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ABSTRACT

This laboratory unit is designed for a minimum of 15 hours of work. Experiments are designed to fit a complete unit of study on energy, and require only simple, inexpensive, or easily constructed equipment. Motivational questions, objectives, support information, feedback items, and follow-up activities are incorporated into the various experiments. (Author/RE)

LAB EXPERIMENTS IN ENERGY FOR HIGH SCHOOL PHYSICS

by W. M. Egger

Prepared for the 1978 Faculty Development Workshop, Mississippi Energy Extension Center and Golden Triangle Regional Educational Service Agency cooperating

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INTRODUCTION

To the Teacher: This unit of laboratory experiments is designed for a minimum of fifteen hours of work. However, the total time devoted to the block may be easily adjusted. The experiments have been especially designed to fit into a complete unit of study on energy. Also, these experiments require only simple, cheap, easily-secured or constructed equipment. Each experiment is designed for laboratory groups of two to three students. Sequence is not necessarily important; therefore, different groups may work on different experiments during the same class period. This will eliminate the necessity for large scale duplication of the equipment.

Motivational questions, objectives, support information, feedback items, test items, and follow-up activities are incorporated into the various experiments.

It is suggested that one day be used in presenting an explanation and overview of the entire unit and in taking care of certain details such as group formation, equipment assignment, and other organizational matters. It is also suggested that a follow-up discussion and preview of the next experiment be conducted during the class period after each experiment. If desired, a follow-up test of the entire unit may be constructed based on selections from the questions and problems at the end of each experiment.

Students should be instructed to prepare for each experiment by studying the appropriate section in a physics textbook which relates to the principal involved. Additional outside reading and preparation may be assigned as desired and deemed necessary.

INTRODUCTION

To the Student: Energy is one of the traditional units of high school physics. At no other time in our history has this topic been more important. All conventional energy resources are in great demand and many are in very short supply. This is the so-called "energy crisis" which we must recognize and solve if our life is to continue as we want it to and as we have become accustomed. Perhaps you will contribute to solving one of mankind's most pressing problems.

Each experiment in this block is carefully chosen and designed to aid you in understanding some of the important concepts of energy. You should prepare for each one assigned by reading and studying material related to the problem under consideration from your textbook and other sources that may be available to you.

Laboratory Experiments in Energy for High School Physics

RATIONALE: Among mankind's most serious problems is the energy crisis. These energy experiments will provide the student with an understanding of some of the basic technical aspects of energy needed to deal with this problem.

SUGGESTED SUBJECT AREA: Science - physics for average 11th and 12th grade achievers.

GOALS: High school physics students will learn about certain physical changes related to energy, its transfer and transformations, and its use. They will learn through experimentation. After completing this unit, the student should:

1. Understand the concept of energy.
2. Be able to deal with energy transfer and transformations mathematically.
3. Understand certain energy related phenomenon by actual experimentation in laboratory procedures.
4. Develop an awareness for energy conservation.

PREREQUISITE SKILLS NEEDED: Students should be average or above achievers at the 11th or 12th grade level. They should have completed at least two units of high school mathematics including elementary algebra.

Experiment 1: Mechanical Equivalent of Heat

Objective: To determine the efficiency of energy transfer in a system with electrical energy input and heat energy output.

Problem: How can the efficiency of energy transfer be determined? Each day we are concerned with the transfer of energy from one form to another. We desire this transfer to be as efficient as possible in our effort to conserve our energy resources. In this experiment you will learn how to determine the efficiency of a system transferring electrical energy into heat energy.

