

ALTERNATIVE ENERGY - PHOTOVOLTAICS

STUDENT INFORMATION

Area of Study: Energy/Power

Objectives:

Students will identify uses of photovoltaics in our society today. Students will discover the potential of solar cells through the capture of energy from light and the application of this energy to different output devices. Students will make observations and measurements.

Related Occupations:

Chemical Engineers

apply their knowledge to design and improve processes for the manufacturing of products. In the solar power industry, they focus on semiconductors and organic chemistry, since solar cells are made from semiconducting materials and the new thin-film collectors are made from organic materials.

Electronics Engineers

design, develop, test, and supervise the manufacture of electrical and electronic equipment. These include electronic circuits and components that are for use in fields such as telecommunications, medical, instruments and controls of solar cells, lighting, automobiles, robotics, and aerospace guidance.



Installation of Photovoltaic shingles.
DOE/NREL - Warren Gretz Photo

Power Plant Operators and Dispatchers

control the flow of electricity through transmission lines to substations that supply consumer electric needs. They monitor solar arrays and generators and regulate output from the generators. Power plant operators also must decide each day when to switch from solar power to secondary power sources like natural gas power generation. Dispatchers monitor a map of the transmission grid system showing the status of transmission circuits. Dispatchers anticipate power needs and notify power plant operators of the need for additional electrical power.

Key Words and Definitions:

1. **Alternating Current:** Electric current that reverses flow of direction at regular intervals. This type of electricity is provided by the power companies and is required to run most modern appliances and electronic devices.
2. **Ammeter:** A device that measures the amount of current flowing in a circuit.
3. **Amperage:** The strength of a current (amount of electron flow or how many electrons move past a certain point in a wire each second) of electricity expressed in amperes.

ALTERNATIVE ENERGY - PHOTOVOLTAICS

Occupational Choices

Focus: Electronics Engineers

Classes to take in School:

- English
- Math
- Drafting
- Technology
- Electricity/Electronics
- Computer Science
- Humanities

After High School:

College/University - 4 or 5 years to earn a bachelors degree. Most engineering programs involve a concentration in an engineering speciality within Electronics Engineering (control systems, communications, nano technology, and signal processing).

Admissions requirements for engineering schools will include a solid background in mathematics, sciences, and courses in English, social studies, humanities, and computers.

Earnings:

In 2010, people employed as Electronics Engineers nationally had an median **salary** of **\$90,200**.

In 2010, Electronics Engineers in Utah had an median yearly wages of **\$88,000**. In Utah, the wage range was from **\$61,900** to **\$111,100**.

In 2010, yearly earnings ranged nationally from **\$57,900 to \$135,100**. Earnings vary by experience and location.

The Work:

Employment of Electronic engineers will be needed to design, develop, test, and supervise the manufacture of electrical and electronic equipment. Some of this equipment includes portable music players medical equipment, photovoltaic systems, to global positioning systems (GPS). Engineers use computers to produce and analyze designs; to simulate and test how a machine, or system operates; and the efficiency of processes in creating the part.

Employment Opportunities

- Federal Government
- Engineering Consulting Firms
- Communication Industries
- Manufacturing Industries

Personal Characteristics

- Good Communications skills
- Excellent Math Skills
- Computer skills to test & analyze designs
- Ability to read and write technical reports
- Must work in team situations

4. **Electron:** A component of an atom. When an atom is in a state with excess electrons, the excess electrons leave the atom causing electricity to flow.
5. **Energy:** The ability to do work.
6. **Photon:** A tiny particle of light.
7. **Power:** The amount of work done¹.
8. **Renewable Energy:** Sources of energy that can be used indefinitely if they are properly managed and maintained. Some renewable sources of energy are geothermal, solar, photovoltaic, & wind energy.
9. **Solar Cell:** A device which converts **light** energy into electrical energy.
10. **Voltmeter:** A device that measures the voltage in a circuit.
11. **Voltage:** A measurement of electricity that measures force or electrical “push” or “pressure.” It is an excess of electrons stored in a location and waiting to move.

Introduction:

Energy is the ability to do work. Energy comes in many different forms. When we turn on a light switch, drive in a car, or mow the lawn, we are using energy. To use energy we must be able to control it. In the simple example of turning on or off a light switch, energy is controlled.

Power is the amount of work done during the use of the controlled energy. It is a measurement of how much energy was used in accomplishing a certain task. Power produced using electricity is expressed in watts.

