Alternative Energy: Photovoltaics and Batteries

By J. Gutow 11/02, revised 11/03

Introduction

There are many alternative energy sources. The most important are solar, geothermal, hydroelectric, nuclear, biomass and wind. Solar energy is the one with the most long-term promise because of the large total amount of energy available, low environmental cost and the fact that it will last until the sun burns out. Some problems with solar energy are the low energy density per square meter at the Earth's surface and the fact that the sun does not shine all the time. Since sunlight is intermittent we need a way to store the energy for use when the sun is not available. One of the best ways to store energy is in batteries.

In this experiment you will try to use photovoltaic cells to power things and compare the characteristics of some common batteries. The goals are:

1) to develop a sense of some of the technological issues surrounding the use of solar energy and batteries as an alternative to the fossil fuels we now use.

2) to get some hands on experience with photovoltaic cells, motors and LEDs (light emitting diodes) in order to gain a basic understanding of electricity and conversion of light to electricity.

Electricity is just moving electrons. The harder the electrons are being pushed (the voltage) the more work can be done by each electron. So to increase the energy available from an electrical source you can increase the number of electrons flowing (the current, which is measured in Amperes, symbol A) or keep the current the same and increase the voltage.

Equipment shared by the whole class	Equipment for each pair of students
Charged 2V sealed lead acid batteries Dead 3.6 V NiMH battery packs Dead 3.6 V NiCd battery packs Dead 3.6 V LiIon batter packs	1 LED sheathed in black shrink wrap 2 small encapsulated photovoltaic cells with alligator clips on leads 1 small open frame electric motor (film advancing or equivalent) 2 14" clip leads 4 4 cm straight pieces of heavy copper wire 1 1000 Ω resistor 2 voltage probes attached to the computer. LoggerPro software set to measure voltages

I. Exploring the Energy Density of Batteries

WARNING: THE 2 V LEAD ACID (Pb-ACID) BATTERIES ARE FULLY CHARGED. <u>DO NOT SHORT THE TWO TERMINALS TOGETHER WITH AN ELECTRICAL CONDUCTOR.</u> THESE BATTERIES CAN GENERATE ENOUGH CURRENT TO GET VERY HOT OR EVEN MELT A PIECE OF METAL WHEN THE TERMINALS ARE CONNECTED DIRECTLY TO EACH OTHER WITH SOMETHING THAT CONDUCTS ELECTRICITY!

A NOTE ABOUT GETTING ELECTRICAL SHOCKS: As long as the voltage is below about 25 V you do not have to worry about getting an electrical shock. This is because your skin is a good enough electrical insulator that electrons pushed by less than 25 V cannot jump through your skin. Lightening, electrical outlets and power lines are dangerous because the voltages are much higher, varying between about 110 V for outlets to over 300 kV for lightening. There is one exception. If you have an open wound the body fluids flowing out of the wound are good electrical conductors; thus you can get a substantial shock from even a few mV if the wound comes in contact with a voltage source.

A. What do the different batteries weigh?

1. Make sure your balance is reading in grams. Tare your balance.

2. Obtain a sample of one of the types of batteries or battery packs available in class.

3. Record the battery type, voltage and capacity (mAhr or Ahr, which is just the number of hours that the battery can supply either 1 mA or 1 A of current at its rated voltage.)

4. Set the battery very gently on your balance. Some of the batteries are quite heavy. If you drop them on the balance you will break it. Record the mass of the battery.

5. Record the approximate relative volume of the batteries (as times bigger than the Pb-Acid battery, for example).

6. Repeat the above procedure until you have weighed all of the different types of batteries.

B. Calculating the energy density (ie. Joules per gram) of the batteries.

1. Units review:
Energy is measured in Joules: $1\ J = 1\ kgm^2s^{-2} = 1\ Nm$ = force * distance.
Power (energy per unit time) is measured in Watts: $1\ W = 1\ Js^{-1}$
This implies that

$$\text{Watts*second = Joules: } 1\ Js^{-1} * s = \text{Joules.} \qquad (1)$$

For electricity we have the following mathematical statement of the relationship between electrical current and power:

$$\text{Electrical power} = IV = \text{Watts}, \qquad (2)$$

where I = current in Amperes (A) and V = voltage in volts (V). Equation 2 is just a restatement of what was said in the introduction. The power available from an electrical source increases in proportion to the amount of current and the voltage pushing the current.

From equation 1, if we multiply the power by the number of seconds during which it is delivered we have the total number of Joules of energy delivered by the power source. For a battery this implies that the total energy available is:

$$\text{Volts * Current * (Seconds current can be delivered) = Joules} \qquad (3)$$

or in symbols

$$IVt = E, \qquad (4)$$

where I = current, V = voltage and t = time in seconds.

