Determining the Efficiency of Converting Solar Power into Mechanical Movement

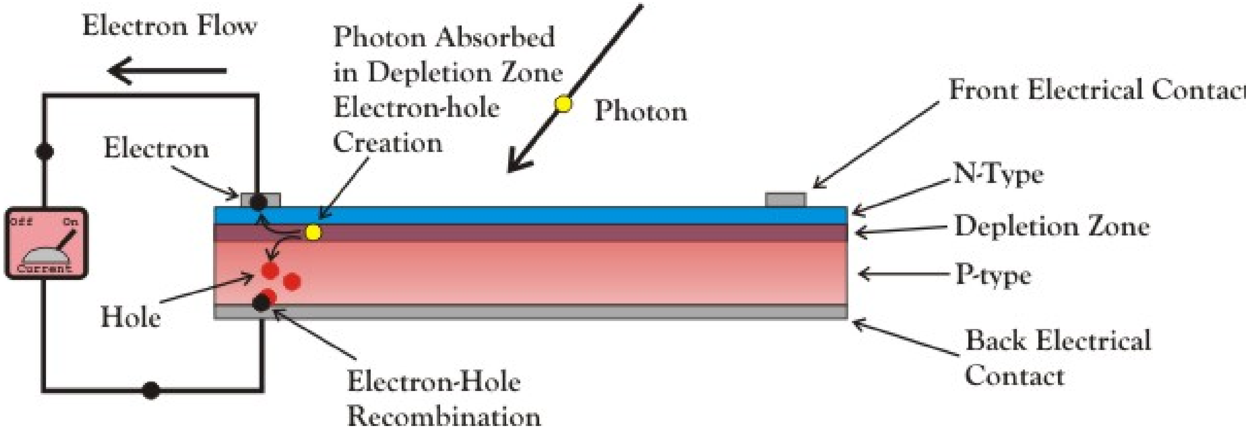
Introduction

There is a growing wide-spread concern over the supply of fossil fuels (gasoline, natural gas, oil, etc..) and the environmental-friendliness of extracting energy from them using combustion (as in your car, likely your home's furnace, airplanes, ships). This is leading to research and innovation in so-called green technologies which (by definition) are based on renewable resources such as sun, wind and hydro power. Technologies strive to maximize the conversion of some kind of energy (light, moving air kinetic energy (wind), moving water kinetic energy (hydro)) into electricity, and then using electricity to perform something useful for us on demand. Integral to this entire system is the storage of electrical energy (How to make a better battery) which is a topic of intense technological research and development (but not investigated here).

In this exercise you will first study the how efficient solar cells are in converting the sun's energy into electrical energy. Next, you will investigate the inherent inefficiencies of a typical DC motor. Finally, you will combine the two investigations into turning the motor using only solar cells.

Part A: Determine the Efficiency of Solar Cells

You may not be aware of it, but Light is strange phenomenon. It is comprised of individual particles called photons. In some experiments, the photons act very much like a wave, and in others they act very much like particles. For the purpose of this experiment, it is more the particle-nature of light which we are exploiting. Photons of different colours have different energy- red being less energetic than blue. When these photons hit a solar cell, they transfer their energy to electrons inside the cell, allowing a current to flow. The details of this process are shown in the figure shown below, and require knowledge of special materials called semiconductors. This only occurs if the photon had enough energy, and for our solar cells, this colour is in the near-infrared part of the spectrum (deep, deep, red).



So how well does this all work? That depends on what you want to do. Solar cells can directly provide electrical current, which in turn can pass through some load (motor, toaster, cell phone charger) and do work. Electrical power, *P*, is a measure of the energy output per time. It can easily be measured in electrical circuits as it is equal to the current(*I*) multiplied by voltage(*V*) of the circuit.

$$P= I\ V \qquad \textit{(equation 1)}$$

Key Fact: A solar cell's ability to generate power depends on the resistance of the load (what it's hooked up to).