In this unit of study, we are going to apply the concepts of power and energy to one way of controlling energy and the power of the sun. Solar Cells are one type of **renewable** energy source that can capture energy from the sun. Renewable energy is a source of energy that can not be used up if it is properly managed. The sun can be harnessed to do many different tasks for us and we will focus on producing energy using solar cells.



What is a Solar Cell?

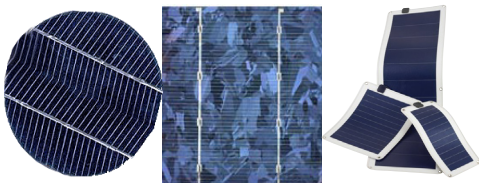
As natural resources (oil, natural gas, coal) used for our energy needs are being used up, we must look to other sources of power. The earth's Sun could give us much of this power. Sunlight is made up of tiny packets of energy called photons. Every minute enough energy in the form

A photo of a competitor in the American Solar Challenge which is a student competition to design, build, and race cross-country in a solar car.

¹ Thode, B., Thode, T



Photovoltaic Arrays @
Dangling Rope Marina,
Lake Powell, Utah
DOE/NREL - Warren Gretz Photo



- Left - Crystalline
- Middle - Polycrystalline
- Right - Thin-film.

DOE/NREL - United Solar Ovonic



Photovoltaic Cells on the roof of
Zion National Park Visitors Center
DOE/NREL - Robb Williamson Photo

of photons reaches the earth to meet the world's energy demand for the whole year². The problem has always been harnessing this energy.

A solar cell is a device which converts light energy into electrical energy. Solar cells do not operate on heat from the sun. The operation of solar cells does depend upon the amount of light present. The brighter the light, the more electricity the cell will produce.

Most solar cells are made of from a material called silicon. Silicon is most commonly found as silica oxide in sand or quartz, and is the second most common element on earth.

There are 3 types of solar cells:

- Crystalline cell where each cell is a single silicon crystal.
- Polycrystalline where each cell is a collection of many small silicon crystals.
- Amorphous or Thin-film solar cells can use silicon or other elements to create the cell and is made by depositing one or more thin layers of photovoltaic material on a substrate. A substrate is a supporting material that electronics can be built into. This type of solar cell has become very cheap to create and is quite common today.

Solar Cells, because of their electrical properties, produce **direct current**. Direct current (DC) is electric current that flows in a single direction. Many simple devices, such as those that run on batteries, use direct current. In the simplest systems, direct current produced by solar cells is used directly. In applications where alternating current (AC) is necessary, an inverter can be added to the system to convert the DC current to AC current.

Another name for a solar cell is PHOTOVOLTAIC CELL (Photo-Volt-Tay-Ick). Photovoltaic technology is still maturing, and development has produced photovoltaic cells that are very inexpensive. If designed into new construction, photovoltaic cells are now cost effective in some geographic areas. The challenge has been to produce more efficient cells at lower prices. Scientist and companies have been working on this problem, and prices have fallen. The price of a solar array, measured by cost per watt of capacity, has fallen 42 percent from December 2010 to December 2011.³

Where are Photovoltaics used?

One area where solar cells are heavily used is in our space industry. Solar cells provide energy for satellites and have been used to power "rover" vehicles which were used to explore the surface of the moon and mars.

² U.S. Department of Energy

³ Grubitzsch, W

Another use for solar cells is in farm and ranch land, where the cells are used to power electric fences which control livestock. Solar cells also provide power to communications systems and water pumps (for livestock watering, etc.) and in remote areas where power line installation is too costly. The use of solar cells in these wilderness areas provides electricity without the expense and environmental damage of power line construction.

Part of a Larger System

Photovoltaic systems refers to a wide variety of solar electricity systems. Photovoltaic systems can be



Photovoltaic Walkway Lights
DOE/NREL - Warren Gretz Photo

stand alone to provide power for a single application, but with more frequency photovoltaics are used to provide power for multiple applications that are inter-tied or interconnected with the grid. All systems whether they stand alone or are connected will include: Input (people, materials, money, knowledge, energy, & time), processes (conversion of light at the atomic level), outputs (electricity), and feedback (complaints if there is no power).



