to answer the following questions:
   - Does your assigned area of the world use solar energy?
   - What types of solar energy are being used in the homes?
   - What are some of the conditions that should be readily available for solar energy to be used?
   - Where is solar energy in homes most likely to occur: In an industrialized country, like the United States, Japan or European countries, or in a Third World country, like African nations or Bangladesh?
4. After students have completed their Internet research, discuss the research results as a class. Each group of students should have a different conclusion based upon the area of the world for which they were collecting information.

## Activity 8 – Assessment (30 minutes)

Distribute a copy of the Assessment Questions to each student. Instruct each student to work alone and answer the short answer and multiple-choice questions. Collect the handouts, grade and return them to the students.

## ADDITIONAL ACTIVITIES – LAB EXTENSIONS

1. **Heat Absorption with Black**
   Using the same setup from the Lab Activity, replace the black aquarium tubing with clear (unpainted) aquarium tubing and repeat the experiment. Compare the temperature readings with ones obtained from the original activity and discuss with the class how the black aquarium tubing affected the temperature measurements.
2. **Larger Collection Surfaces**
   Vary the size of the collector that was made in the Lab Activity by using other items such as two paper towel rolls end-to-end, plastic 2 or 3 liter bottles, or even larger items such as a plastic barrel or bucket cut in half. Instead of aquarium tubing for the larger projects, try garden hoses of different colors (white, green, black) or plumbing supplies such as plastic (PVC) or copper tubing. Compare the temperature readings with ones obtained from the original activity and discuss with the class any differences in temperature measurements. Larger containers for the water supply and water collector should be used if larger collectors are built.

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## HIGHLIGHTS

- **Solar water heaters can provide half or more of the hot water needs in the average home**
- **Simple or complex, solar water heater systems save money**

## SUMMARY

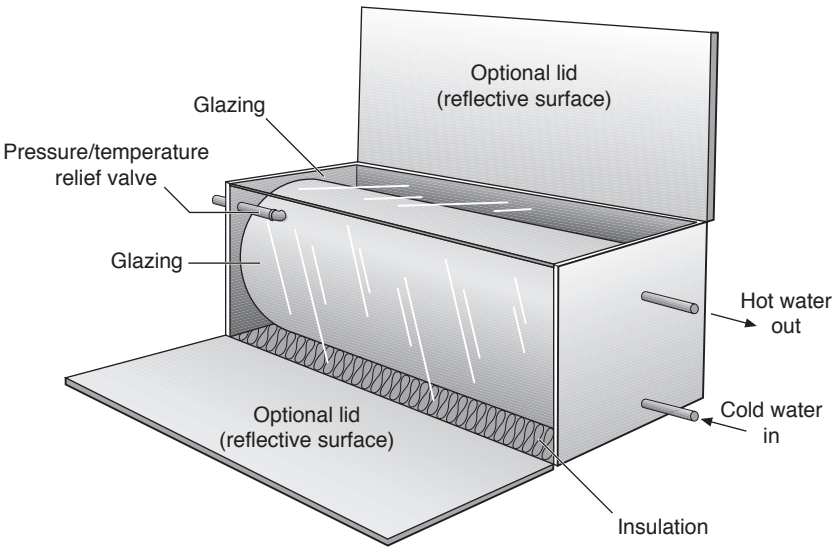
Have you ever turned on the outdoor water faucet expecting cold water to come out but got hot water instead? You have just experienced a solar water heater. Solar water heaters can be as simple as a garden hose left in the sun or as complex as multiple glass-plated solar collectors filled with a fluid. Simple or complex, solar water heaters are an inexpensive way for home and business owners to lower the cost of heating their water by replacing the cost of gas or electricity usually used to heat water with free energy from the sun.