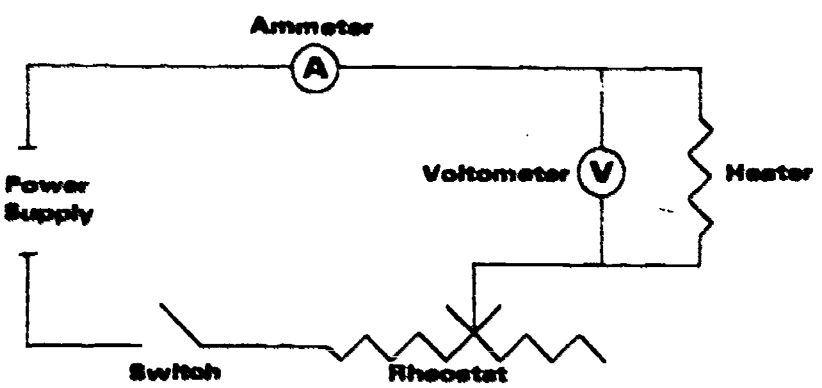
Apparatus: Heater coil or wirewound resistor, about 5 - 10 ohms; ammeter, 0 - 5 a; voltmeter, 0 - 15 v; thermometer, styrofoam cup calorimeter (easily obtained at grocery store); balance; 6 - 12 volt battery or suitable power supply; connecting wire; rheostat; timing device (watch or clock with sweep second hand).

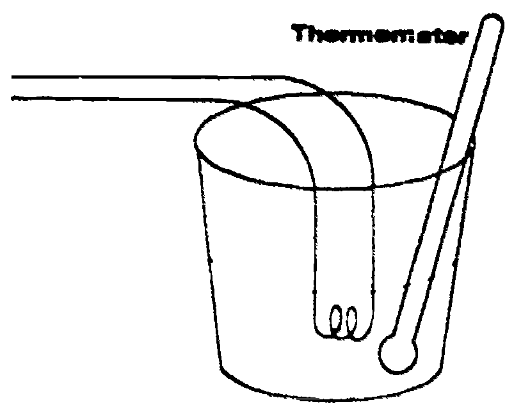
Needed Information and Skills: In this experiment you will measure the amount of electrical energy supplied to the heating coil or resistor and the amount of heat energy which results and is passed to water in a calorimeter cup. You will neglect the effect of the foam cup and thermometer in this process.

The electrical energy supplied to the heater in a given number of seconds is determined by the relationship $W = VIt$, where W is electrical energy in joules, V is the applied voltage in volts, I is current in amperes, and t is the time in seconds.

The heat energy resulting during that same time can be found by immersing the heater in a known amount of water and by measuring the heat energy transferred to the water. Using the relationship Q = mc t, where Q is the quantity of heat in calories, m is the mass of water in kg or grams, c is the specific heat of water 1 $\left(\frac{\text{calorie}}{\text{gram }^{o}\text{C}}\right)$ and t is the temperature change in water in celsius degrees. We can calculate the heat energy transferred to the water in calories.* Using the conversion factor of 4.18 joules per calorie, we will have the energy units the same for both sides of the transfer. Dividing energy out (in water) by energy in (in heater) and converting to percentage, we have an indication of the efficiency of the system.

Procedure: Make set-up and electrical connections as shown below. Be sure to mount heater coil or resistor in such a manner that it does not touch the sides of the foam cup. Place water in the cup and make an initial adjustment of the rheostat and/or voltage to obtain about 2.00 amps of current flow. Open electrical circuit and dry the calorimeter cup.





Heater Coil immersed in water

Note: Use a top on the cup to reduce heat loss from the water.

*Alternatively, you could determine the ratio of the mechanical energy unit, the joule, to the heat energy unit, the calorie. This ratio J could be calculated by the equation:

$$J = \frac{VIt}{mc\ T} = \frac{\text{(voltage) (current) (time)}}{\text{(mass) (specific heat of water) (change in temp)}} = \frac{4.18\ \text{(Joules)}}{\text{Calorie}}$$

Now proceed with the experiment as you collect data as indicated in the table. Fill cup about 3/4 full of water slightly below room temperature. Measure mass of calorimeter and contents. Mount heater coil or resistor into water and stir thoroughly. Record initial temperature and note time. Complete circuit and record ammeter and voltmeter readings. Adjust rheostat, if necessary, to maintain a constant current. Continue heating until the final temperature of water is about 20° C above initial. Note time and open circuit. Stir throughly and note final temperature. Run a second trial if time permits.

