"Solar Circuitry"
with the Solar Powered Energy Kit

Curriculum: Solar Power- (light/electromagnetic radiation, electricity, circuitry, efficiency, energy transformation, subatomic particles)

Grade Level: Middle or High School

Size: Small groups, depending on ability level.

Time: 4 to 5 class periods

Summary: Students will learn how the solar cell changes light energy to electrical energy. Students will work in small groups and construct different solar panel configurations to see the differences and similarities in parallel and series circuits. Student will work with solar cells to see how panels can power loads with different voltage and current requirements. Students will be able to see applications of solar power as a renewable resource. Background information, assessment questions and extensions are provided along with supply sources.

Written by Matt Kuhn at the NREL Office of Education Programs

Provided by the Department of Energy's
National Renewable Energy Laboratory

"Solar Circuitry" with the Solar Powered Energy Kit

OBJECTIVES:

- Students will learn the difference between series and parallel circuits
- Students will learn the basic mechanism of how a solar cell produces electricity
- Students will gain an appreciation for solar and other renewable energy sources
- Students will be able to build series and parallel circuits in order to power different loads with varied voltage and current requirements using simple calculations and actual solar cells

MATERIALS:

I. 1 *Solar Powered Energy Kit* with all components including:
  - 8 solar cells with holding tray
  - 2 plastic wrenches
  - 6 extra circuit connectors
  - 1 solar motor
  - 1 plastic blue fan
  - 1 fan motor mount with base
  - 1 set of white motor lead wires

II. 1 set of alligator clip wires (1 black and 1 red)

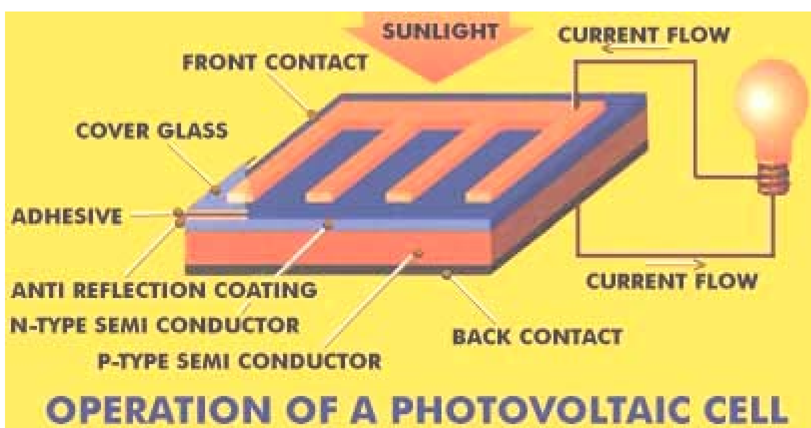
III. 1 electric buzzer

IV. 1 small light bulb

See back page for material ordering suggestions.

INTRODUCTORY DISCUSSION:

HOW A SOLAR CELL (PHOTOVOLTAIC CELL) WORKS



A solar cell is made up of a number of layers. The most important layers of the cell are the middle two, one of which is known as n-type semi-conductor and the other as p-type semiconductor. It is where these two layer meet that the cell generates **electricity**.
Semi-conductors are special electronic materials that are used in computers and other electronic devices. They are called semi-conductors

because they conduct electricity poorly when compared to metals, but they conduct very well when compared to **insulators**. They fall somewhere in the middle of the two. Semi-conductors have two special properties that are essential to the solar cell's ability to make electricity:

1. When light is absorbed within a semi-conductor, the energy in the light causes the semi-conductor to free **electrons** to move.
2. When different types of semi conductors are joined at a common boundary, a fixed **electric field** is usually in effect across the boundary (like a magnet).

So how does the cell generate electricity? When light enters the solar cell and is absorbed in the semi-conductor sandwich, an electron is freed. If this electron is close enough to the boundary of the two semi-conductors, it is attracted across the boundary by the fixed electric field. The movement of the electron across the boundary causes a **charge** imbalance in the semi-conductors. The semi-conductors naturally want to get rid of this charge imbalance. However, the electric field works in only one direction and thus prevents the electron from recrossing the boundary, so if it is to return, it must travel through an external circuit - thus we have electricity! (Because **electric current** is the flow of electrons through a wire.)

The outermost layer of the cell is a cover glass. This is designed to protect the rest of the structure from the weather and environment. It is attached to the rest of the cell with see-through glue.

When sunlight passes through the glass, it runs into an anti-reflection (AR) coating. This coating is also see-through. It is designed to lower the amount of sunlight reflected by the cell. Without the AR coating, the solar cell acts like a mirror, reflecting up to 30% of the light hitting the cell. The AR coating minimizes this reflection off the cell, reducing reflection losses to less that 5%, so that as much sunlight as possible is available for the cell to use to make electricity.