## TYPES OF SOLAR WATER HEATING SYSTEMS

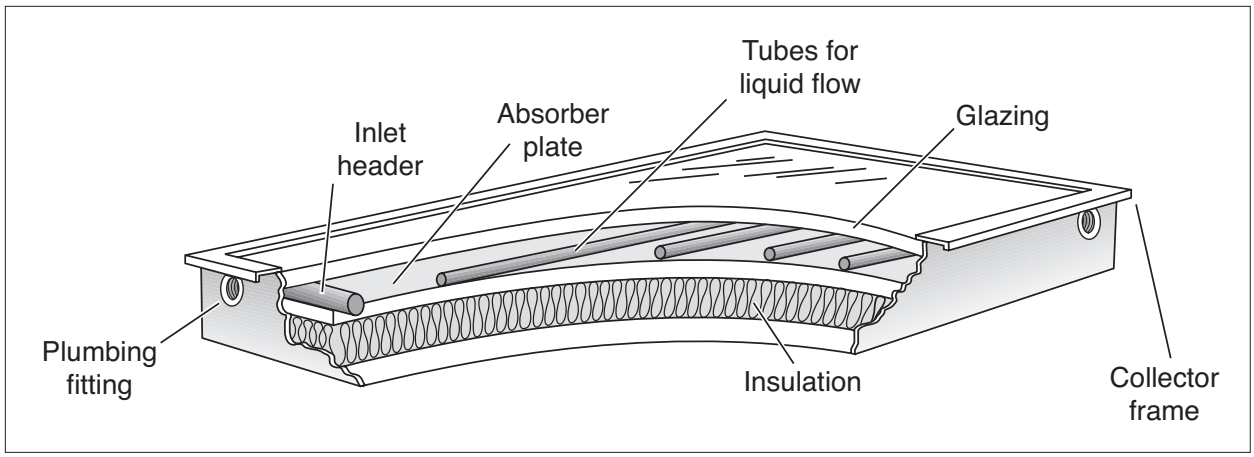
### *PASSIVE SYSTEMS*

In simple terms, a passive solar water heating system requires no moving parts and no external energy source except the sun itself.

The basic passive water heater consists of a water tank that has been painted black and placed in a well-insulated box that has glass or plastic on one side. This set up allows the sun's rays to heat the tank. This type of system is often called a




**BREAD BOX OR BATCH HEATER** *The basic, passive water heater allows cold water to flow in from the bottom and hot water to flow out of the top.*




**ACTIVE, INDIRECT SOLAR COLLECTOR** *It is a very simple machine.*

"bread box" or batch heater. It allows cold water to flow in from the bottom and hot water to flow out of the top. The system operates using only the water pressure from the water provider. Water from the system is then transferred to a standard water heater. The water is then stored where your thermostat can determine if the water is already hot enough for use. If the water is not hot enough, additional heat is added to increase the water temperature.

## *ACTIVE SYSTEMS: DIRECT AND INDIRECT*

Active solar water heaters are more efficient than passive solar water heaters. But they also require more equipment like collectors, sensors, pumps and controllers.

Active systems come in two types: direct and indirect. Direct systems heat water in the collectors. Indirect systems do not heat the household water, but instead they use another fluid such as freon, distilled water or propylene glycol. After the fluid is heated in the collectors, it travels through a heat exchanger, where the heat it contains is transferred to the household water.

While direct systems are more efficient than indirect ones, they require more maintenance and could develop a problem called scaling. Scaling is a build up of mineral deposits that can clog the smaller pipes so that water cannot flow through them much like what happens to veins and arteries when they get clogged, slowing down the flow of blood. Also, all water from inside the pipes may need to be drained in an active system. This is to prevent damage to the pipes or system from freezing or overheating. This need for a drain requires additional parts.

## *SOLAR COLLECTORS*

A flat solar collector is a very simple machine. It consists of an insulated rectangular box. It contains a metal plate (usually copper) that has been painted black, with a pipe at each end (called headers) that are connected to small tubes (called risers) also made from pipe. Water flows from the header into the risers. Water is first heated in the risers and then returns to the storage tank. The entire box is covered with a special glass that is hail resistant. The entire box is then installed, usually on the roof of a building, and tilted so it can capture as much sunlight as possible.