	Trial 1	Trial 2
Mass of empty calorimeter (g)		
Mass of calorimeter and water (g)		
Mass of water (g)		
Initial temperature (°C)		
Final temperature (°C)		
Heat gain by water (cal)		
Time of run (sec)		
Voltage across heater (volts)		
Current through heater (amps)		
Energy supplied to heater (j)		
Energy supplied to heater (cal)		
Efficiency of system (%)*		

*Percent efficiency of system = $\frac{\text{Energy gain by water (cal)}}{\text{Energy supplied by heater (cal)}} \times 100\%$

Questions and Supplimentary Activities:

1. List some reasons for being unable to obtain 100 percent efficiency in energy transformation.
2. Could a system ever be more than 100 percent efficient? Explain.
3. How would the efficiency expected vary with the number of transformations necessary in a working system or machine?
4. Design a perpetual motion machine that would work assuming an energy transformation system could be greater than 100 percent efficient.

Note: This experiment does not really measure the efficiency of converting electrical energy into heat energy in the resistor. That efficiency is 100 percent. What is being measured is the amount of heat that is added to the water by the heater and is not lost to the environment.

Experiment 2: Efficiency of Electric Lamps

Objective: To determine and compare the efficiency of several lamps by using the joly photometer and a standard lamp.

Problem: How can the efficiency of two or more electric lamps be compared? An electric lamp converts electrical energy into light energy and heat energy. There is a great loss in the conventional lamp due to heat. The conventional lamp is rated in light efficiency as the rate at which it emits light energy to the rate at which it uses electrical energy, expressed as a ratio. In this experiment you will measure and compare the efficiencies of two or more lamps.

Apparatus: Joly photometer (easily made from two blocks of paraffin separated by a thin sheet of metal foil); meter stick and supports; lamp of known candle power (if none available use 40 watt lamp and assume 35.0 cd as standard); various lamps of unknown candle power (different wattage and different brands suggested).

Needed Information and Skills: Intensity is the rate at which a light source emits light and is measured in candle power (cd). We will measure the candle power of unknown lamps by comparing their intensity with that of a known standard lamp.

Procedure: Put the standard lamp of known candle power at one end of the meter stick and the lamp whose candle power is to be measured at the other end. Note diagram for detail.

Viewing the edge of the photometer, move it between the two lamps until its screen is equally illuminated. Measure the distances between the lamps and the screen and record as indicated. Record wattage of the unknown lamp. Repeat this process with the other lamps to be measured.

Lamp	Wattage Rating (watts)	Candle Power of Standard (Cd)	Distance of Unknown Lamp, S_1 (CM)	Distance of Known Lamp, S_2 (CM)
1				
2				
3				

Determine the candle power of the unknown lamps from the following relationship:

$$\frac{X}{S_1^2} = \frac{\text{Standard (Cd)}}{S_2^2}$$

Find the ratio of the candle power output to the wattage input. Record in table below:

Lamp	Input (watts)	Candle Power Output (Cd)	Efficiency (Cd per watt)
1			
2			
3			

Questions and Supplimentary Activities:

1. Are all lamps of the same wattage (Westinghouse, GE, etc.) equally efficient?

2. Would one 100 watt lamp be exactly as efficient as two 50 watt lamps used together?

3. Is the light output of an incandescent lamp equal in all directions?

4. Could the intensity of a lamp be changed by placing mirrors around it?

5. What would you consider to be the source of greatest error in this experiment?

6. Build a Joly photometer for use at home and compare two lamps of the same wattage rating but made by different companies. To compare one with the other you do not need a standard lamp. Report to class on your findings.

Experiment 3: Conservation of Energy

Objective: To varify the conservation of energy in heat transfer between two quantities of water at different temperature.

Problem: What relationship exists between heat energy given up by a relatively warm mass of water and the heat energy gained by the colder mass of water?

