Julia Frothingham

Lab 12

Experiment #1: ***If a solar cell is a diode, wouldn't we be able to see that with the LCR meter?***

Figure 1. Solar panel in ambient light read with an LCR meter.

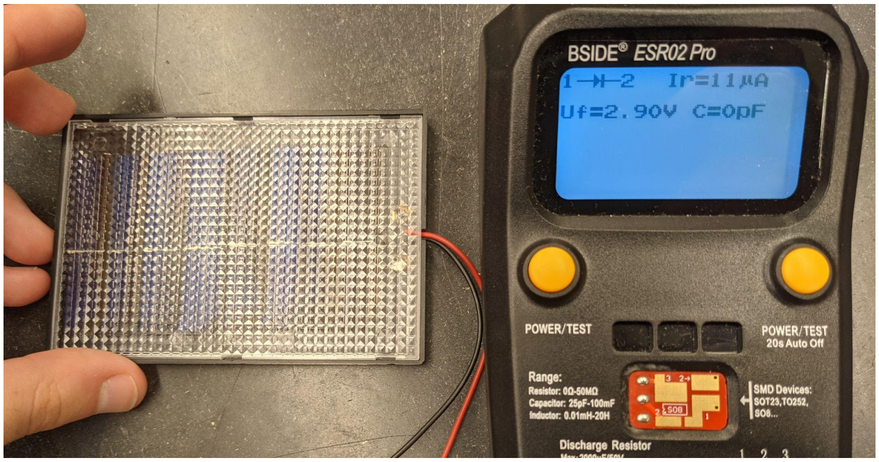
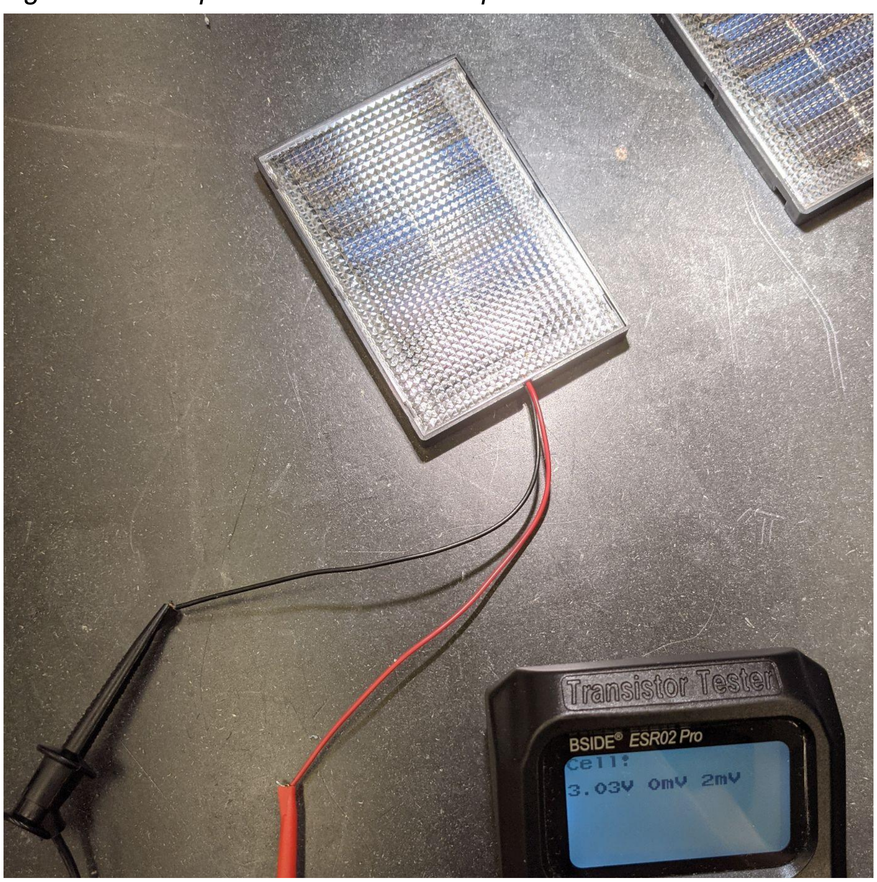


Figure 2. Solar panel under solar lamp read with an LCR meter.



In ambient light, the LCR meter registers the solar panel as a diode with a forward voltage of about 2.9V. However, when the solar panel is lit by a lamp, the LCR meter registers it as a 2.02V power source!