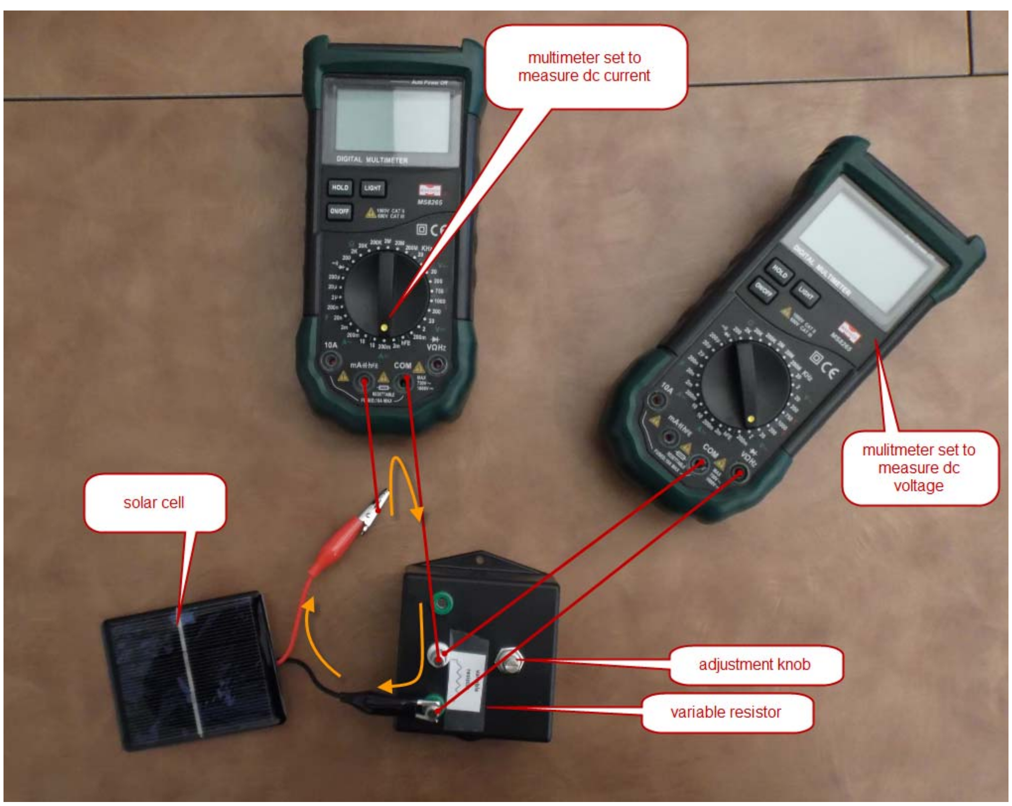
We can use a variable resistance to help us determine the current and voltage (hence power) output of a solar cell. In the first exercise, you will study what is the most power possible to be extracted from a solar cell.

A1. Determine the load resistance will allows for the solar cells to generate the most power.

First, let me introduce the multimeter.

The mulitmeter can measure current, voltage, resistance, and many other things depending on it settings. Its function is controlled using the large dial, and it matters which input ports are used. You always attach one probe to the COM port, and depending on what else you want to measure the other probe to another port. Wire colours don't matter. If you attach something incorrectly, the multimeter beeps at you.

Set up the following circuit (note the settings of the multimeter dials and ports used):



The orange arrows show the direction of current flow. To measure current, one multimeter is in series (current flows though it) and to measure voltage, the other multimeter is in parallel (no current flows into it).

Now illuminate the solar cell with a desk lamp.

Open the file *Solar Cell Power.xlsx* on the Desktop.

Vary the load resistance by adjusting the variable resistor. For each setting, enter the values of current and voltage (read off of the multimeters) in the prepared table. A plot will automatically be created showing Power vs Voltage. What maximum power (P_{max}) can you attain?

A2: Compare this power generated to the "light power" incident on the solar cell.

To know the intensity of light that is actually hitting your solar cell (I_{actual}), you will use the calibrated sensor attached to the laptop. Run the program LoggerPro on the desktop. When it opens, it will be displaying the light power incident on the probe in the bottom left corner. Put the probe at the same distance from the lamp as was the solar cell. Note the units of this measurement are Watts per Square meter (W/m^2) as we are measuring Intensity (power per area). Your result from Part A1 is a power. To know the intensity of light in the solar cells, divide P_{max} by the Area of the solar cell. You can measure the area using a the calipers provides (overkill, I know). Be sure to put it in unit of meters.