Heat is a form of energy and should obey the law of conservation of energy when it passes from one substance to another. You will test this law by measuring and comparing the heat lost by hot water and the heat gained by cold water when the two are mixed.

Apparatus: Styrofoam cup calorimeter; balance; thermometer; some means for heating water (Bunsen burner or electric heater)

Needed Information and Skills: When two masses of water at different temperatures are mixed, heat passes from the warm to the colder water until an equilibrium is reached at some temperature between the two original temperatures. In this experiment, measured masses of hot and cold water at known temperatures will be mixed in a foam calorimeter cup. An equilibrium temperature will result when all heat transfer ceases. The heat loss and gain will be determined by noting the drop in temperature by the hot water and the gain in temperature of the cold water. Both loss and gain will be determined by the following relationship:

$Q = mc\Delta t$

Q = quantity of heat in calories

m = mass of water involved in grams

c = specific heat of water (1 cal/g-C°)

The effect of the styrofoam cup on the transfer will not be considered. It is an excellent insulator and will have minimum affect.

Procedure: Measure the mass of the cup and record. Add cold water until the cup is a little less than half full. Measure and record as indicated below. Heat some water to a temperature of about 90.0°C. Record data as indicated and add it to the calorimeter until it is almost full. Try not to use exactly the same mass of hot and cold water. Stir the mixture with a thermometer and record the equilibrium temperature. Make calculations as indicated and enter in table. Compare the heat loss and heat gain.

Questions and Supplimentary Activities:

1. Do your values for heat lost and heat gained differ significantly? If so, can you explain the difference?
2. Under what conditions would a mixture of masses of cold and hot water result in an equilibrium temperature exactly midway between the two initial temperatures?
3. What would differ in our calculations if one of the two liquids used (hot and cold) had not been water?
4. Devise a problem, and solve it, in which you mix three quantities of water together, all at a different initial temperature.

Experiment 4: Evaporation

Objective: To demonstrate that evaporation is a heat absorbing process

Problem: Is moving air alone a cooling process? Why do people use electric fans?

Many processes involving heat transfer involve a change of state. In this experiment you will verify the fact that evaporation requires heat and thus must cool the source of this energy in taking place.

Apparatus: Two thermometers; cloth wick; beaker; electric fan; support stand.

Needed Information and Skills: It has been experimentally determined that 540 calories of heat are required to evaporate 1 gram of water at 100°C. This is known as the heat of vaporization. If water evaporates, this heat must be supplied from some sources, thus cooling that source.

Procedure: Mount one thermometer directly in front of the electric fan. Mount the other thermometer to sense room temperature but not in the moving air of the fan. Run fan for about five minutes. Record time of fan run and the beginning and final temperatures of both thermometers.

Suspended Dry Bulb Thermometers Time of run:_________ minutes	Initial temp. (°C)	Final temp. (°C)	Temp. Change (C°)
Thermometer in still air			
Thermometer in moving air			

Next, mount both thermometers directly in front of fan with the cloth wick attached to the bulb of one thermometer and the end of the wick suspended into the beaker of water. Dip the entire wick into water to start the process. Run for approximately the same time as above and record as indicated.

Suspended Wet Bulb and Dry Bulb Thermometers (both in moving air) Time of run: ________ minutes	Initial temp. (°C)	Final temp. (°C)	Temp. Change (C°)
Dry bulb thermometer			
Wet bulb thermometer			

<u>Questions and Supplimentary Activities</u>:

1. Does air in motion guarantee cooling?
2. What was happening to the water in the wick on the wet bulb thermometer?
3. Why does a very hot person find some relief in getting in front of a fan?
4. Find some information on evaporation coolers as used in some western states. Are they recommended in our area? Why or why not?