Experiment #2: ***If a solar cell is a diode, we should be able to make an I-V plot that looks like other diode I-V characteristics.***

Figure 3. Circuit diagram

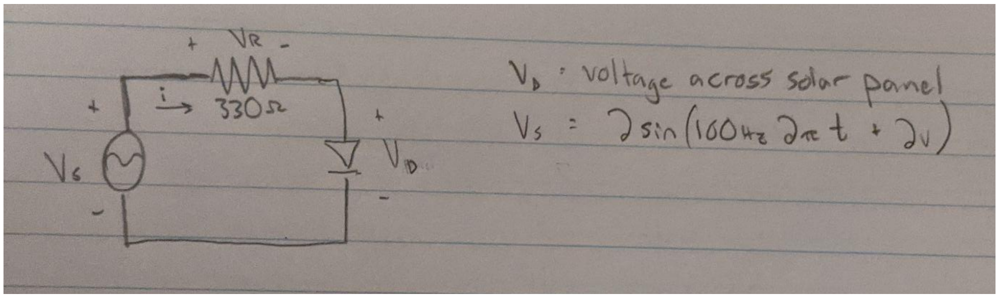
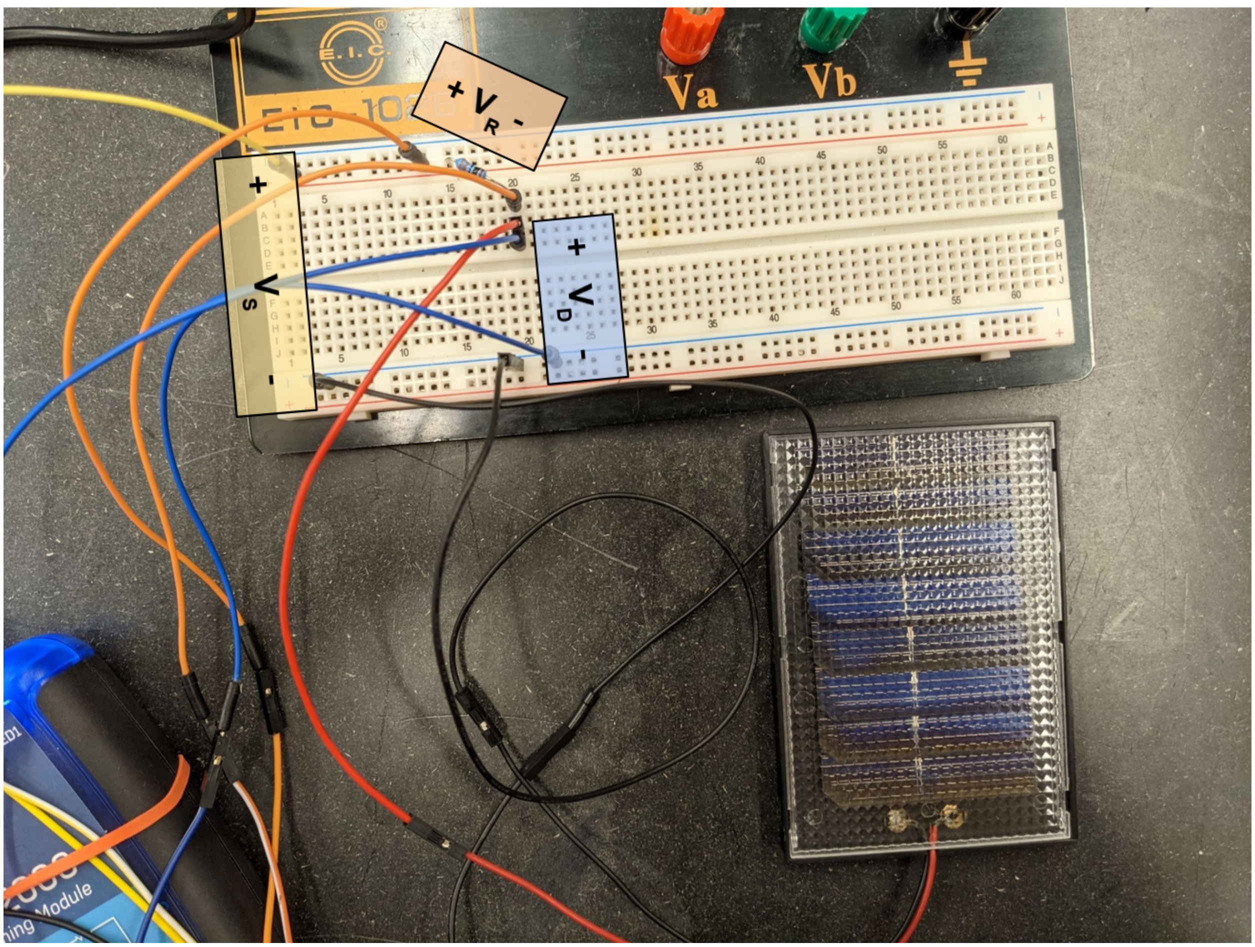


Figure 4. Built circuit.