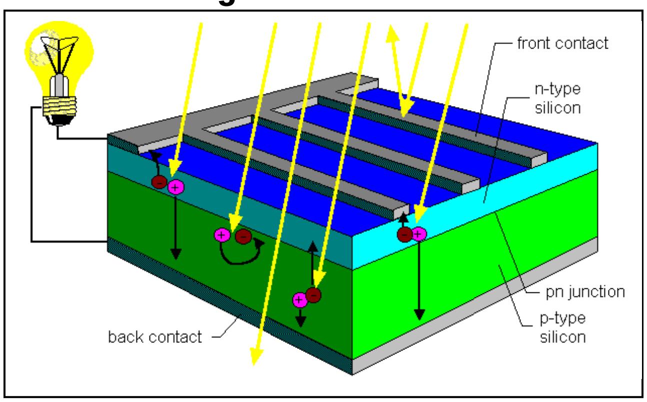
For the solar cell to be useful, there must be some way for the electricity it produces be passed to the outside world. This is the purpose of the front and back metal contacts. Their function is to carry the electrical current produced by the cell.

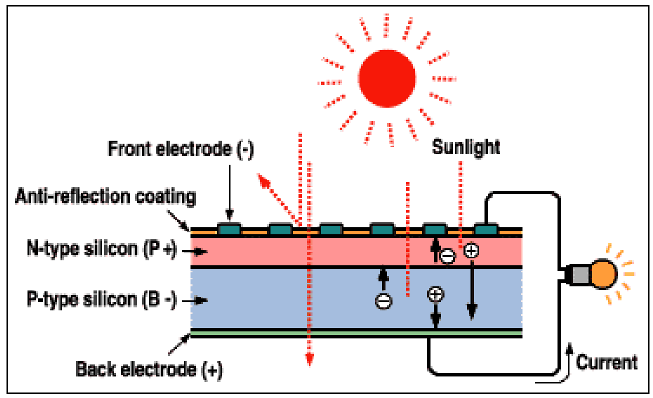
The electricity generated by the light hitting the solar cell flows from all parts of its surfaces, so it is important that the **contacts** reach everywhere on the cell. Ideally, to reduce losses caused by the electricity needing to travel any distance across the surface of the cell, we would like to cover the whole top and bottom surfaces of the cell with the contacts. However, if we did this, the top contact would block the sunlight and the cell wouldn't work. So, the top contact is usually made of thin strands of metal that reach most of the cell and only block a small amount of light. The bottom contact is not in the way of the light, so it can be a sheet of metal.

As long as light shines on the cell, we get electricity. Light comes into the cell and gets absorbed. Electrons are freed and pulled across the boundary by the electric field. They pass through an external circuit and return to their starting point.

This happens as long as light shines on the cell, so how come the cell takes 30 years to wear out? It is because the sunlight provides the energy input rather than a fuel. Also, there are no moving parts to wear out and break. Just like sunlight provides the energy for plants to grow, it also provides the energy for solar cells to produce electricity. This is why solar energy is called a **renewable energy source**. Renewable energy sources such as solar, wind, hydroelectric, bioenergy, and geothermal never run out of supply.

Solar Cell Diagrams:





VOLTAGE AND CURRENT

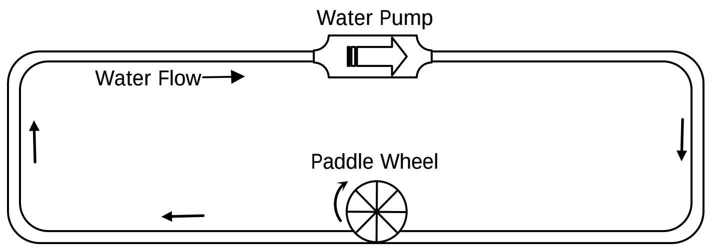
Voltage (V) is sometimes called potential difference. This is because it is the potential difference in energy between two points or the force of energy at an instant. You might think of it as the possible ability to push electrons from one point to another. An elephant has a large potential to push, similar to having a high voltage. A mouse has a low potential to push, similar to having a low voltage. It is also similar to the potential energy of a rock on a mountain falling compared to the same rock falling off a table. One has high potential energy and one has low. Voltage is measured in volts or V.