Ranchers set up a photovoltaic panel and a battery back-up to electrify a fence after moving cattle to a field in Kansas.
Mike Breen Photo

Today photovoltaic technology costs have improved enough that in new construction solar cells are starting to be incorporated in commercial and some public buildings. Although solar cells are not common in residential homes, the time for solar cells to be used to provide electrical power for homes could be around the corner as the cost of solar cells are reduced and the efficiency improved. Every year we see solar cells used more and more around us. For example, there are more than 1 billion hand-held electronic **calculators**, several million wristwatches, and a couple of million portable lights which are “solar powered.” The worldwide market for photovoltaic products is estimated to be growing at 40 to 45% a year today.⁴ As the technology improves, solar cells will be less costly and more common place.



There are several photovoltaic power systems in the United States that will soon dwarf this one at Nellis Air Force Base, in Nevada. The 70,000 units of solar panels at Nellis follow the sun throughout the day and are known as “trackers.”

U.S. Air Force photo - Airman 1st Class Nadine Y. Barclay

⁴ Glynn, M



This view of the International Space Station (ISS) was taken while it was docked with the Space Shuttle Atlantis and the photovoltaic arrays seem to be aglow as the sun rises or sets.

NASA Photo

Photovoltaic cells have disadvantages such as they do not produce energy at night or on cloudy days. However, photovoltaic-generated power offers advantages over diesel generators, batteries (onetime use), and even conventional utility power because there is no cost once they are installed. The fuel is free! Photovoltaics use only the energy from the sun.

Impacts on Society and the Environment

A big advantage of photovoltaic cells is that they do not pollute as other power sources can. This has been a positive impact on the environment as they do not contribute to global warming, or produce noise. They also work very efficiently for as power systems for utility companies.

The biggest impact with photovoltaics occur in outer space. Photovoltaics are used as a power source in many spacecraft. NASA relies on photovoltaics for space exploration. Space probes, and **satellites** that are put into outer-space can be powered for long periods with photovoltaics. Without photovoltaic cells, on-board batteries couldn't be recharged as easily as they are now.

If you didn't realize it before, photovoltaics are directly impacting your life. Photovoltaic technology impacts us directly when we use communication devices or look up the weather forecast. Satellites that we rely on for weather reports, GPS navigation, and communications, would need to be drastically altered without photovoltaics.

Photovoltaic technology is becoming the power of choice in more and more cases every day. However, until the cost of photovoltaic products becomes competitive with standard means of producing electricity or its ease of installation outweighs the cost of installation, photovoltaics will remain a secondary means of producing power. Heavy use of this technology is drawing very near as research in this area matures. Photovoltaic power is expected to one day be cheaper than conventional power sources. If this happens, photovoltaic power will be powering your future.

STUDENT ASSIGNMENT I

Watch the 1^{1/2} minute video on how a photovoltaic cell works or the 3 minute video on solar power basics. Your teacher may direct you to use a certain computer that is book marked, has the web page saved on the computer, or has this movie loaded on it. Once the movie has been viewed continue with Activity II.

STUDENT ASSIGNMENT II

On the worksheet, as you start Activity A, perform the experiments and write down the answers to the questions on your worksheet as experiments A - G are completed.

Materials Needed:

Photovoltaic station | Lamp | Flashlight - (checkout) | 1 paper or card stock - (checkout)

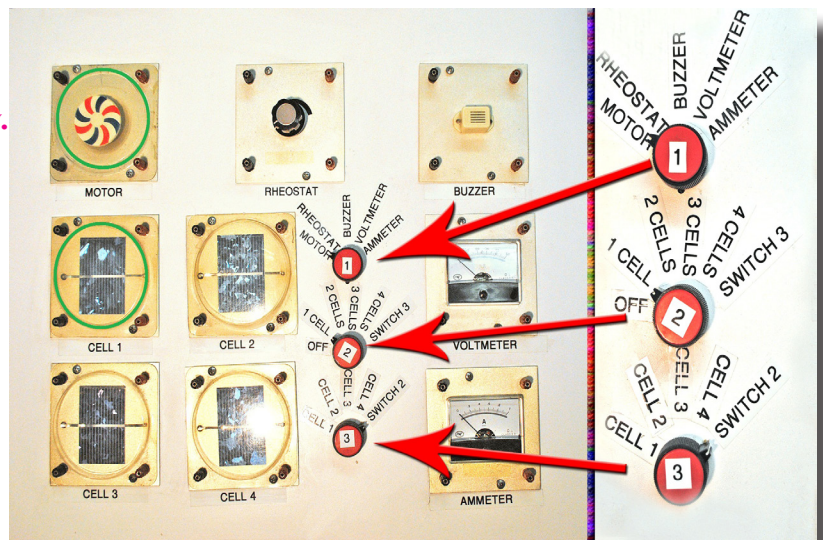
Please read the following cautions before proceeding with the activity:

1. Be very careful with this equipment as it is very fragile.
2. Do not place the lamp too close to the solar cells. This would create excess heat which might melt the solar cells. Don't put the lamp closer than 6" to the solar cells.
3. Do not leave the lamp on between experiments. Turn the lamp off and allow it to cool between experiments.