I used channel 1 of Scopy's wave generator to provide a 4V p-p triangle wave at 100Hz with a 2V offset. I used Scopy's oscilloscope to measure V_R (channel 1) and V_D (channel 2).

Figure 5. Source voltage V_S

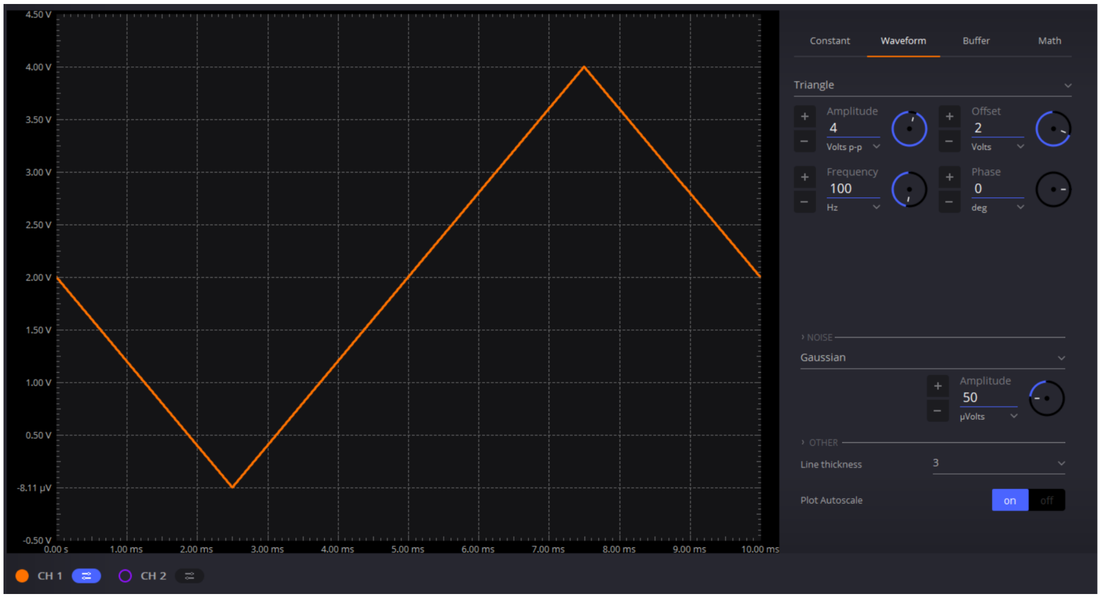
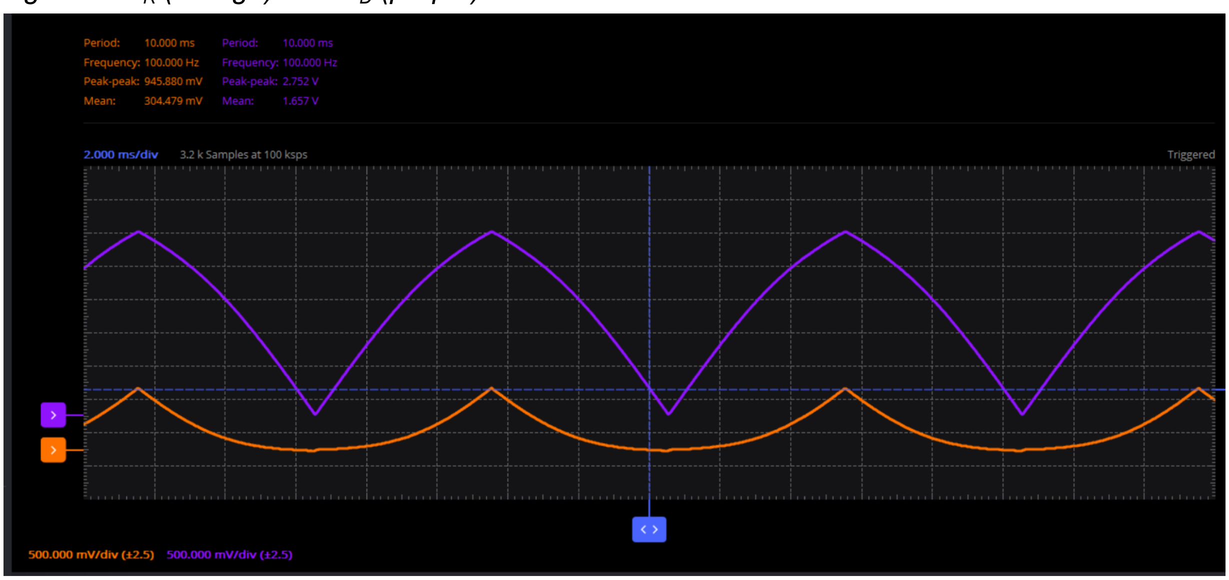
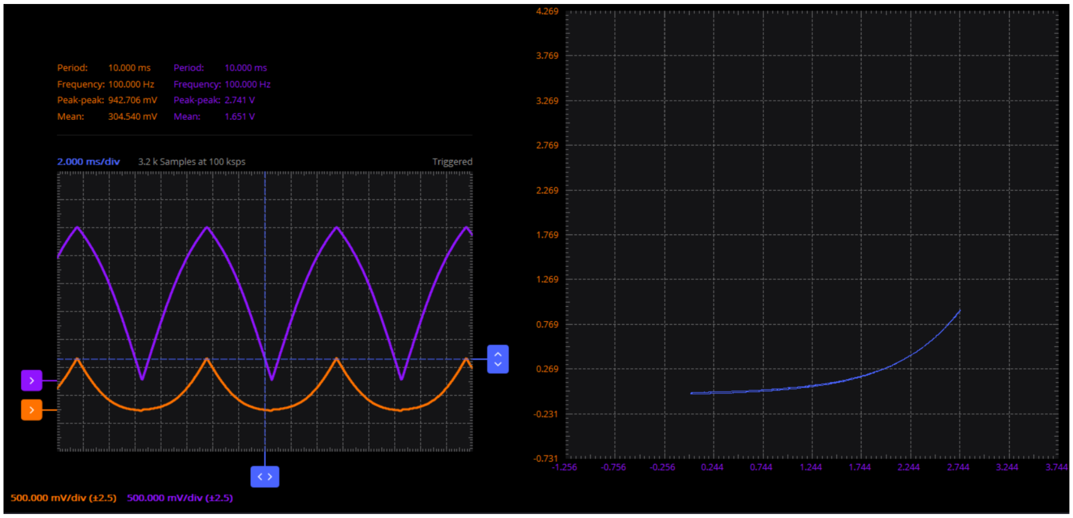