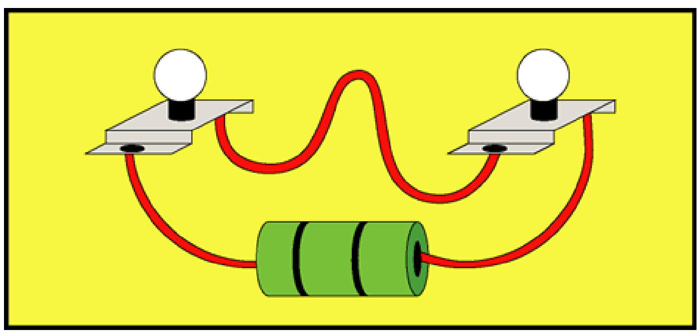
Current (I) is the amount of electricity that can pass a certain point per second. The more current, the faster electrons are flowing. The less current, the fewer electrons are flowing. The elephant may be able to push a lot of weight, but he may only get ten tree trucks pushed in an hour. So it is like his voltage is high but his current is low. The mouse may not push much weight, but she can move one hundred sticks in an hour. Therefore, it is like her voltage is low but her current is high. Current is also like traffic. More lanes mean more cars can get through. The thicker the wire, the more electricity that can get through. Current is measured in units called Amperes or milliamps. For our experiment, milliamps or mA for short will be used.

SERIES AND PARALLEL CIRCUITS

A **series circuit** is a single path for electrons to flow. The circuit must not have any breaks in it or the electricity will not flow. An example of a series circuit is a flashlight. In a flashlight, the batteries are arranged top to bottom (+ to –) and the wiring is arranged so that the electricity can only flow through one path once it is switched on.

Compare the flow of electricity to the flow of water. If we have a water pump (like a battery) and a closed loop of tubing (like wires) we have a water circuit.



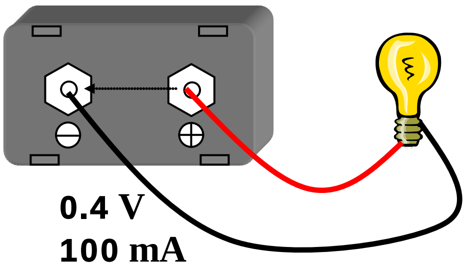


In this series circuit two light bulbs are connected to a battery. The electricity can only travel through one path to complete its journey from the negative end of the battery, through the bulbs, and back to the positive end of the battery. The advantage of a series circuit is that it is easy to increase the voltage. The problem with a series circuit is that if any part of the circuit breaks or fails, the whole circuit stops flowing. Cheap holiday lights are often wired in series. That is why the whole sting of lights will go out if one bulb burns out.

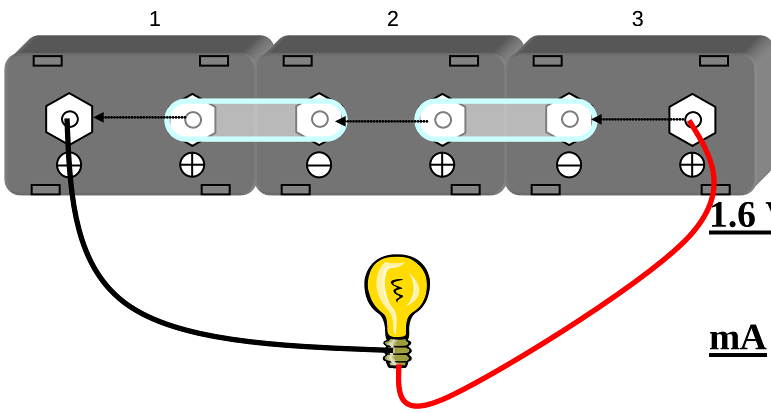
Series Circuit Math:
In a series circuit, the voltage of all power sources combine (such as flashlight batteries) to increase the voltage. In a series circuit, the current is the average of all voltage sources or the current of the lowest current carrying part of the circuit.

<u>total voltage</u> = combined voltage of all power sources in the series circuit $V_T = V_1 + V_2 + V_3$
<u>total current</u> = the current of the lowest current carrying device. If they are all the same, current equals the current of any one device.

[Negative (-) and Positive (+) contacts are connected within the cell]