### *STORAGE TANKS*

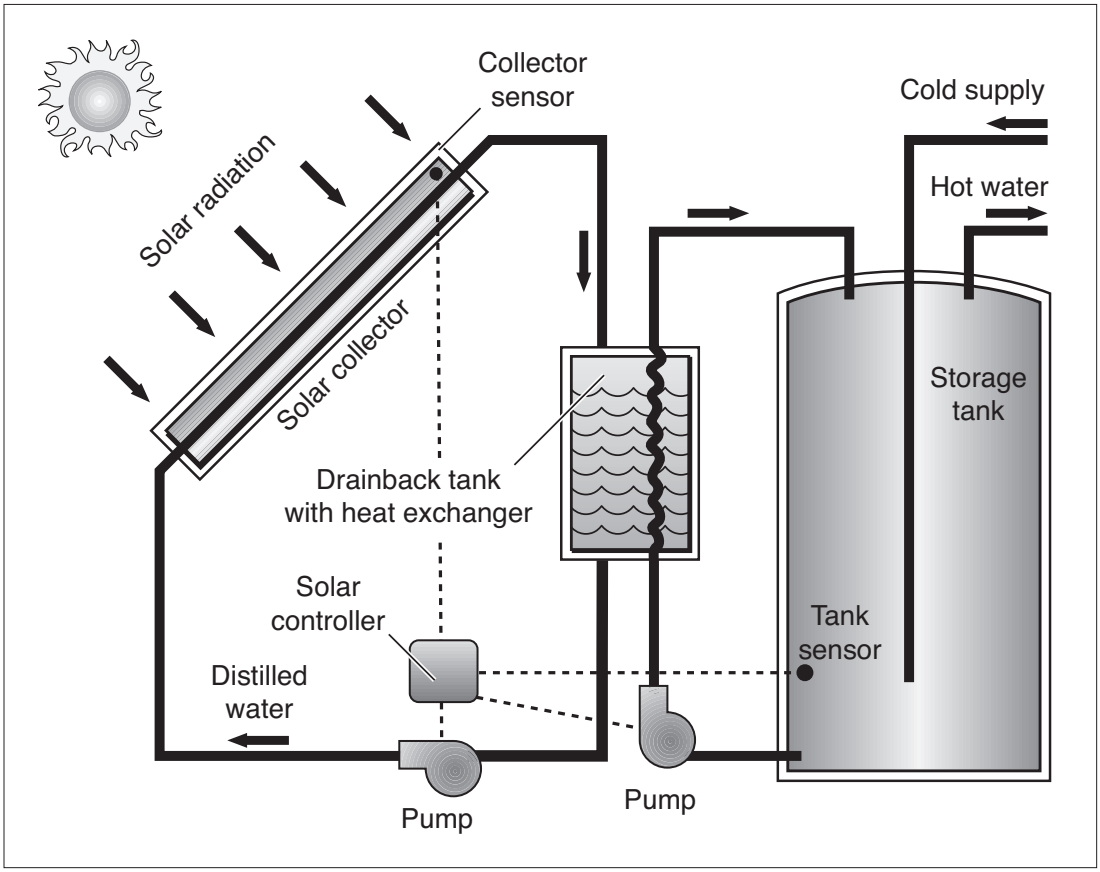
Whether you use a direct or indirect solar water heater, a large storage tank will be needed. The most commonly used size is 80 gallons. Solar water storage tanks look similar to standard water heater tanks. But they are very well insulated to save the heat gained by the collectors. Water is usually transferred from the solar water storage tank to a standard water heater tank.

Solar water heaters can heat water to a temperature that is much higher than needed in the home. Therefore, special valves, called tempering or mixing valves, are recommended to control the water temperature. The special valve can be set to the desired temperature, such as 120 degrees Fahrenheit. If the solar heated water is too hot, it mixes cold water with the hot water before it reaches the faucet.

## GETTING MORE FROM YOUR SYSTEM

Solar water heating systems can range in price from $800 for a simple passive water heater to $3,500 for a professionally made system. Conventional water heaters typically cost less than $1,000 when installed. You can get the most out of your solar water heater by installing low flow showerheads and aerators on all faucets. This is an affordable way to conserve water and reduce hot water use as well.

Do you realize that the time of day when you use water could greatly affect how well a solar system works? For instance, after you are done with your normal morning water needs like showering, you could wait until around noon to do laundry. This gives the solar water heater time to heat up more water that can be used in the afternoon.