Experiment 5: Conversion of Energy

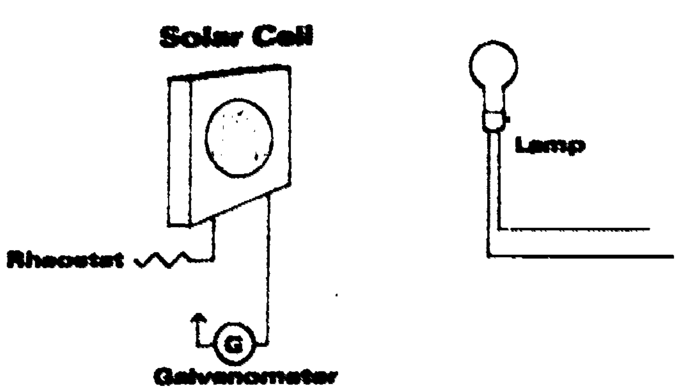
Objective: To demonstrate the conversion of solar energy to electrical energy.

Problem: What are some of the factors to be considered in the conversion of solar energy directly into electrical energy? Solar energy is of increasing importance to us. The conversion of all our energy sources into useful forms must be made as efficiently as possible. In this experiment you will observe the actual conversion and some of the factors that must be considered in this particular conversion.

Apparatus: Solar cell (obtainable from electronics store); galvanometer; rheostat (very low value -- this may not be necessary); source of light to simulate sun, protractor; meter stick.

Needed Information and Skills: In this experiment you will observe the effect of distance and angle of incidence of light on the solar cell by making measurements (relative) of its output as shown by the galvanometer. Although in the practical sense we can do very little about adjusting our distance from the sun, the effect of distance is an important consideration in many physics applications and can readily be shown here. This is called the inverse square law.

Procedure: Set up equipment as illustrated.



Adjust rheostat and/or lamp distance to obtain a mid-scale reading on the galvanometer (one half scale right or left of zero). Record distance and reading.

Now double the distance and then halve the distance. Record as indicated.

Distance (cm)			
Galvanometer reading (relative)			

Set up again as above and obtain a useable deflection on the galvanometer. Keeping the distance constant, obtain readings for various angles of incidence (angle between incoming ray and normal to the surface of the solar cell). Record distance and meter readings as indicated.

Distance; _____ cm

Angle of incidence (degrees)	0	30	45	60
Galvanometer reading (relative)				

Questions and Supplimentary Activities:

1. What is the effect of distance between source and cell on the amount of electrical energy output?
2. How does the angle of incidence affect the energy output?
3. If sufficient equipment is available, experiment with various combinations of solar cells (parallel and/or series connections). Note and report on the effect on electrical energy produced.

Experiment 6: Change of State

Objective: To demonstrate that a change of state from a solid to a liquid requite energy.

Problem: How can the heat required to melt a given quantity of ice be determined? For a change of state, energy must either be gained or lost by the substance undergoing the change. In this experiment you will determine the constant "heat of fusion" for ice -- the quantity of heat necessary to melt one gram of ice at 0° C.

Apparatus: Styrofoam cup calorimeter; balance; thermometer; beaker; ice; means for heating water.

Needed Information and Skills: The number of calories needed to melt one gram of any substance at its melting point without any temperature change is called heat of fusion. The heat of fusion of ice may be determined by the method of mixtures. The temperature drop of a known amount of hot water in a calorimeter when a certain quantity of ice is added will be measured. The heat lost by the hot water melts the ice and warms the resulting water formed from zero to the final stabilized temperature.

Procedure: First find the mass of the empty calorimeter cup. Then fill it about half full with water having a temperature of about 40° C. Find the mass of the calorimeter and the added water. Stir the water with a thermometer and read the temperature. Wipe two or three ice cubes or lumps with a towel to remove any water and put them into the calorimeter. Stir until all the ice is melted and a stabilized temperature has been reached. Record data as in the table. Make a second trial if time permits.