Three cells connected in series

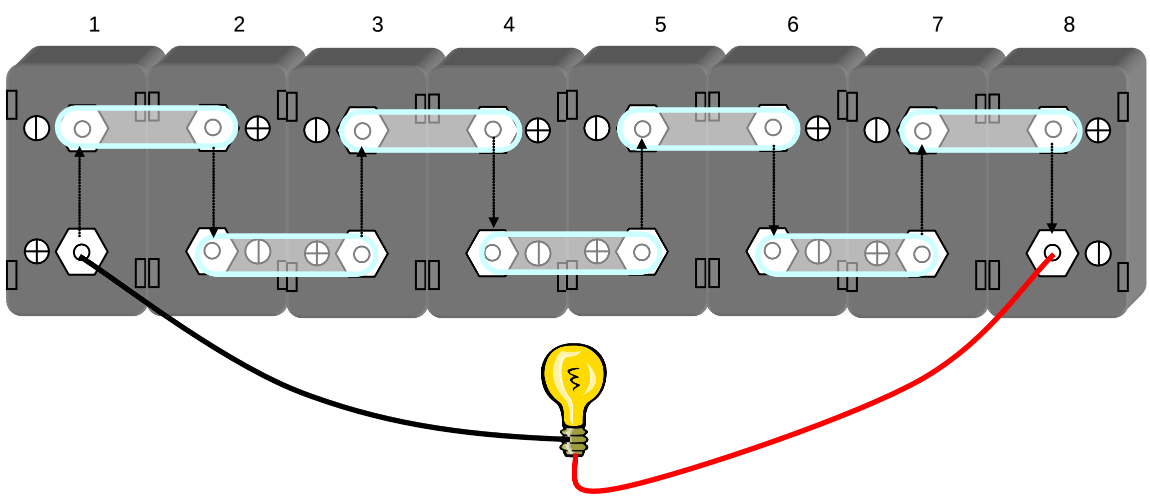


$V_T = V_1 + V_2 + V_3$ ➔

$V_T = 0.4 + 0.4 + 0.4 =$ **<u>1.6 V</u>**

$I_T = I_1 = I_2 = I_3 =$ **<u>100 mA</u>**

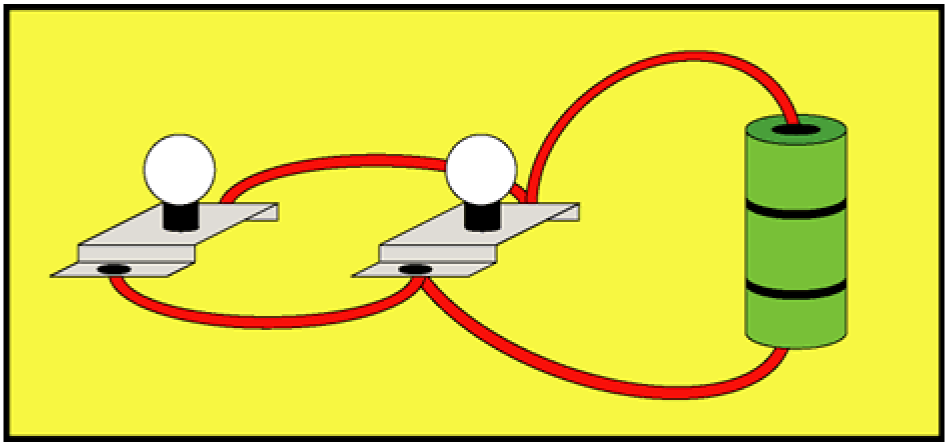
Eight cells connected in series



$V_T = V_1 + V_2 + V_3 \ldots V_8$ ➔ $0.4 + 0.4 + 0.4 + 0.4 + 0.4 + 0.4 + 0.4 + 0.4 =$ **<u>3.2 V</u>**

$I_T = I_1 = I_2 = I_3 = I_4 = I_5 = I_6 = I_7 = I_8 =$ **<u>100 mA</u>**

parallel circuit is arranged in multiple paths for electrons to flow. The electricity has many paths to take to get back to the power source. Houses are wired in parallel so that electricity can flow through one appliance without needing to also flow through other circuits in other appliances. If a house were wired in series, all circuits would have to be switched on at the same time for any of them to work.



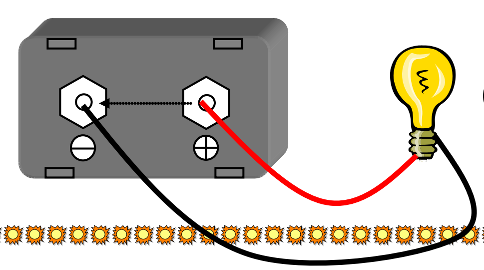
In this simple parallel circuit, if one bulb burns out and thus causes a break in the circuit, the electricity can still flow back to the battery by going through the remaining bulb's circuit loop. The advantages of parallel circuits are their ability to connect multiple devices to one or many power sources and increase current. The disadvantage is that stronger power sources are needed to maintain a high voltage level.

Parallel Circuit Math:

In a parallel circuit, the current of all power sources combine to increase the milliamps. The voltage is the average of all voltage sources in a parallel circuit.