**ACTIVE, DIRECT SYSTEM** *A direct system must be allowed to drain to prevent damage.*

## Understanding The Reading Passage

1. Describe how a passive solar water heater system works. Why does the water tank need to be painted black?

_____

_____

2. What is one major difference between a passive solar system and an active solar system?

_____

_____

3. What is the purpose of a storage tank?

_____

_____

4. What are two ways that you can conserve your solar heated water?

1 _____

2 _____

5. What is a direct, active solar system?

_____

_____

6. What is an indirect, active solar system?

_____

_____

7. How is a direct, active solar system different from an indirect, active solar system?

_____

_____

8. Which type of solar water heating system would you install at your home? Why?

_____

_____

## Vocabulary

Based on the Reading Passage, write down your understanding of these words or word pairs and verify your definitions in a dictionary, on the Internet if available or with your teacher:

absorb _____

active solar water heater _____

concave _____

convex _____

glazing _____

heat exchanger _____

parabola _____

passive solar water heater _____

radiation _____

reflect _____

solar collector _____

# LAB ACTIVITY – Building a Parabolic Solar Water Heater

## BEFORE YOU START

Review the vocabulary words from the Reading Passage. Ask your teacher if you are unsure of any of the meanings. Divide up all the steps in the Lab Activity first, so that everyone has a clear job to do.

## EQUIPMENT

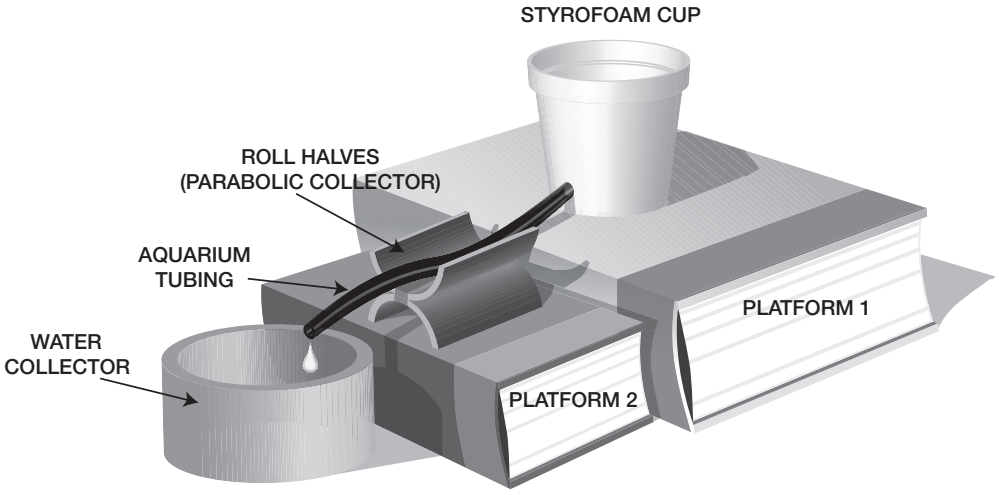
Collect an equipment kit from your teacher and check that it includes these items:

- 40 cm of aquarium tubing, painted black
- a cardboard paper towel roll
- 1 small sheet of aluminum foil
- 1 pair scissors
- 1 self-adhesive fastener for binding holed paper
- 2 brass brad fasteners
- 1 gooseneck lamp with 100 watt bulb (to represent the sun) or access to strong, direct sunlight
- 1 Styrofoam cup
- 1 tube of caulk (your group may be sharing a tube with other groups)
- 1 collecting jar or small beaker
- 1 pencil
- goggles

### Part A. Constructing the Solar Water Heater (wear goggles)

Read through the instructions first and draw in your science notebook what you think the final lab setup will look like.

1. Cut the paper towel roll in half lengthwise.
2. Place the roll halves together so their convex sides are touching (back to back)
3. Join the two roll halves together with brass fasteners at both ends of the rolls. (In order to insert the brass fasteners, you must carefully poke holes in the rolls if it has not been done prior to the lab.)
4. Pull off the paper covering the adhesive side of the self-adhesive fastener, and stick the self-adhesive fastener (adhesive side down) lengthwise in the middle of one of the paper towel roll halves.
5. Bend the 2 prongs of the self adhesive fastener straight up and then line the inside of one paper towel roll half with the aluminum foil, shiny side facing up (make slits to slide the foil over the prongs). This now is your parabolic collector or heater.



