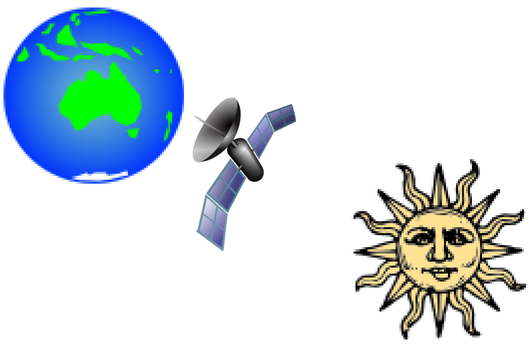
ENGR 110: Bright Ideas: Photovoltaic panels and Solar Power

SAFETY NOTES:

1. **in the following, bear in mind that incandescent lamps get very hot and you cannot touch the bulb until it has been off for quite a while.**
2. **Our solar panels are very low voltage (a few Volts). But higher voltage solar panels can easily electrocute a person.**
3. **Note also resistors can get very hot if they carry too much current. They can smoke and burn.**
4. **The motor is to be connected ONLY to the solar panel. Do not connect it to a power supply .**



Introduction

We use electricity constantly for countless purposes, and recent developments in battery and motor technology are expanding the range of electrical technology. For example, affordable and practical electric cars, once the stuff of science fiction, are rapidly becoming mainstream. Some experts argue that self-driving, electric cars may largely replace human-driving, petrol and diesel vehicles within a few decades or even soon[1]. In general electric energy is essentially an *energy currency* that can be used for nearly anything.

We seem to be on the cusp of a major technological revolution in the ways electrical energy is used, and in parallel, a revolution in the way electrical energy is produced and transmitted. The "old" way of making most electricity consisted of burning some sort of fuel and using the energy to run an engine. The engine would then spin a magnet in a coil and produce electricity. Electric energy production in NZ developed in a different way, using mostly hydroelectric plants in which falling water provides the energy to spin magnets in coils[2]. in both cases the power plants were and mostly still are very large scale facilities often far from the end user. Now wind generators and solar energy are rapidly expanding. They are often smaller scale facilities coupled to a "smart grid" that can distribute electric energy produced in a wide range of methods to a very complex set of loads (users). Photovoltaics or solar panels are semiconductor devices, usually made of silicon, which convert light energy to electrical energy. At present they produce a small but rapidly increasing share of the world's electricity[3]. Photovoltaics have dropped rapidly in price in recent years[4]. While they were previously used in remote locations, far from the grid, commercial installations that feed the grid are now becoming widespread. We will learn a bit about these devices in this lab and in parallel tutorials.

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[1] For example, see Rethinking Transportation 2020-2030 by Stanford Economist Tony Seba.
[2] Electricity generation data for NZ is available from the NZ Government. See for example http://www.mbie.govt.nz/info-services/sectors-industries/energy/electricity-market/electricity-industry/electricity-generation.
[3] https://www.eia.gov/outlooks/ieo/electricity.php
[4] https://blogs.scientificamerican.com/plugged-in/the-price-of-solar-is-declining-to-unprecedented-lows/

Working in Groups

Students will work alone or in pairs to complete this lab. It is absolutely required that ALL students get to have fun connecting the circuits and making measurements. It is not acceptable for one member of the group to do all the hands-on work while others watch. To make sure everyone gets a chance, complete the following table while you are working on the lab. Specify what circuit construction and/or measurements each member of the group completed. Identical tables should appear in the lab scripts for each group member. If you worked alone, describe at least one measurement or connection exercise you completed.

Work Summary: (10 marks)

Group member 1 name James Small

Circuit construction and measurements done by this group member:

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Did core and designed circuits

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Group member 2 name David Nangoi

Circuit construction and measurements done by this group member:

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Early core circuits and design, with documentation. Calculation on Challenge #1, did challenge 2 aswell

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Group member 3 name Om Mistry

Circuit construction and measurements done by this group member:

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Completion circuits design, as well as documentation

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Group member 4 name ___________________________

Circuit construction and measurements done by this group member:

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Group member 5 name ___________________________

Circuit construction and measurements done by this group member:

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CORE : Getting Started

CORE 1: (10 marks)

We will use anglepoise lamps with incandescent light bulbs to simulate the sun. Connect your solar panel to the place the lamp about 15 cm above the solar panel, and turn on the lamp. Be sure the solar panel faces the lamp directly. Listen to the bell! Then use your two meters to measure the voltage and current delivered to the device and thus calculate the power. Note: Use the Fluke DMM (digital multimeter) as the ammeter. The other meters have a larger internal resistance than the Fluke and are not suitable for measuring current in this lab exercise.