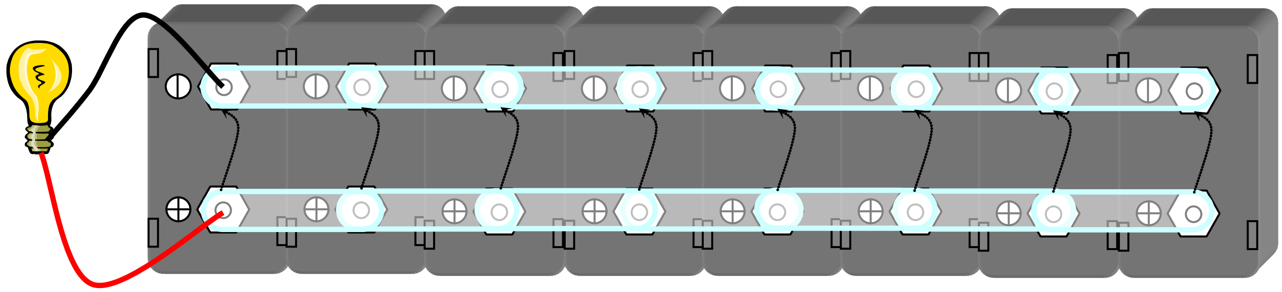
total voltage = the average voltage of all power sources in the parallel circuit $V_T = \frac{V_1 + V_2 + V_3}{3}$
total current = combined current of all power sources in the parallel circuit $I_T = I_1 + I_2 + I_3$

Parallel Circuit Math Examples:
Single Solar Cell Values
[Negative (-) and Positive (+) contacts are connected within the cell]



0.5 volts 100 mA

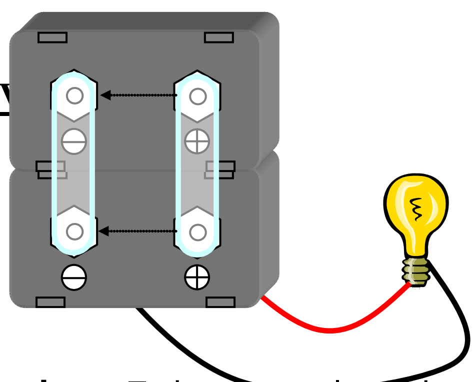
Eight cells connected in parallel



$I_T = I_1 + I_2 + I_3 \ldots \rightarrow 100 + 100 + 100 + 100 + 100 + 100 + 100 + 100 = \underline{800\ \text{mA}}$

$V_T = \frac{V1 + V2 + V3 + V4 + V5 + V6 + V7 + V8}{8} = \frac{0.5 + 0.5 + 0.5 + 0.5 + 0.5 + 0.5 + 0.5 + 0.5}{8} = 4.0 \div 8 = \underline{0.5\ \text{V}}$

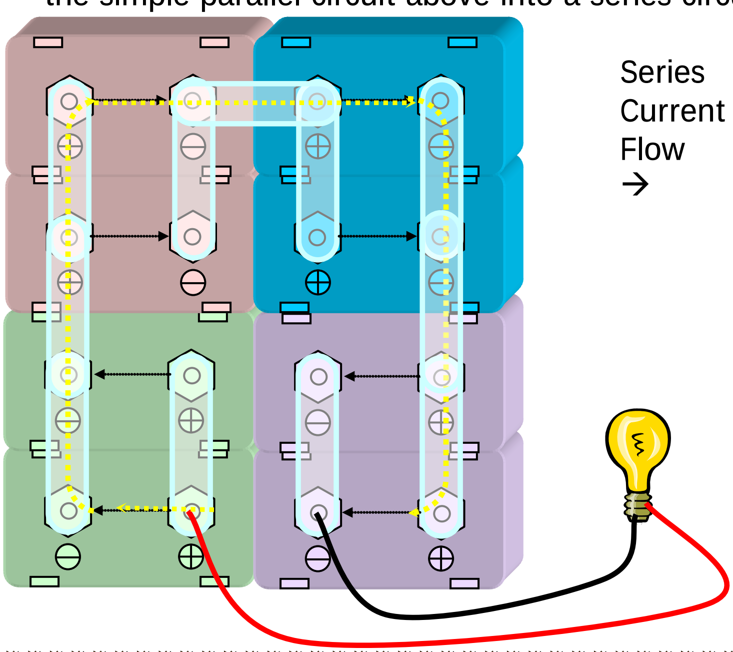
A simple two cell parallel circuit



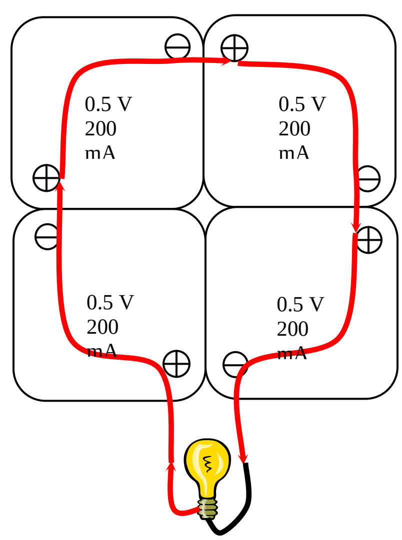
$V_T = \frac{V_1 + V_2}{2} = \frac{0.5 + 0.5}{2} = 1.0 \div 2 = \underline{0.5\ \text{V}}$

$I_T = I_1 + I_2 = 100 + 100 = \underline{200\ \text{mA}}$

Combinations- To increase voltage, but keep at least 200 mA of current, we arrange the simple parallel circuit above into a series circuit of four, 2-cell parallel circuits.