TRIAL	1	2
MASS OF CALORIMETER CUP (g)		
MASS OF CUP AND COLD WATER (g)		
MASS OF COLD WATER (g)		
TEMP. OF COLD WATER (°C)		
TEMP. OF HOT WATER (°C)		
MASS OF CUP, COLD AND HOT WATER (g)		
MASS OF HOT WATER (g)		
EQUILIBRIUM TEMP. (°C)		
CHANGE IN TEMP. OF HOT WATER, AT (C°)		
CHANGE IN TEMP. OF COLD WATER, AT (C°)		
HEAT LOSS BY HOT WATER (CAL)		
HEAT GAINED BY COLD WATER (CAL)		

You may want to ask students about what data they need and how they can get it rather than supply them with the entire table.

TRIAL	1	2
Mass of calorimeter (g)		
Mass of calorimeter and water (g)		
Mass of water (g)		
Mass of calorimeter and water after ice is melted (g)		
Mass of ice (g)		
Temperature of water - initial (°C)		
Temperature of water - final (°C)		
Temperature change of water (C°)		
Calories lost by water (cal) $Q = mc\Delta t$		
Calories used to warm water formed by melted ice (cal) $Q = mc\Delta t$		
Calories used to melt ice (cal)		
Heat of fusion of ice (cal/g)		
Accepted value for heat of fusion of ice (cal/g)		
Error (cal/g)		
Percentage error (%)		

Questions and Supplimentary Activities:

1. What is the "heat of fusion" of a solid?

2. What are some of the things that caused errors in the experiment?

3. What practical use is sometimes made of the heat of fusion of ice?

4. Do all solids have the same heat of fusion?

5. If the ice had not already been melting (at the melt point), would heat have been necessary to bring it to the melt point?

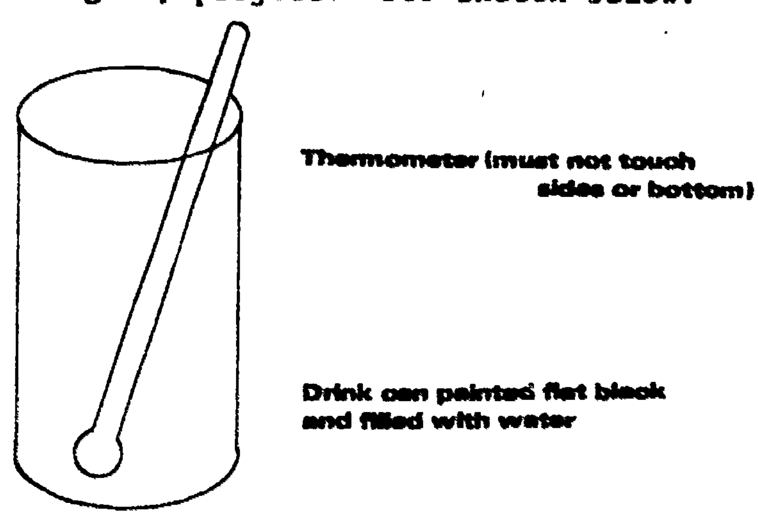
Note to Teacher for Experiment 7: It is suggested that this experiment, which involves the design, construction, and testing of solar energy reflectors, involve approximately four class periods. The students generally enjoy any type of contest and it is suggested that this experiment be handled that way. It can be assumed that each laboratory group is an engineering company which must design, construct, and test the reflector in competition with other companies. The suggested day-by-day activity is noted in procedure step of experiment.

Experiment 7: Solar Energy Reflectors

Objective: To demonstrate that shape, size, and other factors greatly affect the efficiency of solar reflectors.

Problem: What configuration of reflector would be best for collection of solar energy? Solar energy may be part of the solution to our energy crisis. In this experiment you will design reflectors, construct, collect data, and compare with others in order to arrive at some conclusions as to the most efficient devices.

