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HW 8 - Solar Cell Lab

1) Characterize your solar cell in the DARK. Cover it as well as possible. Your goal is to make sure that when you connect your cell to a voltmeter, it measures close to zero volts. You can ensure the cell is in the dark by turning it upside down and covering it with another material. Now connect your cell to the power supply and measure the I-V characteristics of your cell. Your voltage measurements will be the levels you put into the cell. Your current measurements should be taken using the multimeter. Plot the results and attach to your report.

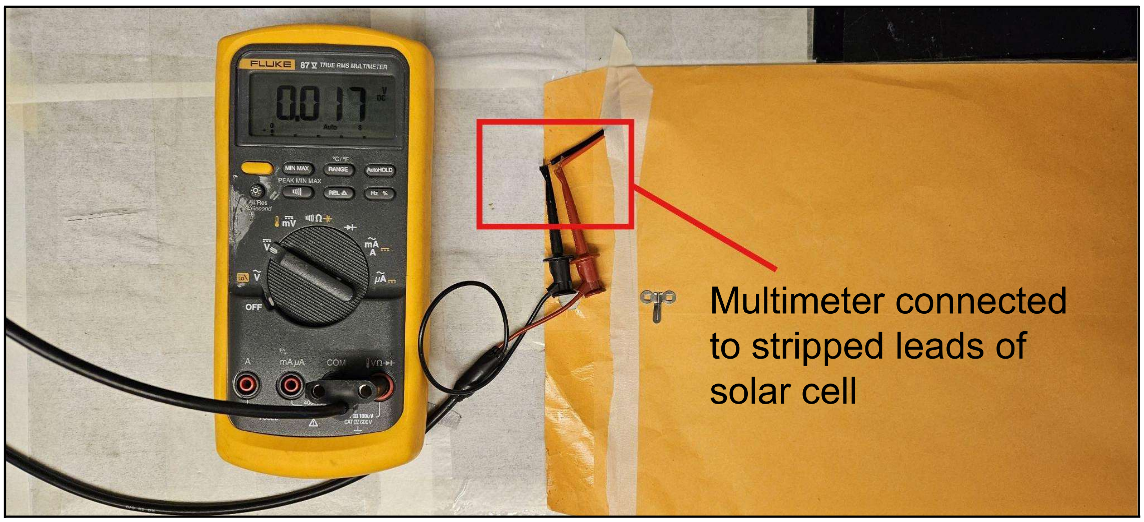

Figure 1. Setup - Solar cell characterization (dark)

In darkness, our solar cell produced 0.4 uA of current with a voltage difference of 17 mV. This data was found by covering the solar cell as described, but with only a multimeter attached.

We attempted to use the AD2 power supply to complete the experiment as described. But we were unable to generate changes in current by applying other voltage levels across our solar cell.

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2) Now find a light source. First simply uncover the cell and measure the open circuit voltage. Increase the light intensity and observe the increase in voltage. You should be able to increase to 7V. Play with light, use solar light, indoor light, etc. and see how the results change. Track the light source you used and the voltage you were able to obtain from this source. This part is purely observational and does not require a graph.

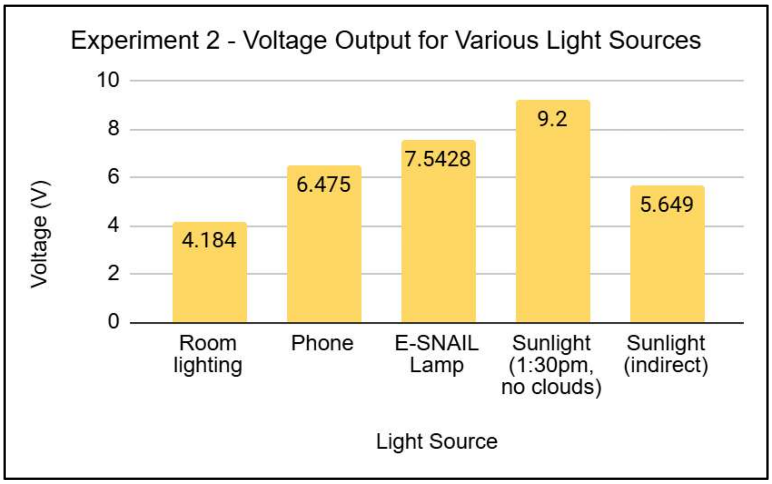

Figure 2. Various light sources

The light source that produced the greatest voltage difference was the early afternoon direct sunlight at 9.2 volts. However, for the following experiments we used the E-SNAIL lamp for accessibility to laptop charging ports when running the AD2. Additionally the lamp provided a reliable source without the need for remeasurement or wait due to changes in weather, temperature, etc.