Series Current Flow →



$I_T = I_1 = I_2 = I_3 = I_4$

$\rightarrow = \underline{200\ \text{mA}}$

$V_T = V_1 + V_2 + V_3 + V_4$ = 0.5 + 0.5 + 0.5 + 0.5 = **2.0 V**

Table A	Devise	Voltage	Current
	Fan Motor	1.0 V	200 mA
	Buzzer	1.0 V	100 mA
	Light Bulb	2.0 V	200 mA

Building Circuits Activity

1. Get your kits and study the Table A to the upper right.
2. The table gives the required voltage and current required to operate each devise. You will need these values to build solar circuits to power each devise.
3. Using the individual cells, determine how many cells will need to be connected in series, parallel, or a combination of both based on the voltage and current output of one cell. (One cell puts out about **0.5 V** and **100 mA**)
4. **Example:** The motor & fan requires 1.0 V according to the table. It also requires 200 mA of current. To increase the voltage of one cell, it needs to be connected in series. To increase the current, the cells need to be connected in parallel. We will start with current since it needs to be increased even more than the voltage.
5. Divide the needed current by the current of one cell to find out the number of parallel cells needed.

   200 mA ÷ 100 mA = 2 units needed connected in parallel
6. To increase the voltage, divide the needed voltage by the voltage of one cell.

   1.0 V ÷ 0.5 V = 2 units needed connected in series
7. This means that we will need two units of 0.5 V connected in series. The only way to get both an increase in voltage and current is to combine parallel and series circuits. We will construct two parallel circuits using two cells each to add up the individual currents to 200 mA. Then we will connect the two parallel units together in series to add the voltages of each two-cell unit and achieve a voltage of 1.0 V.

Motor & Fan:

8. Using the last example, arrange the cells into two parallel circuits connected together in series to achieve $1.0\ V$ and $200\ \ mA$. You may want to use the cell holding tray to keep you cells straight. Use the plastic wrench only after you have checked the arrangement and have hand tightened the fasteners onto the contacts.
9. Make sure that when you connect cells in parallel that you connect positive ⊕ (RED) contacts with positive ⊕ (RED) contacts and negative ⊖ (BLACK) contacts with negative ⊖ (BLACK) contacts.
10. When you connect units in series, make sure you connect one positive ⊕ (RED) contact of the unit with one negative ⊖ (BLACK) contact from the other unit and vise-versa.
11. Mount the fan blade on the motor. Then connect the motor mount to the base. Finally, mount the motor and connect the wires to it.
12. Connect the wires to the proper positive ⊕ (RED) and negative ⊖ (BLACK) contacts on your circuit.
13. Hold you solar circuit perpendicular to the sun or a very bright light. If the fan works, you were successful. If not, check your circuit and try again. Once your fan and circuit are working properly, get the attention of the teacher and have them initial this box before going onto step 14.

Teacher Initials: ☐

Buzzer:

14. Using Table A, calculate the number of cells needed to achieve the required voltage and milliamps.
15. Using your calculations, determine if your cell will need to be connected in series, parallel, or a combination of both.
16. Construct your circuit. Use the plastic wrench to tighten the nuts only after you have checked your circuit and hand tightened the fasteners.
17. Using alligator clips, connect the black wire to the negative contact and the red one to the positive contact.
18. Hold you solar circuit perpendicular to the sun or a very bright light. If the buzzer works, you were successful. If not, check your circuit and try again. Lightly tapping the buzzer on a table may help start it working.

Once your buzzer and circuit are working properly, get the attention of the teacher and have them initial this box before going onto step 19.

Teacher Initials: ☐

Light Bulb:

19. Using Table A, calculate the number of cells needed to achieve the required voltage and milliamps.
20. Using your calculations, determine if your cell will need to be connected in series, parallel, or a combination of both. (Hint: if you need both the voltage and current to increase, you will need a combination circuit.)
21. Construct your circuit. Use the plastic wrench to tighten the nuts only after you have checked your circuit and hand tightened the fasteners.
22. Find your light bulb and make sure it has two metal contacts.

23. Using the alligator clips, connect the black wire to the negative contact and the red one to the positive contact. Then connect the other ends to the two contacts on the light bulb.

23. Hold you solar circuit perpendicular to the sun or a very bright light. If the light bulb glows, you were successful. If not, check your circuit and try again. It may be hard to see the bulb glowing in bright sunlight. Once your light bulb and circuit are working properly, get the attention of the teacher and have them initial this box before going onto step 25.