NOTE: Fill out the student worksheet as you go through the activity.

Activity A:

In this activity, you will construct a set of circuits using the photovoltaics trainer. The parts are all labeled and are "hard wired" together. If you look at the back of the trainer, you will see that all the parts are soldered together. The direction that the electrical current travels is controlled by a series of switches. Make the connections to the devices called for on the circuit by turning the knobs on the switches as instructed.



The switches on the photovoltaics trainer, as they are set, will control the objects that are circled in green. An enlarged section of the middle of the board is on the right.

Figure 1

Solar cells are devices that convert **light** energy into electrical energy. To see this in action, connect a solar cell to the electric motor, making a circuit as shown in **figure 1**. **Switch #1** should be pointed to the label "**motor**", **switch #2** should be pointed toward the label "**1 cell**", and **switch #3** should be pointed toward the label "**switch #2**". Aim the lamp toward the solar cell. See if the motor shaft turns when the lamp is on. Now repeat the experiment using these two light sources:

1. Using a flashlight
2. Using the classroom light

Answer the question for Activity A on the worksheet.

Activity B:

Connect the ammeter into the circuit instead of the motor as shown in **figure 2**. Switch #1 should now be pointed to the label “**ammeter**”, switch #2 **will not change** and should be pointed toward the label “**1 cell**”, and switch #3 **will not change** and should be pointed toward the label “**switch #2**.” Measure the amount of current produced by the flashlight and the lamp. Which produces the highest reading? If you have trouble reading the ammeter, turn to Appendix A on page 11. Record your answer on #2 of the worksheet.

Activity C:

Disconnect the ammeter from the circuit and connect the motor in its place. To do this, Switch #1 should be pointed to the label “**motor**” as in **figure 1**. Turn the lamp on and move it close enough that the motor spins.

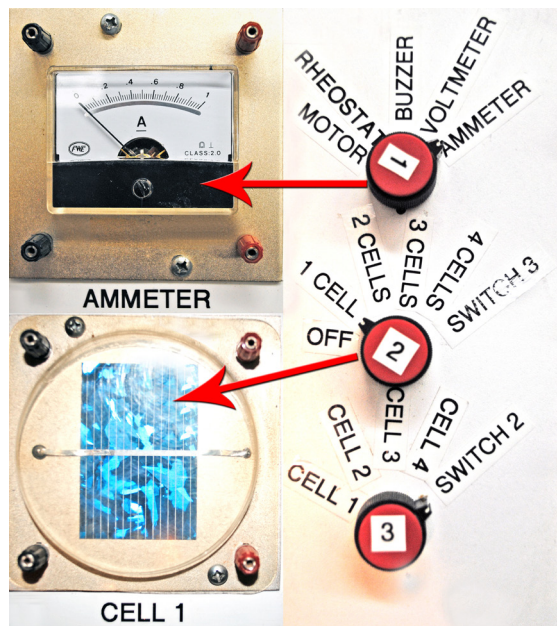
Take a piece of paper and slowly move the paper over the cell until the cell is completely covered as shown in **figure 3**. As you move the paper, watch how the motor slows down and eventually stops.

Disconnect the motor and connect the ammeter as it was in **figure 2**. To do this, Switch #1 should be pointed to the label “**ammeter**.” Once again, slowly cover the cell with paper as shown in **figure 4**.

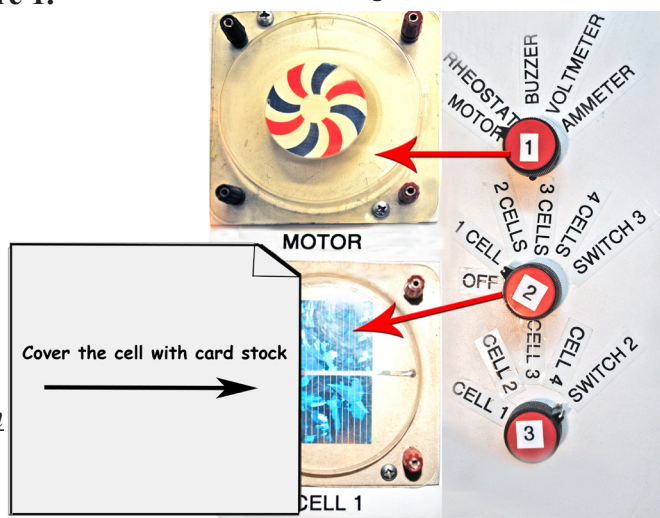
Can you see how the current decreases as you slowly cover the cell?