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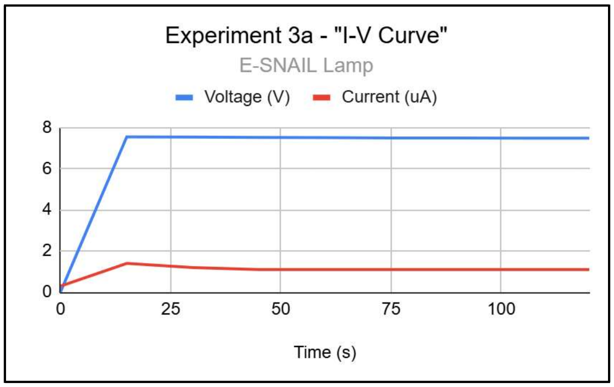
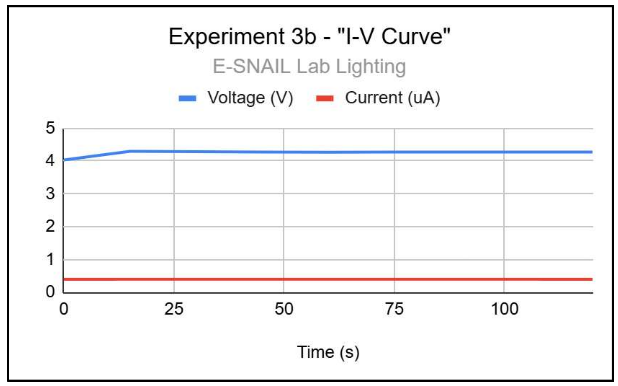
3) At this point you should characterize your solar cell in LIGHT. Under the light source that provided the highest voltage from part 2, again measure the I-V characteristics. You are performing the same process as part 1 (inputting a voltage into the cell and using a multimeter to measure the output). You should see that the current shifts down in the I-V curve. Recalling the LIGHT characterization from class, plot a new I-V curve.





Figures 3 and 4. Solar cell characterization (E-SNAIL Lamp and Lab Lighting, respectively)

Due to the previously stated complications in measuring output current under an applied current, we were instead instructed to measure the stabilization of the voltage and current of the cell under our chosen light (E-SNAIL lamp). After around 45 seconds of exposure, we were able to observe a stable output voltage of around 7.5 volts and 1.1µA of current. This was consistent with our previous measurements and a significant step up from our additional measurements of the ambient room lighting which return 4.2 Volts and 0.4µA

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4) Next connect your cell to the tunable resistor and design a circuit enabling you to measure power delivered to the load. Plot the power delivered to the load as a function of load resistance. Find the optimum load resistance by finding the point where the most power was produced. Then find the optimum efficiency of your solar cell. Repeat the measurements under a different light intensity and replot your data.