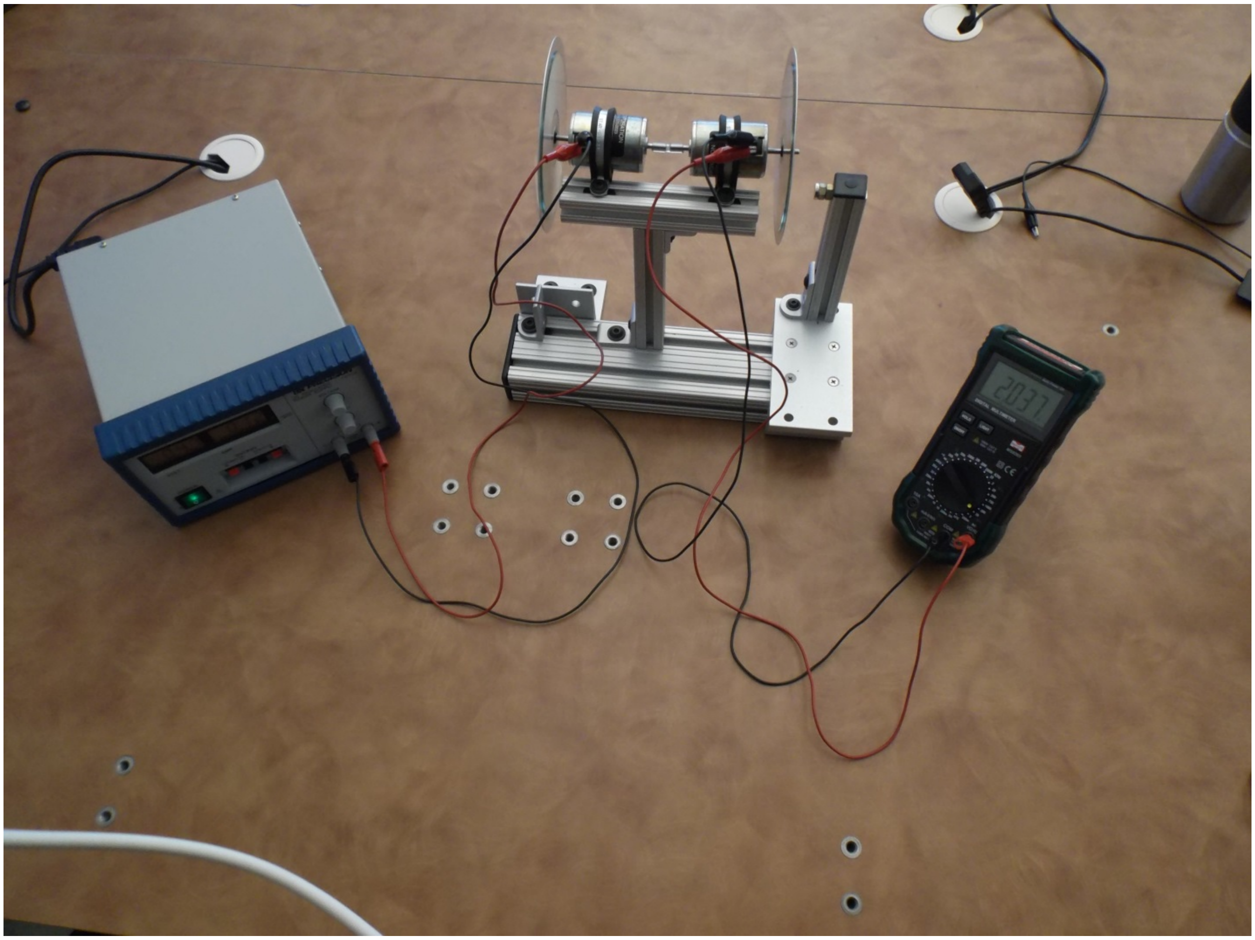
Now divide this intensity by I_{actual} to determine the solar cells efficiency!

Don't be sad by the low result…after all, the sun's energy is free, (practically) never ending, and available to everyone! Also, cutting-edge high-performance solar cells are now close to 40% efficient.