From the two previous activities you have seen that the amount of electricity produced depends upon two things:

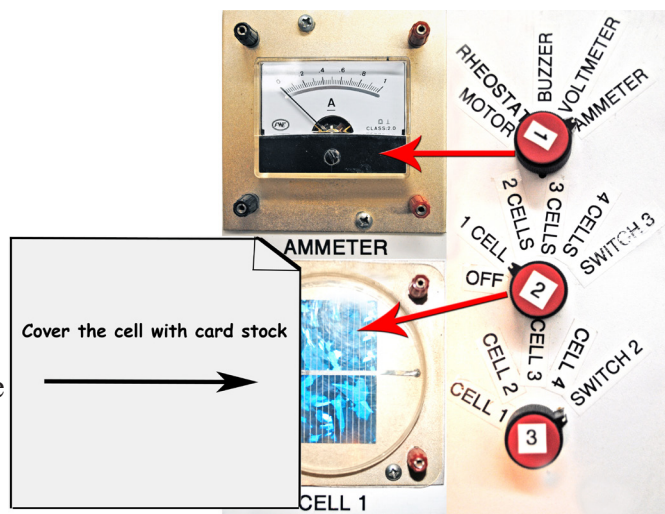
1. The brighter the light, the greater the amount of electricity produced.
2. The larger the area of the cell, the greater the amount of electricity produced.



Connecting the Ammeter.
Figure 2



Covering the cell with the motor connected.
Figure 3



Covering the cell with the ammeter connected.
Figure 4

Activity D:

The voltage produced by the cell is almost the same regardless of the light source. To demonstrate this, connect the voltmeter into the circuit as shown in **figure 5**. Switch #1 should now be pointed to the label “**voltmeter.**” **Switch 2 and 3 will not change.** Measure the voltage with two light sources (flashlight and lamp). If you have trouble reading the voltmeter, turn to Appendix B on page 12. Remember to answer questions 9 and 10 on your worksheet.

Connect the cells and voltmeter into the circuit as shown at right in **figure 6**. Switch #1 will not change. Switch 2 will be moved to the label “**four cells.**” and Switch 3 will not change.

Using the lamp as a light source, measure and record the voltage across all four cells. The next step will be to measure and record the voltage across three cells. Next, measure across two cells, then one cell. As you take these readings, **the only switch that needs to be moved is switch 2**. **Round your readings to the nearest 1/2 volt.** Record the readings on your answer sheet.

Are the voltages the same?

Add the voltage from 4 cells, 3cells, 2 cells, & 1 cell.

What is the sum of the four readings?

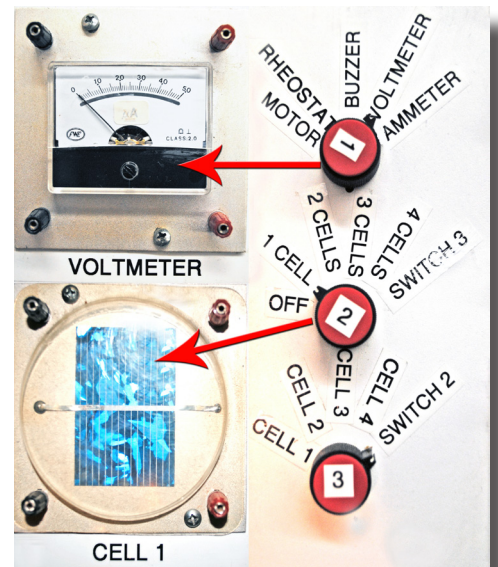
Record your answer on the answer sheet.