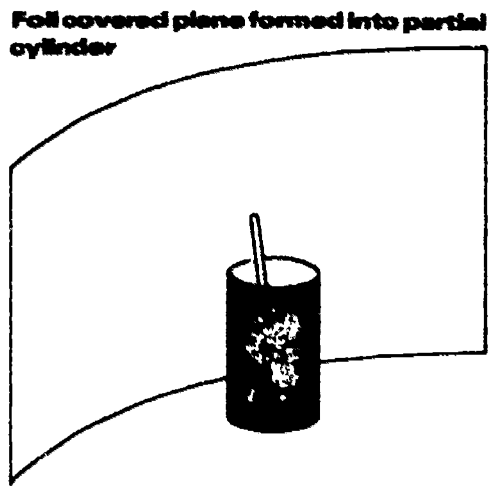
Apparatus: Student designed and constructed reflector units; identical heat receiver units for each laboratory group consisting of a thermometer mounted in a drink can, painted flat black and filled with water. These may be constructed by students as a group project. See sketch below.

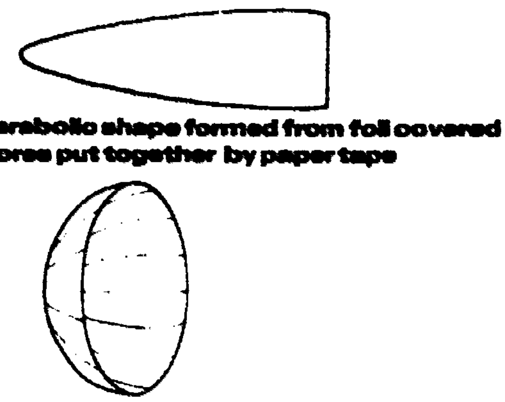


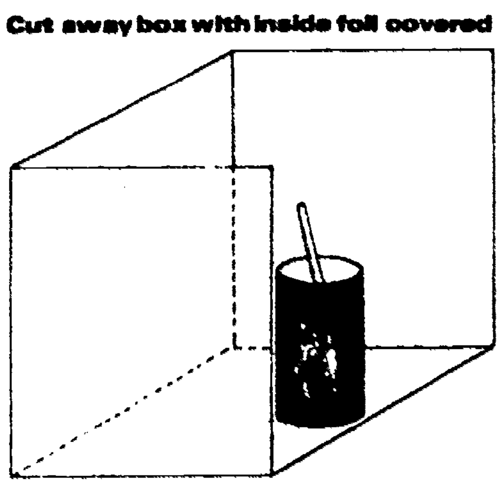
Needed Information and Skills: This experiment will differ somewhat from the conventional. Each laboratory group will plan, design, and construct a reflector system of any reasonable size and configuration. Each group will then mount identical heat receiver units to he reflector system and test them with all groups by taking them out into the sunlight and exposing them over the same interval of time. Using the temperature rise indicated by the collector thermometer as an indication of energy collected, the various devices may be compared. You should attempt to beat all other groups! Physics is and should be fun.

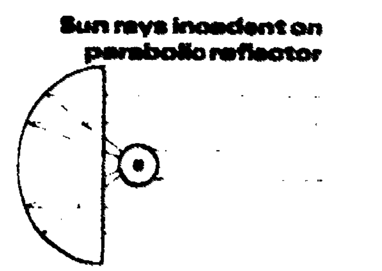
Procedure: It is recommended that approximately four class periods be devoted to this experiment as indicated by the following:

First period -- Discuss experiment and agree on design for your group. Finalize design and agree on each bringing certain materials to class next day to construct the reflector. Following are some suggested sketches to help you in your thinking:









Cardboard forms covered with aluminum foil.

Second period -- Construct the solar reflector units.

Third period — Take the solar reflector units out into the sun and mount the collector devices by a method of your choice. With the other laboratory groups and under the same conditions, collect data to enable you to determine temperature change of collector unit.

Fourth period -- Compare and discuss your results with other groups.

Initial temperature (°C)	________
Final temperature (°C)	________
Duration of test (min)	________
Temperature change (C°)	________

Questions and Supplimentary Activities:

1. Of the various designs tested, can you choose one that is superior to all others?
2. How does size affect the ability to gather heat by the reflector?
3. See if you can find any information on solar cookers. Report to class.
4. Do you think steam could be generated by a solar reflector device efficiently enough to drive a steam engine?

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