6. Using a pencil, twist and bend each prong to form a closed loop through which the aquarium tubing will slide.
7. Slide the black aquarium tubing through the 2 loops leaving equal amounts of tubing on each end of your parabolic collector
8. Poke a small hole in the side of the Styrofoam cup (in the lower side about one fourth inch from the bottom of the cup). (Note: The hole should allow the aquarium tubing to fit snuggly through it. Do not make the hole too big.) A pencil or other object can be used for this purpose.
9. Insert one end of the aquarium tubing into the hole in the side of the cup (should be a tight fit). Seal the hole with a small amount of caulk.
10. Place the parabolic collector on a raised object such as a book.
11. Place the cup on an object raised approximately 1/2 to 1 inch higher than the collector such as 2 books (or a thicker booker). The cup now is on one level and the parabolic collector is a half step lower than the cup.
12. Place a water collector (a small jar or beaker) on the tabletop and place the other end of the aquarium tube in it. The top of the water collector should be approximately even with the platform that the parabolic collector is placed on. See graphic below. Now there are three stairs or levels. The cup is the highest, the parabolic solar collector is second highest and the jar or beaker is on the lowest level.

## Part B. Performing the Experiment

(wear goggles)

1. Using the set up from your construction, place the parabolic water heater (collector) so that the concave, shiny, aluminum covered side faces the light from the goose necked lamp at a distance of 3 cm. (strong direct sunlight can be used and may take longer).
2. Measure 100 ml of water in a beaker or graduated cylinder. Record the temperature of the water in the beaker or cylinder.
3. Add the 100 ml of water to the Styrofoam cup, which is standing on the top level of your set up.
4. Immediately raise or lower the position of the collection jar (which is on the lowest stair or level), so that the water flows through the black tubing of the parabolic shiny collector at the slowest rate possible.
5. Record the temperature of the collected water in the jar or beaker during the collection process, recording the temperature every 30 seconds. Mark the reading when all of the water has flowed through the collector and no more is left in the Styrofoam cup.
6. Keep recording the temperature readings after all of the water has flowed through the solar collector for 2 - 3 minutes more.
7. Create a graph to indicate the temperature readings taken every 30 seconds. Indicate the time when all the water has flowed through the tubing.
8. Interpret the results of your graph to include what happens to the temperature during the flow of water and what happens after it has stopped flowing.

## Lab Report Form – Building a Parabolic Solar Water Heater

Date _____

Purpose of this lab is to _____

_____

**Instructions:**
Follow the directions in the Lab Activity to build your parabolic solar water heater model. Record the time and temperature every 30 seconds and note when all the water has flowed out of the first cup into the beaker.

### DATA TABLE 1. Water Temperature Readings

| Time | Temperature | Notes |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

### DATA SUMMARY

1. What was the temperature of the water when you started? _____

2. What was the highest temperature reached? _____

3. How long did the water stay at the highest temperature? _____

4. How could you keep the water at the highest temperature longer?

_____

_____

# STUDENT DATA SHEET

## Assessment Questions

1. How can the amount of solar energy collected in a passive solar system be increased?

_____

_____

2. Why is a parabolic curve used as a collector?

_____

_____

3. Why is the tubing painted black?

_____

_____

4. How can you design a bigger and better collector?

_____

_____

5. What are some limitations of a solar water heater?

_____

_____

6. What arguments can you make for using solar energy to heat water?

_____

_____

7. Are you currently making use of solar energy?

_____

_____

## Multiple Choice Questions

1. A solar water heater can be:
   a) a passive system
   b) an active system
   c) a money saver
   d) answers a, b, and c

2. A solar water heater collector often is covered with:
   a) a copper sheet
   b) special glass
   c) a large drain
   d) none of the answers