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Voltage: 4.92v

Current: 1.3 - 0.3 Amps

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CORE 2 (5 marks)

Your solar panel has three separate sections. These each produce 1.5 volts, and they can be connected in series or parallel. Make a diagram of the three sub panels connected in series and another in parallel and discuss the differences. Our motors draw quite a lot of current but can run on a small voltage. The bells draw less current and can operate on either lower or higher voltage, but operate better at higher voltage. Should you use series or parallel for the motor? For the bell? Flip the solar panel over and see how it is connected. Is it what you expected? Test your bell and borrow a motor to test with parallel and series.

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The buzzer is bad in parallel and the motor is bad in series.

Parallel is the best for the motor as it draws a lot of current which is why there is less resistance. Which leads to better impedance match, also cause it's ⅓ overall.

For the bell you should use series circuit as it works better at a higher voltage because of solar panels.

Each solar panel panel has 1.5v which adds to 4.5v , this leads to way higher resistance so it means a better impedance match.

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CORE 3: (5 marks)

What does intensity of light mean? What are the units of intensity?

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Light intensity is a measurement of the amount of power either emitted or reflected by a source.

The SI unit for intensity is watts per square meter W/m^2

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CORE 4: (5 marks)

Write a formula for the intensity of light a distance R from a small (point) light source.

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Intensity of light = P/ (4 * Pi * R^2)

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CORE 5: (5 marks)

Based on your formula, what would happen to the intensity of light if the distance between the solar panel and the "sun" was reduced from 15 cm to 7.5 cm? What would happen to the power delivered? Make a prediction.

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7.5cm

Voltage: 4.3 - 4.2

Current: 1.3 - 0.3 mA

15cm

Voltage: 4.9v

Current: 1.3 - 0.3 mA

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CORE 6: (10 marks)

Test your prediction. Use a ten Ohm resistor as a load. If you prediction was incorrect, explain where your reasoning went wrong. If your prediction was approximately correct explain where measurement errors may have arisen. **Solar panels lose efficiency as they warm. So after you finish your measurements, move your lamp back to 30 cm to avoid warming your solar panel as the output of the solar panel will vary with temperature.**

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15cm

Voltage: 1.44v

Current: 0.06 A

30cm

0.08 Amps 0.14

Voltage: 0.8 Volts

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It's Complicated

You will be unsurprised to learn that there are complications with solar panels. We will explore two of them: angle dependence and impedance matching.

CORE 7: (5 marks)

Vary the angle of the solar panel so it does not point directly at the lamp. What happens to the power output as indicated by the bell or motor?

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When the light is twisted by an angle, the main noticeable difference is that the voltage is dropping slightly and the ampere jumps (current) significantly.

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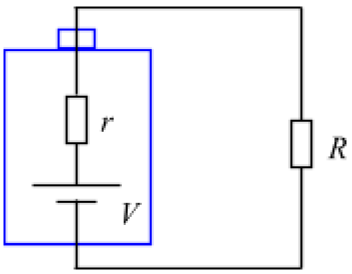
Impedance Matching

We discussed "impedance matching" in lecture and lab. We will investigate how it affects the use of solar panels.

Power sources such as a battery or a solar panel can be modelled as an ideal voltage source V in series with an internal resistance r as in the diagram below. Note that the internal resistance r is not a physical resistor. Instead it is a way of modelling the fact that the power source cannot deliver unlimited current and the voltage drops once we start drawing current from it.

In the diagram below the power source is connected to a load R. The load is the motor in our case. If the load resistance is very large, then very little current flows and very little power is delivered to the load. On the other hand, if the load resistance is much smaller than the internal resistance of the power source then a large current flows but most of the power is delivered to the internal resistance of the power supply. In an extreme case of a shorted power supply all of the power is delivered to the internal resistance. A shorted battery for example gets very hot and can be quite dangerous. There is an optimum load resistance that delivers as much power as possible to the load. In a challenge problem you will show this is when $r = R$, so the load and internal resistances are the same. This is called *resistance matching* or *impedance matching* for circuits with reactive circuit elements (inductors and capacitors).



We can measure the internal resistance of our solar panels just by finding the load resistance that maximizes the power to the load. To do this we will use various resistors as our load and measure the current and voltage for each resistance. A graph of power versus load resistance then tells us the optimum.

COMPLETION 1: (20 marks)

Make a data table, measure P versus R so that you see a maximum. Graph your data. What is the internal resistance of your solar panel?

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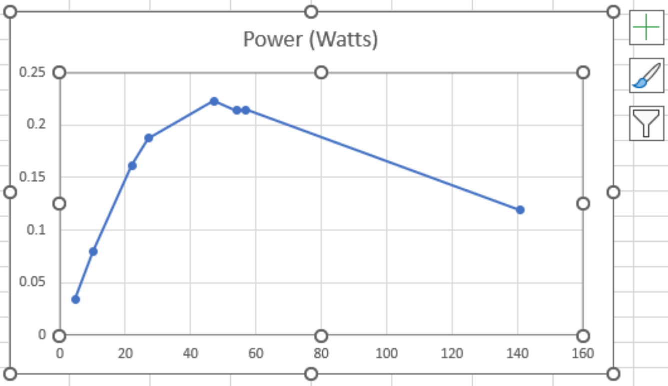
the light is placed at a 30 cm distance from the solar panel.