2. Calculating the Joules stored in each battery.
If you look at your table of information on the batteries you will notice that you

have recorded the voltage and the mAhrs or Ahrs, not the voltage and the current. What is going on is that the battery manufacturers record the current times the time as the battery capacity rather than the Joules. Since the unit is mA or A times hours you need to convert the units to A times seconds before multiplying by the voltage to get the total Joules. Do not forget that you need to have all the currents in Amperes (A) not milliamperes (mA).

a. First convert all the battery capacities that are in mAhrs to Ahrs using equation 5:

$$\text{Ahrs} = \text{mAhrs}*\{1\ \text{A}/(1000\ \text{mA})\}. \tag{5}$$

b. Second convert Ahrs to A*s using equation 6:

$$\text{A*s} = \text{Ahrs}*\{3600\ \text{s}/1\ \text{hr}\}. \tag{6}$$

c. Now calculate the Joules stored in the battery using equation 7, which is just a restatement of equation 4:

$$V*A*s = E, \tag{7}$$

where E = total Joules available from the battery, V = battery voltage and A*s = I*t and was calculated using equation 6 above.

3. The energy density of the battery is just the Joules/(mass of the battery):

$$E/g = \text{energy density}, \tag{8}$$

where E = Joules available from the battery and g = mass of battery in grams.

II. Electricity from Light using Photovoltaic cells

For this part of the experiment you will be using a number of different electronic components. Computers, household appliances, cars, radios and all the other electrical equipment you use contain some or all of these:

A resistor is just something that is a poor conductor. So it resists the flow of electricity; thus it limits I, the Amperes flowing between the two leads. The larger the resistance the larger the Ω (Ohms) of the resistor. Ohms are defined so that the power (P), in Watts, dissipated as heat in a resistor can be calculated with the formula:

$$P = I^2R = V^2/R, \tag{9}$$

where P = power in Joules, I = current in Amperes, R = resistance in Ohms and V = voltage in Volts.

An LED (light emitting diode) is a semiconductor device that converts electricity into light with very high efficiency. LEDs now come in many colors although those emitting high energy blue and purple photons are very expensive. It is expected that their prices will come down substantially in the next few years. One special characteristic of all diodes is that they only allow current to flow one direction. The other direction their resistance is almost infinite, like an open switch.

Copper wire is used when a convenient but good conductor is needed. Gold and silver are better conductors, but too expensive for most uses. The key characteristic of a conductor is that reasonable lengths of it have near to zero resistance to the passage of electrons from one end to the other. It is possible to get some materials to become super conducting at very low temperatures (4 - 77 K). A super conductor actually has no resistance at all; thus none of the energy carried by the electrons moving through a super conductor is lost. There is some hope that super conductors will become practical for large scale electrical transmission in the near future. For the time being super conductors are used primarily to make very large magnetic coils like those used in MRI imagers, used to take images of the insides of a body without having to go inside. In chemistry labs an NMR spectrometer uses the same kind of signals in a different way to identify compounds.

An electric motor converts electrical energy into kinetic energy. Modern electric motors are very efficient and can convert in excess of 80% of the electrical energy they use into useful motion. Most motors are like the little ones you are using in class that convert electricity into rotational motion. However, motors can be built to convert electricity directly into linear motion.

Photovoltaic cells (photocells) are found in fewer devices. They are semiconductors that convert light directly into electricity. The most efficient cells commonly available can convert about 15% of the light that falls on them into useful energy. Some experimental devices exceed 24% efficiencies. For comparison photosynthesis converts less than 1% of the light that falls on the leaves to energy the plant can use.

DO ALL THE EXPERIMENTS WITH THE PHOTOCELLS UNDER THE BRIGHT LAMP ON YOUR BENCH. THE ROOM LIGHTS ARE NOT BRIGHT ENOUGH TO GENERATE SIGNIFICANT CURRENT FROM THE PHOTOCELLS. TRY TO KEEP THE DISTANCE FROM THE LIGHT CONSTANT.

A. Determining the voltage polarity of your photovoltaics.

Each photocell has two colored leads with alligator clips on their ends. Connect the two alligator clips from one of the cells to opposite sides of the 1000 Ω resistor. Now clip the two leads from one of the computer voltage probes to opposite sides of the resistor as well. If the red lead on the voltage probe is attached to the most positive voltage the computer will read a positive voltage. Use this to determine which lead on your photocell is the most positive. The electrons are flowing from the other lead towards the most positive lead through the resistor. Record the voltage measurement.

B. Series versus parallel circuits.

Each photocell can produce a fixed amount of current at a voltage of about 0.4 V. To increase the voltage you must connect the cells in series. To increase the current produced you must connect the cells in parallel. See figure 1 below.

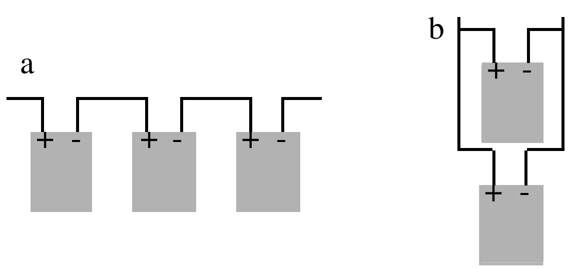

Figure 1: Series versus parallel connections: a) photocells connected in series, V = (# cells)* (volts/cell); b) photocells connected in parallel, V = volts/cell, I = (# cells)*(Amperes/cell).