3. A solar water heater system must have:
   a) wind turbines
   b) PV cells
   c) a storage tank
   d) gas

4. Using solar energy has value because:
   a) solar energy does not pollute the environment
   b) solar energy saves money
   c) solar energy is not "used up"
   d) answers a, b, and c

5. The color black:
   a) reflects the wavelength of all colors
   b) absorbs the wavelength of all colors
   c) should be used to keep cool
   d) is rarely used

6. Use of solar energy is demonstrated by:
   a) a passive solar water heater
   b) clothes drying in the sun
   c) answers a and b
   d) a gas engine

7. A solar water heater:
   a) can heat water only 20 degrees above outdoor temperature
   b) can heat only 5 gallons of water at a time
   c) is best positioned facing north
   d) can heat water to 180 degrees

8. A solar collector has the following:
   a) dark surfaces inside
   b) a turbine
   c) convection currents
   d) biomass

9. As a homeowner in the future you would:
   a) never try using a solar water heater
   b) encourage everyone to use a solar water heater
   c) plan to use only fossil fuels to heat water
   d) not worry about energy resources

## Understanding the Reading Passage

1. A passive solar system operates with no moving parts and no external energy source other than the sun. The system operates from the water pressure from the source and routed to a standard water heater.
2. A passive solar system requires no moving parts or other energy source while an active solar system requires multiple equipment and electronics.
3. A storage tank is important for storing water heated by the solar system while waiting to be used within a house. Temperature of the heated water can be controlled at the storage tank.
4. Installing low flow showerheads and aerators on faucets and adjusting time of day for using hot water within a home can extend the effectiveness of a solar water heating system.
5. A direct, active solar system heats the water in the collectors.
6. An indirect, active solar system does not heat water directly, but heats another fluid that transfers the heat energy to the water.
7. The two systems are different by which fluid is heated directly.
8. Answers will vary since this is asking the student's opinion about solar heating systems.

## Assessment Questions

1. To maximize the amount of solar energy collected in a passive solar system you can increase the size of the solar collector, enhance the reflective surface by concentrating the rays on the tank, and insure that the position of the tank and system get optimum sunlight.
2. The parabolic curve concentrates or focuses the sun's rays on the collector, which maximizes the heat energy transferred to the water.
3. Black absorbs light because it has no color to reflect.
4. Find materials to further focus the sun's energy; insulate the collecting tank; check the sun's angle at different times of the year; use a thermal mass under and around the collector, etc.
5. Some limitations are hot water storage at night, when the sun is not available (good insulation would be required) and climate, such as winter in Alaska without sunlight.
6. Sunlight has no cost; energy bills would be less; less pollution would be emitted.
7. Accept your students' answers. Passive solar energy is commonly used if south-facing windows receive sunlight in winter or simply if clothes are hung outside in the sun to dry, which saves a significant amount of energy.

## Multiple Choice Questions

1 d; 2 b; 3 c; 4 d; 5 b; 6 c; 7 d; 8 a; 9 b (best answer)

## Vocabulary Definitions

**absorb** – to gain energy from and reduce the intensity of light (black absorbs)

**active solar water heater** – a water heater that uses the sun's energy to heat water and that requires equipment such as circulating pumps, collectors, sensors and controller mechanisms

**concave** – curved like the inside of a circle (looks like a cereal bowl waiting to be filled)

**convex** – curved like the outside of a circle (looks like a cereal bowl placed upside down)

**glazing** – covering with glass

**heat exchanger** – a device that passes heat from one substance to another; in a solar water heater, the heat exchanger takes heat harvested by a fluid circulating through the solar panel and transfers it to domestic hot water

**parabola** – a curve formed where a plane intersects a cone

**passive solar water heater** – a water heater that uses the sun's energy to heat water and that requires no moving parts and no external energy except the sun; uses only water pressure to operate

**radiation** – energy transmitted in the form of waves; passage of energy through open space

**reflect** – to send back light radiation after striking a surface (materials or objects white in color reflect)

**solar collector** – a device that allows the sun's rays to heat water or other liquid (can include using glass, concentrating solar energy with parabolic shapes, using black to absorb energy, and concentrating rays with shiny reflective materials)

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