How many cells would you need to produce 17 volts? (question #12)

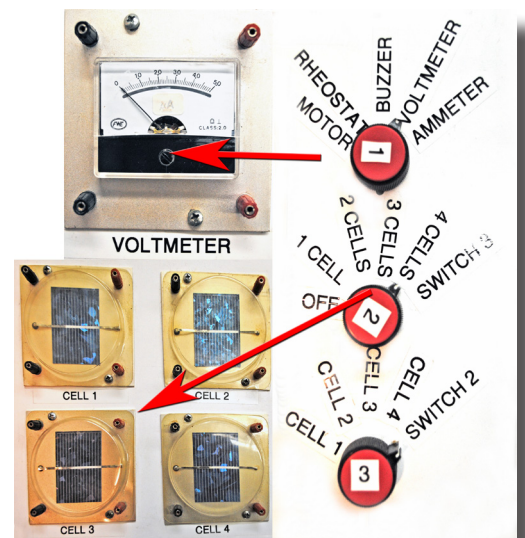
Activity E:

The speed of the motor depends upon how much voltage is present. Connect the motor in the circuit shown in **figure 7**. Switch #1 should be pointed to the label “**motor**”, switch #2 should be pointed toward the label “**1 cell**”, and switch #3 should be pointed toward the label “**switch #2**”.

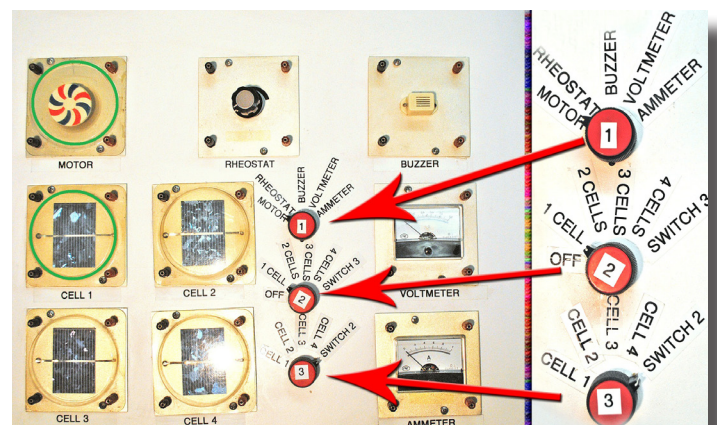
Turn on the lamp. Watch to see how fast the motor turns. Add another cell to the circuit by turning switch #2 toward the label “**2 cells**”. (Similar to diagrams on previous page). Add a third cell to your circuit. Add the fourth cell. See what happens.



1 cell with the voltmeter connected.
Figure 5



4 cells with the voltmeter connected.
Figure 6



In activity “E”, use the lamp to visually see the motor’s speed as more cells are added to the circuit.

Figure 7

Activity F:

The sound made by a buzzer depends on the amount of voltage. Repeat the last experiment, but replace the motor with the buzzer as shown in **figure 8**.

Activity G:

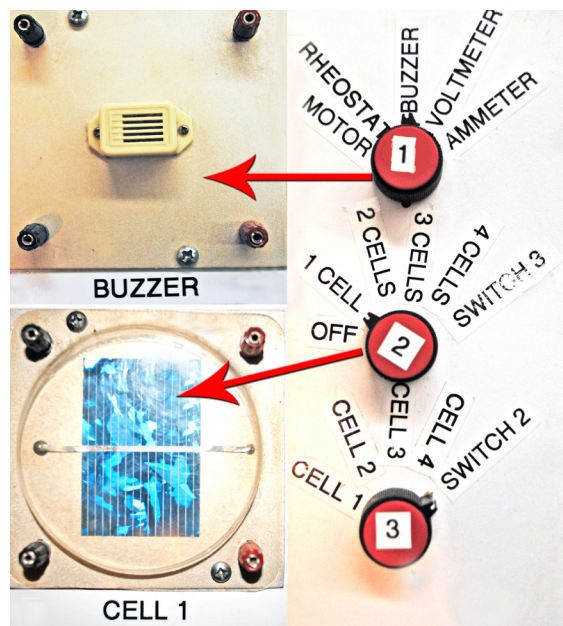
The speed of the motor and the sound from the buzzer can be controlled by limiting the voltage to the motor or buzzer. This was done in the last two experiments. Now try it a different way. This time you will use a rheostat.

Connect the circuit shown at right in **figure 9**. Switch #1 should be pointed to the label “*rheostat*”, switch #2 should be pointed toward the label “*4 cells*”, & switch #3 should be pointed toward “*switch #2*”.

Aim the lamp at the cells and turn it on. Turn the knob on the rheostat.