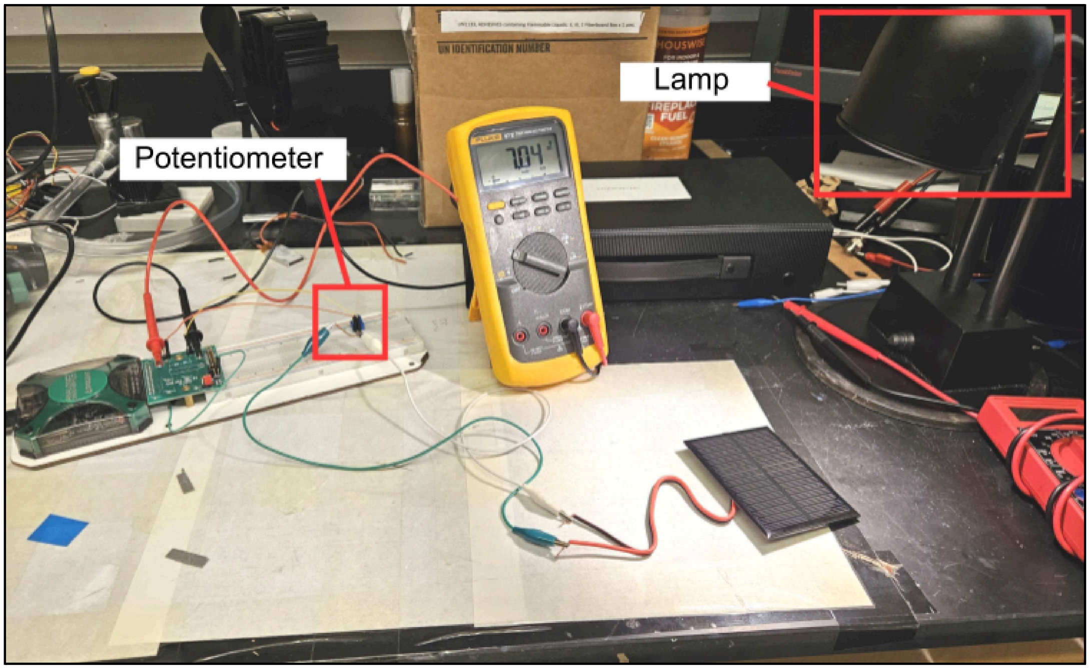
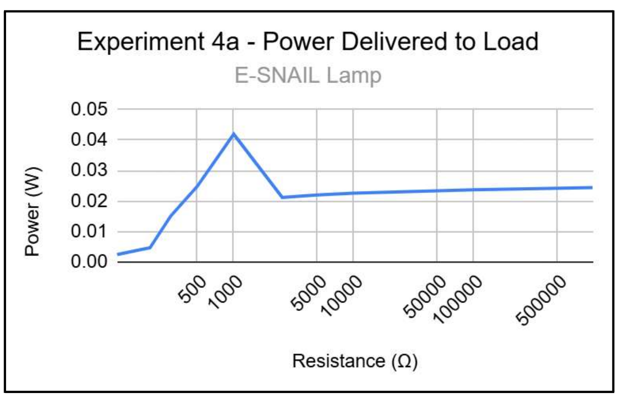
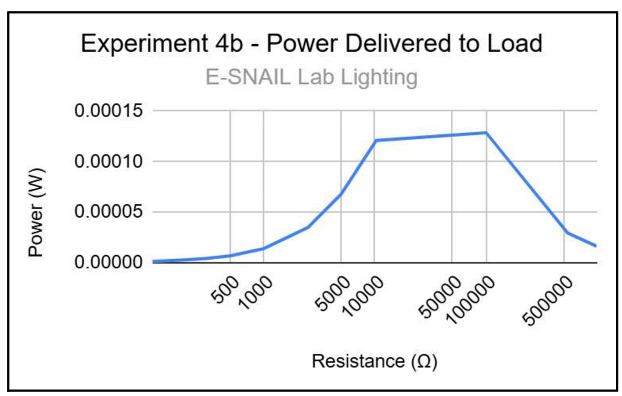


Figure 5. Setup - Solar cell power delivered (E-SNAIL Lamp)





Figures 6 and 7. Solar cell power delivered (E-SNAIL Lamp and Lab Lighting, respectively)

The calculations for optimum efficiency are listed on the following page.

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4) continued.

Experimental maximum power produced:

$$P_{produced} = 0.0420\ W$$

Calculate E_lamp using the proportion of the voltage generated times E_sun:

$$E_{lamp} = \frac{V_{lamp}}{V_{sun}} * E_{sun}$$

$$E_{lamp} = \frac{7.54\ V}{9.2\ V} * 1000\ \frac{W}{m^2} = 819\frac{W}{m^2}$$

Calculate A_solarcell using the manufacturer dimensions:

$$A_{solar\ cell} = 90mm * 70mm = 0.0063m^2$$

Calculate P_theoretical:

$$P_{theoretical} = E_{lamp} * A_{solar\ cell}$$

$$P_{theoretical} = 819\frac{W}{m^2} * 0.0063m^2 = 5.163W$$

Calculate optimum efficiency:

$$\eta_{optimum} = \frac{P_{produced}}{P_{theoretical}}$$

$$\eta_{optimum} = \frac{0.0420\ W}{5.163\ W} = 0.81\%$$ optimum experimental efficiency

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5) Calculate the ideal efficiency of your solar cell under solar light from the point where you measured the highest power. Then compare your ideal efficiency to the efficiency you measured. How different are the efficiency measurements? Explain.