Teacher Initials: ☐

24. Disassemble all of the cells and parts you put together in this activity. Neatly place all the parts back into the compartments you found them in. Get the attention of the teacher and ask them if you can check in you kit.

Questions to Ponder:

1. How could solar power be used in your home?

2. What parts of the county or world have the most sunlight?

3. Why is it important to hold the solar cells perpendicular to the sunlight?

4. Which advantages does solar power have compared to traditional coal fired electrical generators?

5. What advantages and disadvantages do series circuits have in comparison to parallel circuits?

Solar Energy Education Resources
And Ordering Information

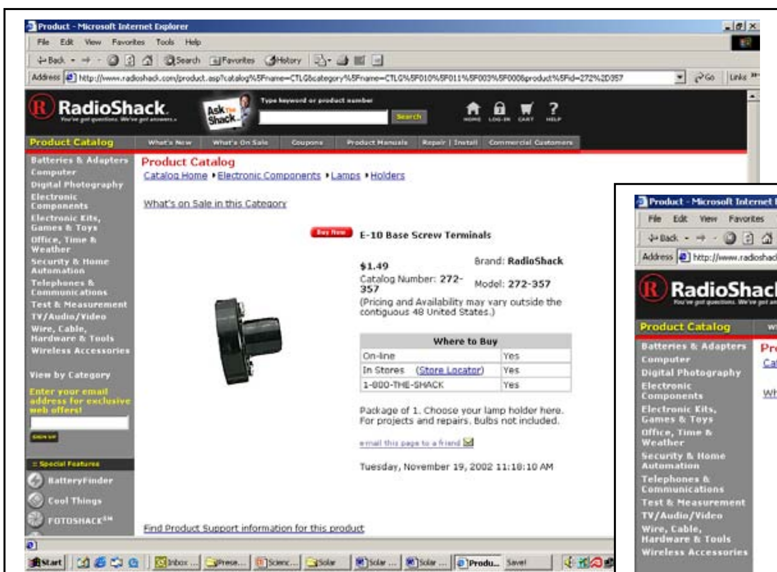
This solar model is designed to demonstrate solar energy potential. The kit consists of 8 pcs. single crystal silicon solar cell, solar motor, plastic stand, plastic base, motor clip, spanner, electric wire, fan blade and copper links. It is a complete system that produces energy for a radio, calculator, battery charger, 1.5V cassette player, and more. You can add a bulb and base and a buzzer to the kit to increase the amount of possible experiments.

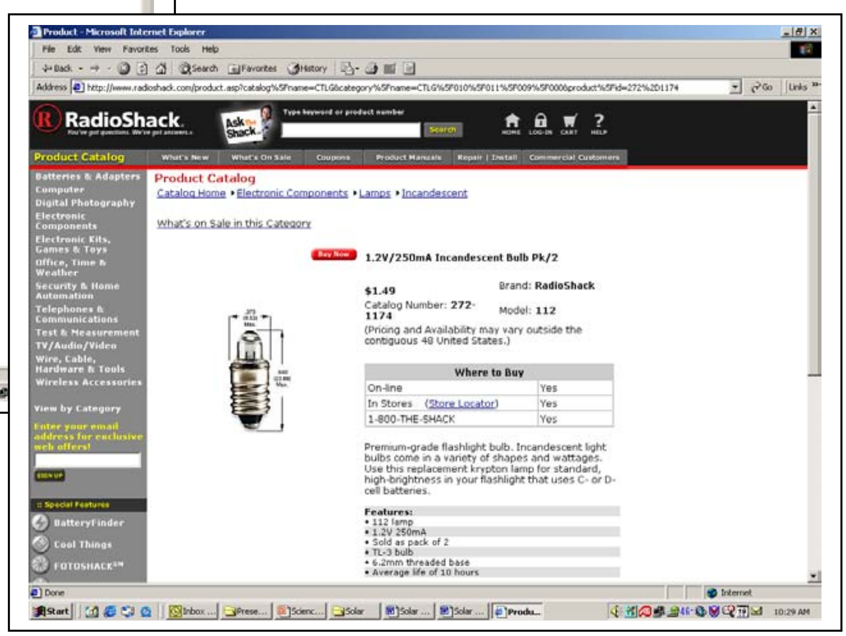
$16.20 each with a 10% educator's discount. Order online at http://www.sun-mate.com