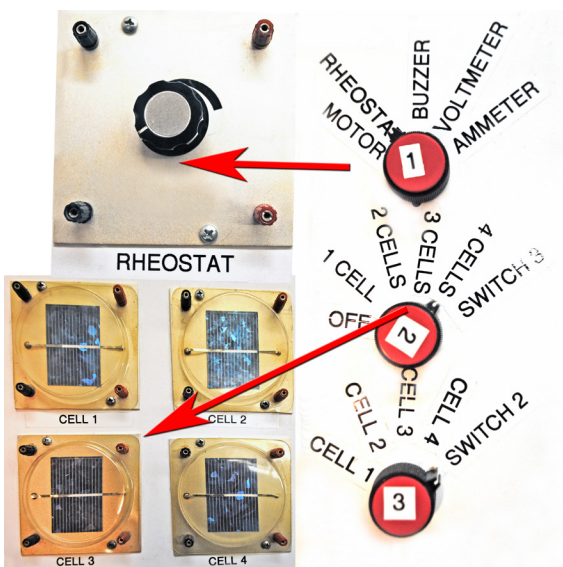
What happens when the knob on the rheostat is turned to the left? What happens when the knob on the rheostat is turned to the right? When you turn the knob to the left, the resistance of the rheostat is increased, thus decreasing the amount of voltage available.

This concludes this activity. Make sure that the flashlight is returned to the checkout station, and make sure the lamp has been turned off. Clean up the area where you have been working. Complete the rest of your evaluation sheet and hand it in to your instructor.



In activity “F”, use the lamp & add cells to the circuit to determine the answer.

Figure 8



In activity “G”, use the lamp & 4 cells to see what the rheostat does to the circuit.

Figure 9

APPENDIX A:

Reading the Ammeter

The Ammeter has a face which appears as in the picture at right. If you look closely at the face, you will notice that the Ammeter will only indicate a maximum reading of 1 “Ampere,” or “Amp” for short.

The “Ampere,” or “Amp,” is the unit of measure for electrical current, much like the “Gallon” is the unit of measure for how much water is flowing through a pipe.

The large numbers in between the 0 and 1 Amp markings are for fractions of an amp. Look at the face on your ammeter and find the markings of .2, .4, .6, and .8 Amps.

When you take your readings, round your answers to the nearest numbered marking.

If the pointer is half the way or more than half the way to the next higher number, record the higher number.

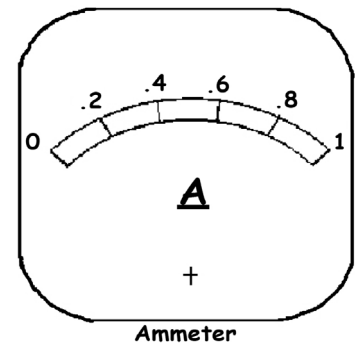
For example, the reading shown in illustration 2 would be .2 Amp.

If the pointer is less than halfway toward the next higher number, record the lower number.

The reading shown in illustration 3 would be recorded as .8 Amp.

The reading shown in illustration 4 would also be recorded as .8 Amp.

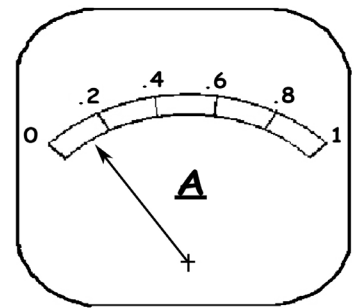
If you are still having trouble understanding how to read the meter, ask your teacher for help.



Ammeter

The ammeter is read to the nearest numbered marking.

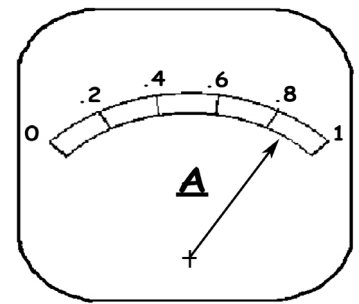
Illustration 1



Ammeter

The reading on this ammeter is .2 of an Amp.

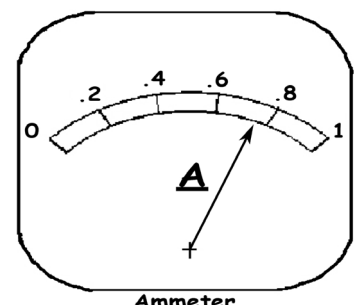
Illustration 2



Ammeter

The reading on this ammeter is .8 of an Amp.