Part B: Determine the Efficiency of a DC motor

DC motors convert electricity into motion, typically rotational motion. Internally, the motors contain windings of electrical wire and magnets. It is the process of the Magnetic Induction which allows this all to happen. In magnetic induction, a changing current though a coil of wire generates a changing magnetic field which then interacts with the permanent magnets of the motor to provide a force for rotation. This is all to the good, however, **Key Fact:** inherent to the motors design are other unwanted magnetic forces which oppose this motion, causing inefficient operation. This is call back-EMF (electro-motive force)- The motor is trying to slow itself down! This means we have to put in extra energy to overcome this effect. Such DC-motors have a built-in inefficiency.

In this exercise we have two motors attached together. One motor will be powered with the power supply, then using the second motor we will determine the back-emf. Attach the experiment as shown below:



The power supply powers one motor, and then we measure the voltage induced on the second motor. We can measure the current and voltage output from the power supply simply by looking at its front panel display. Set the power supply to about 10 V using the control knob. We are supplying a power (P_{supply}) equal to this current (I_{supply}) times voltage (V_{supply}). The back emf (V_{emf}) can be measured by the multimeter attached to the second motors. Therefore, the useful power actually being used to drive the motor is:

$$P_{useful} = (V_{supply} - V_{emf}) \times I_{supply}$$

The efficiency of the motor is then P_{useful}/P_{supply}.

You'll be happy know that high-quality DC motors can attain close to 95% efficiency.

What is the minimum voltage required for the motor to turn? What current needs to be supplied?

Further Investigation: Measure the speed of rotation, and Magnetic braking (Time Permitting)

You may have noticed that attached to one of the spinning aluminum disks are a pair of magnets. Nearby by this disk a sensor which can detect when a magnet passes nearby. We will use a device called a SensorDAQ to read the signal output from this sensor onto a computer, and measure the speed of rotation.

For the computer to talk this device, we will be using a program called Labview. Open the program *Desktop -> Speedometer.vi*. Notice how two windows pop up. One is called the front panel- this contains the user interface for the finished program, the other is called the back panel where the program is written. To run this program, click the Arrow icon in the top left corner of the front panel. Adjust the voltage of the power supply to vary the speed of the motor.

Now, to see the effects of magnetic braking, there is a strong magnet mounted on the post on the other side of the motor apparatus. This post is on a movable base. Slide the base so the magnet is close to, but not touching, the spinning aluminum disc. What happens to the speed of the motor? What happens to the power (Voltage x Current) of the power supply? Can you think of some applications of this effect?

If you're interested, have a look at the program on the back panel. Labview is a graphical programming language. Data flow is controlled by wires, larger solid blocks are functions (such as the DAQ Assistant), smaller blocks are variables, and program structures (while loop, if statements, etc…) are large open boxes which contain functions and variables (a while loop in this case).

Labview is very powerful software for data collection, controlling devices and instruments, and data analysis. Our first year physics students spend a lot of time with this software in collecting and analysing data in their experiments. It is also widely used in research labs and in industry- a very useful and marketable skill for students to have.

Part C: Put them together and see what you get!!

What efficiency can you hope to get when combining solar cells to power an electric motor based on your calculations?

Try it! You will need to use all 6 solar panels. Assuming each panel can supply approximately 1.5V, and you want to maximize current, how must they be connected? (All in Series? All Parallel? Some in series and some in parallel?)

You will need two desk lamps to illuminate all panels. Try first with the small dc motor, that should work really well. Now try with the unmounted large dc motor. That also should spin relatively easily. Try stalling the motor with your fingers to get a feel for how much work could be done with that motor.

Now, if you've done everything correctly, you should be able to power the mounted dc motor-generator apparatus used in Part B.

Things to consider

1. What is the intensity of the sun's rays on the surface of the earth? How does that compare with our lamps? How much better would this work outside.
2. Estimate the fraction of the day/year that you can obtain that maximum intensity from the sun.
3. If you wanted to switch the entire energy-generating capacity of Quebec to solar energy generation, taking into account typical solar cell efficiencies, and fraction of time sun's energy is available, what area of solar panels are required? What fraction of the area of the Island of Montreal does that correspond to?
4. Is the production of solar cell an environmentally-friendly process?
5. What is the usable lifetime of a solar panel?