1. Connect two cells together in series by clipping a (+) clip from one to a (-) clip of another. Connect the leads at the ends that are not connected to anything to opposite sides of the resistor. Measure and record the voltage.

2. Combine your two cells in series with the two cells from the group across form you on the bench. Stick in the resistor then measure and record the voltage.

3. Try covering one or two of the photocells in your series circuit so that they receive no light. Record what happens to the voltage.

4. Use the copper wire to connect two cells together in parallel. Connect the positive side of this circuit to one side of the resistor and the negative to the other. Measure and record the voltage.

5. Combine your two cells in parallel with the two cells from the group across from you on the bench. Connect the positive side of this circuit to one side of the resistor and the negative to the other. Measure and record the voltage.

6. Cover one or two of the photocells in your parallel circuit so that they receive no light. Record what happens to the voltage.

C. Lighting an LED using photocells.

1. Determine which lead on the LED must be connected to the positive side of the photocell so that it will light by using your two ended clip leads to connect the LED to one of the 2V Pb-Acid batteries. WARNING: BE CAREFUL NOT TO SHORT THE WIRES CONNECTED TO THE TWO SEPARATE BATTERY TERMINALS TOGETHER OR YOU COULD START A FIRE. If necessary bend the leads on the LED so that they cannot accidentally touch each other. One way you connect the LED it will light the other it will not. Write down whether it is the short or long lead of the LED that is connected to the positive (+) terminal on the battery when it lights. This lead should be connected to the positive lead from the photocells. If the leads are both the same length use a piece of tape to mark them. Please remove the tape at the end of lab.

2. Clip the positive voltage probe lead to the positive side of the LED and the negative lead to the negative side of the LED.

3. Start with one photocell and clip it to the LED in the proper orientation. Record whether it lights and the measured voltage.

4. Connect two photocells in series and try using this to power the LED. Record whether it lights and the measured voltage.

5. Continue adding photocells in series until you can see the LED light up. You may have to share with other groups to get enough cells. Record the measured voltage across the LED at each step.

6. Try combining two series circuits that have enough cells to light the LED in parallel with each other. You may have to share with other groups to get enough cells. Record what happens to the intensity of the LED.

D. Running an electric motor with photovoltaic cells.

1. Convince yourself that your motor will run using one of the 2V Pb-Acid batteries. WARNING: BE CAREFUL NOT TO SHORT THE WIRES CONNECTED TO THE TWO SEPARATE BATTERY TERMINALS TOGETHER OR YOU COULD START A FIRE. Notice that if you switch the leads the motor spins the other direction.

2. Now try to get a motor running using the photocells as the power supply. Each of these little motors needs between 1 and 1.5 V to run as well as a significant amount of current. You may have to share with other groups in the class to get enough photocells. When you get a motor running record the number of photocells used and how they were connected. Draw a diagram.

Questions

1) Make two lists of batteries from least energy dense to most energy dense. The first list should be energy density with respect to mass and the second energy density with respect to volume. Which battery would you pick as a power source for a moving vehicle? Which battery would you pick as a power source for a home with little extra space? Why the particular choices you made?

2) In addition to energy density considerations, disposal and recycling of batteries when they can no longer be recharged is an issue. Cd and Pb are very toxic and the solvent in LiIon batteries is toxic and flammable, whereas Ni and the metal hydrides are more benign. Note that all the batteries can be recycled. Based on this information and your measurements in lab, which battery would you choose to use and why?

3) Do photocells become more or less conductive when light falls on them? What experimental result supports your assertion?

4) As mentioned in the introduction and as you demonstrated trying to run a motor with photocells, the power available using photocells to convert light energy to electricity is limited. Given that most of our uses of power are intermittent, devise and describe a way to use photocells and batteries in combination to drive power hungry devices like motors, but only for brief periods.

Name____ Date_________________

Partner_______________________________________ Section_______________

DATA SHEET FOR PHOTOVOLTAICS AND BATTERIES LAB

Table 1: Data and calculations of energy density in J/g of batteries.

Description of Battery (Pb-Acid, NiMH, NiCd, LiIon, etc...) Include the voltage	A Mass of Battery (g)	B Capacity (mAhrs)	C Capacity (Ahrs = B/1000)	D Capacity (Amp*s = C*3600)	E Joules Stored = D* Volts	F Energy Density (J/g = E/A)

Table 2: Data for energy density in J/(unit volume) of batteries.

Battery Type					
Relative Volume					
Energy Density (J/unit volume)					

Table 3: Voltages from photocells

# of cells	1	2	3	4	5
In series measured Volts					
In parallel measured Volts					

What happens when one cell is covered so that it receives no light?

In a series circuit:

In a parallel circuit:

Table 4: photocells and LEDs.

Which lead of the LED must be connected to (+) for current to flow?

# of cells in Series	1	2	3	4	5	6	7
Does LED light?							
Voltage across LED							

What happens to the light from the LED when two series circuits are combined in parallel to power the LED?

Table 5: Running an electric motor with photocells.

# of photocells used	Diagram of Circuit