Illustration 3



Ammeter

The reading on this ammeter is .8 of an Amp.

Illustration 4

APPENDIX B:

Reading the Voltmeter

The Voltmeter has a face which appears as in the picture at right. If you look closely at the face, you will notice that the Voltmeter can read a maximum of 5 Volts.

The Volt is the unit of measure for electrical “push” or “pressure” much like we use “pounds” to indicate how much pressure is pushing water through a pipe.

In between each of the Volt markings on the meter are marks which represent a fraction of a Volt. Each of these small markings has a value of .2 Volt.

See the illustration 6 to the right.

Follow this procedure to take readings from your experiments:

1. Write down the number of full Volt marks the needle has passed.
2. Find the fractional part of a Volt by counting the .2 Volt marks.
3. Round your answer UP to the nearest **1/2 Volt** (1/2 volt is the same as 5) **Do not round down.** This is necessary because of errors in the meter adjustment. See examples that follow.

Example #1

In illustration 7, the needle has passed the 2 Volt mark and has traveled up to the .4 mark, giving a reading of 2.4 Volts. You are to round this to 2.5 when you record your answer.

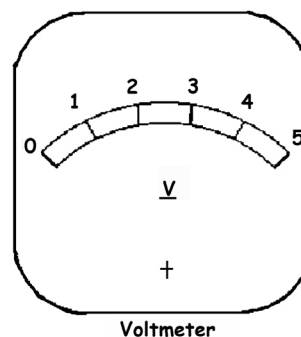
Example #2

In illustration 8, the needle has traveled to the 0.8 Volt mark. The answer you recorded would be 1.0 Volt.

Example #3

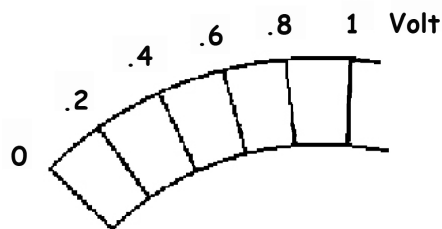
In illustration 9, the needle has traveled past the 4 Volt mark to the .2 mark (4.2 Volts). Record your answer as 4.5 Volts.

If you need further help with the meter readings, see your teacher.



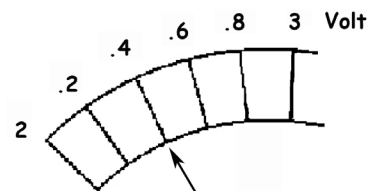
The voltmeter is read to and rounded up to the nearest half volt.

Illustration 5



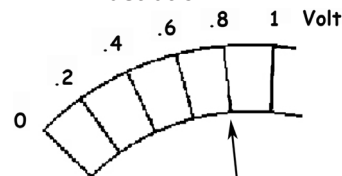
On a voltmeter, there are marks that represent a fraction of a volt.

Illustration 6



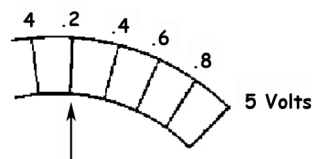
An example of rounding up.

Illustration 7



Another example of rounding up.

Illustration 8



Example 3
Illustration 9

ALTERNATIVE ENERGY - PHOTOVOLTAICS

Student Worksheet

Name _____ Period _____ Date _____

Directions: In the blank on the left, write the correct answer to the statement or question.

1. _____ A solar cell converts _____ energy into electrical energy.
2. _____ Solar cells are a _____ energy source.
3. _____ Solar cells produce ____ (alternating/direct) current.
4. _____ One of the most common applications for solar cells are hand-held electronic _____.
5. _____ Space probes, and _____ that are put into outer space can be powered for long periods of time with photovoltaic cells.

Activity A - G

6. _____ Activity A: What was the strongest light source?
7. _____ Activity B: What item produced the strongest reading?
8. _____ Activity C: How much of the cell had to be covered to stop the motor?
9. _____ Activity D: What is the voltage produced by the flashlight?
10. _____ Activity D: What is the voltage produced by the lamp?
11. _____ Activity D: What is the total voltage of all 4 cells?
12. _____ Activity D: How many cells does it take to equal 17 volts?
(Hint: 1 cell produces 1/2 volt)
13. _____ Activity E: The motor _____ (increased/decreased) speed each time a cell was added to the circuit?
14. _____ Activity F: How many cells were needed to activate the buzzer?
15. _____ Activity G: What happened to the speed of the motor when the rheostat was turned to the left?