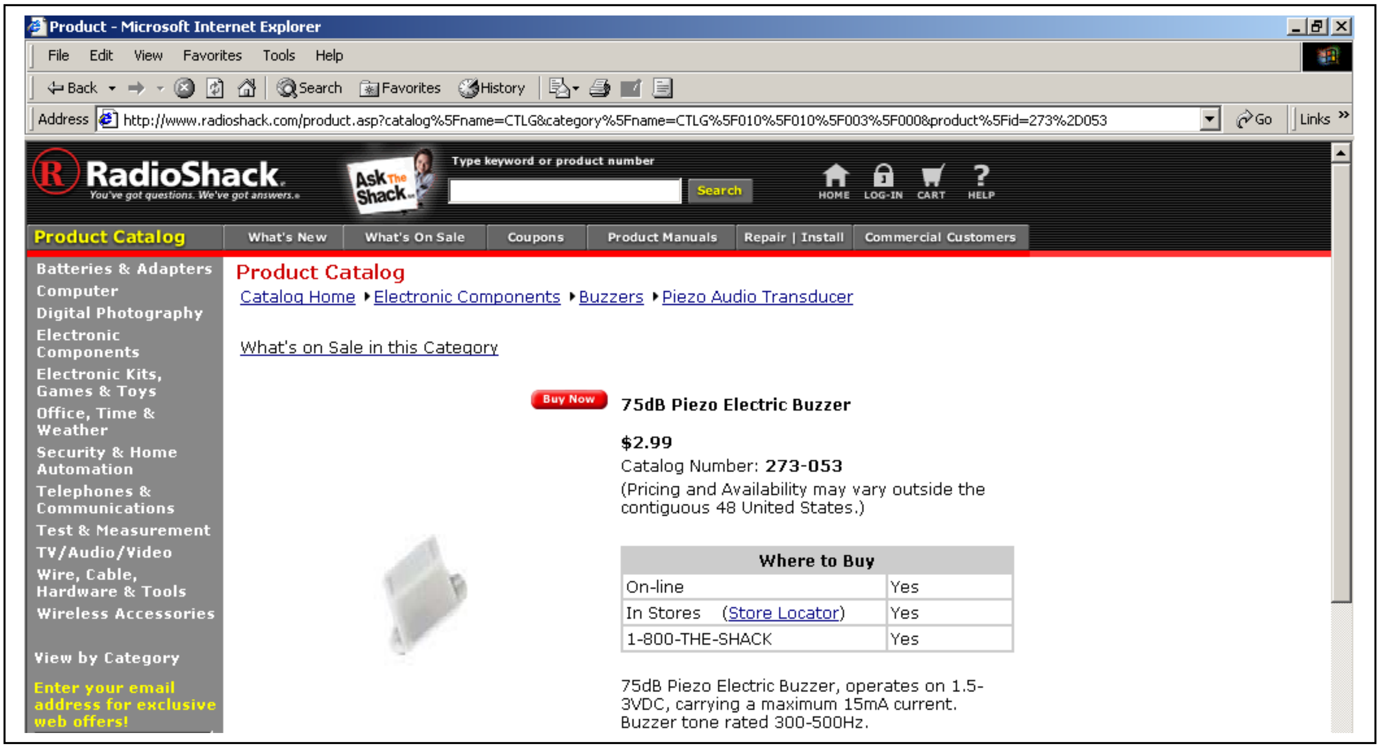
You should supplement the kits with small light bulbs and bases or cut holiday lights and a small buzzer.

www.radioshack.com

NOTE: A cheaper light option is to use Christmas lights cut into sections at about & 7 cents per light. Students like the colors too.

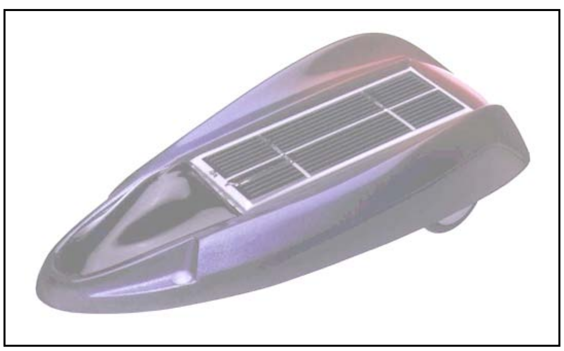






PHOTON SOLAR RACER KIT® (This is not part of the kit but is a good enrichment.)
Build your own Solar Racer and tap into the power of the sun! This easy-to-assemble kit comes with everything you need including: 1) High-powered (1v, 500 milliampere) ultra lightweight encapsulated solar cell; 2) High amp/low voltage motor for maximum torque and speedy acceleration. Sleek transparent plastic body (made from recycled pop bottles) looks great as is, or add your own custom paint job. The Photon can travel 10 feet in three seconds on a smooth, flat surface, when exposed to full sun.8 1/2 x 3 3/4 x 2"H

$24.95 each. Order online at http://www.solar-world.com/Educational.htm



Other great solar education supply sources:

- http://www.knexeducation.com/solar.html
- http://www.shop-pitsco.com/
- http://kelvin.com/