Resistance (Ω)	Power (Watts)
4.7	0.034
10	0.079
22	0.162
27	0.1875
47	0.223
54	0.214
57	0.2149
141	0.1192



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COMPLETION 2: (5 marks)

Check the internal resistance you measured in completion 1 directly by measuring the solar panel voltage with no load and the current when the solar panel is shorted. Note this would be DANGEROUS with a power supply, battery, or larger solar panel. Ours is not capable of delivering large currents and this measurement is safe.

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It is the same as before

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It's even more complicated.

The internal resistance of a solar panel is not a constant. It depends on the intensity of the light and also on the temperature. For small scale solar panels powering small devices we largely ignore this complication, but for larger commercial applications it needs to be taken into account and increases the complexity of photovoltaic installations.

CHALLENGE

CHALLENGE 1: (5 marks)

Show that $r = R$ optimizes the power delivered to the load. Hint: take the derivative with respect to R. Note this is worth only five marks because it was done in the in-class exercise in lecture, but review the calculus and algebra. It turns out matching impedance is a good way to connect a solar panel to a load but is not a good way to connect a fuel burning generator to a load. Why? Again we discussed this in lecture.

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The power delivered to the load (P) can be calculated using the formula:

P = (V_R)^2 / R

where V_R is the voltage across the load resistor.

The voltage across the load resistor can be expressed as:

V_R = V_source - I * r

where V_source is the source voltage, and I is the current flowing through the circuit.

To find the value of R that maximizes P, we need to take the derivative of P with respect to R and set it equal to zero:

dP/dR = 0

Let's proceed with the calculation:

1. Express V_R in terms of R:

V_R = V_source - I * r

2. Express I in terms of V_source and R using Ohm's law:

I = V_source / (r + R)

3. Substitute the expression for I into the equation for V_R:

V_R = V_source - (V_source / (r + R)) * r

4. Simplify V_R:

V_R = V_source - (V_source * r) / (r + R)

5. Now, calculate the power P:

P = (V_R)^2 / R = [(V_source - (V_source * r) / (r + R))^2] / R

6. Take the derivative of P with respect to R:

dP/dR = -[2 * (V_source - (V_source * r) / (r + R)) * (V_source * r) / (r + R)^2] / R + [(V_source - (V_source * r) / (r + R))^2] / R^2

7. Set dP/dR equal to zero and solve for R:

-[2 * (V_source - (V_source * r) / (r + R)) * (V_source * r) / (r + R)^2] / R + [(V_source - (V_source * r) / (r + R))^2] / R^2 = 0

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CHALLENGE 2: (5 marks)

Discuss the what happens to the voltage across a varying load in two cases: first, if the load resistance is comparable to the internal resistance (approximately impedance matched). Second, if the load resistance is much larger than the internal resistance. Would you ever want to have a load resistance much smaller than the internal resistance? Why or why not?

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When the load resistance in a circuit with an internal resistance varies, the voltage across the load behaves differently in two cases: impedance matched (load resistance comparable to internal resistance) and much larger load resistance.

1. Impedance Matched (Comparable Load and Internal Resistance): In impedance-matched scenarios, where the load resistance matches the internal resistance, the circuit is optimised for maximum power transfer. The voltage across the load is approximately half of the source voltage, ensuring efficient power delivery.
2. Much Larger Load Resistance: When the load resistance is much larger than the internal resistance, the voltage across the load will be close to the source voltage. However, practical limitations should be considered as excessive load resistance may cause the source to be unable to supply enough current.

Having a load resistance much smaller than the internal resistance is generally undesirable. It leads to inefficient power usage, wasting energy as a significant portion of the source voltage drops across the internal resistance. The power delivered to the load is limited, potentially causing the load to function ineffectively.

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CHALLENGE 3: (5 marks)

Reminder: in the following, bear in mind that incandescent lamps get very hot and you cannot touch the bulb until it has been off for quite a while. Borrow the fluorescent lamp or LED from a tutor. Illuminate the solar panel connected to the motor or bell with the LED lamp. Nothing happens even though the LED lamp is brighter than the incandescent! Explain this.

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1. Incandescent Lamp vs. LED Lamp: Incandescent lamps produce light by heating a wire filament until it becomes hot enough to emit visible light. However, a significant amount of the energy used by incandescent lamps is converted into heat rather than light, making them inefficient light sources.

On the other hand, Light Emitting Diode (LED) lamps are much more efficient light sources. They produce light by passing current through a semiconductor material, which emits photons. LED lamps convert a larger portion of the electrical energy into visible light, resulting in higher brightness while generating less heat.

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CHALLENGE 4: (5 marks)

Is the motor well matched to the solar panel? Explain your reasoning and any measurements you made. Hint: a motor behaves differently when it is running.

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