Calculation for ideal efficiency:

$$\eta_{ideal} = 1780 * \frac{V_g}{T} \int_{\frac{qV_g}{K_B T}}^{\infty} \frac{x^2}{e^x - 1} dx$$

Calculate lower limit assuming monocrystalline solar panel is made from silicon:

$$q * V_g = E_g(silicon) = 1.12eV$$

$$K_B = 8.617 * 10^{-5} \frac{eV}{K}$$

$$T_{lamp} = 5500K \ (estimation)$$

$$\frac{qV_g}{K_B T} = \frac{1.12eV}{(8.617*10^{-5} \frac{eV}{K})(5500K)} = 2.363$$ lower limit

Calculate n_ideal using Appendix A:

$$\eta_{ideal} = 1780 * \frac{V_g}{T} * X_{solar\ cell}$$

$$\eta_{ideal} = 1780 * \frac{1.12eV}{5500K} * 0.3$$

$$\eta_{ideal} = 10.87\%$$ ideal efficiency

Comparison to optimum:

$$\eta_{optimum} = \frac{0.0420\ W}{5.163\ W} = 0.81\%$$ optimum experimental efficiency

The ideal and optimum efficiencies calculated are different by two orders of magnitude. Both calculated efficiencies are lower than the Shockley-Queisser maximum theoretical limit for efficiency.

The ideal efficiency may be too high based on the estimated temperature of the light bulb used for the experiment. Lowering the temperature of the lightbulb would result in a much smaller ideal efficiency due to the new “lower limit” for the calculation being outside of the range of the Appendix A table.

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6) Use the I-V characteristics to find the number of photons per second that are absorbed by your solar cell during your experiment. (Hint: Use the equation involving short-circuit current.)

$$I_{\upsilon} = I_{sc} = q * \Phi_g * A$$

Since Φ_g is photon flux density (photons per second per unit area) all that is needed is to solve for $\Phi_g * A$:

$$\Phi_g * A = \frac{I_{sc}}{q} = \frac{1.1\mu A}{1.602*10^{-19}C} = 6.866 * 10^{12} \text{ photons per second}$$

Our circuit used for question 4 and pictured in Figure 5 is shown below. It is modeled as a current source and diode in parallel representing the SC20072 solar cell, which is in turn connected in parallel to our potentiometer. It should be noted that the cell is modeled ideally in which there is no internal resistance, or R_s = 0 Ω.

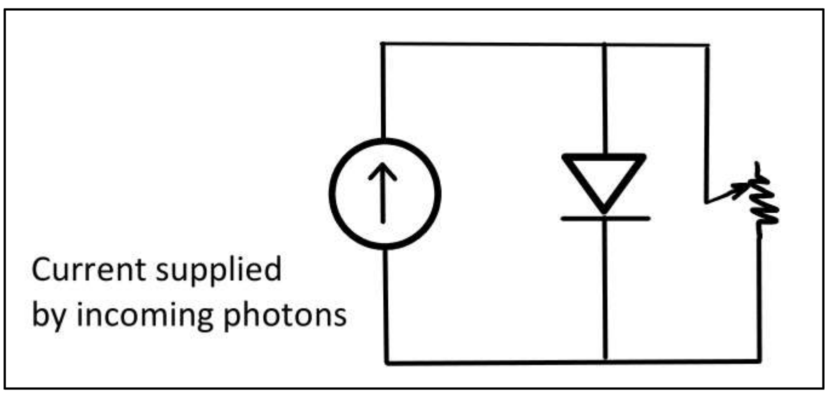

Figure 8. Solar cell circuit

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7) Reflections and Improvements

Direct sunlight produces the highest open circuit voltage of (9.2V) but it is inconsistent however the E-SNAIL lamp is a reliable source producing (7.2v and 1.1μA) making it more ideal for power and efficiency calculations. From the power delivery experiments, we observed the maximum power output to be around 42 mW at an optimal load of 1 kΩ, resulting in an experimental efficiency of 0.81%. When compared to the ideal efficiency of 10.87%, the error is very high. We likely mismeasured because there wasn't an accurate way to measure quickly enough for the small inconsistency. On top of that there are real life application differences vs ideal.

Our initial attempts to generate varying current responses using the AD2 power supply in both dark and light environments were inconsistent. As a result, we adapted our approach and instead focused on recording stabilized voltage and current values over time, for the IV curve. Lastly when measuring for our load when changing the resistance the voltages and current would very quickly fluctuate e and not stabilize at one measurement. In the future we would use more tools to accurately measure the temperature and intensity of the light sources.