Figure 6. V_R (orange) and V_D (purple)



Using an xy plot of V_R and V_S in the oscilloscope produces the same shape as an I-V characteristic of a diode, since V_R is proportional to I by a constant.

Figure 7. V_R and V_D plotted against each other



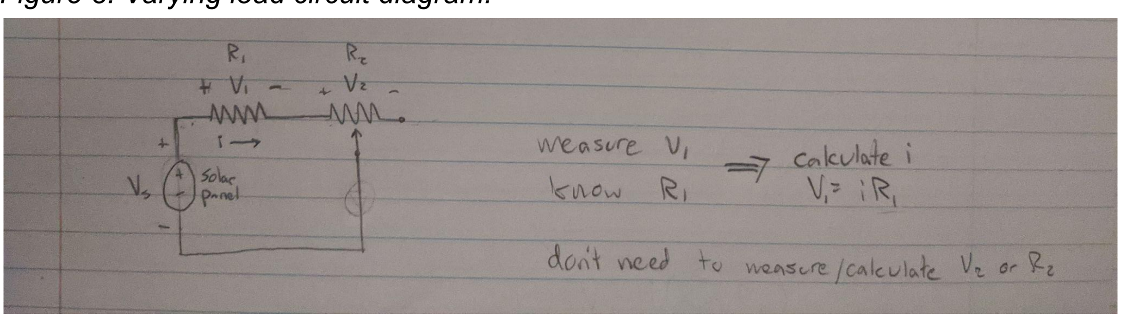
As the ambient light of the room hits the solar cell's surface, the I-V curve gets steeper and moves down and to the right. The voltage across the resistor decreases and the voltage across the panel increases. These changes are documented in this video: https://youtu.be/BY8lIFid_b0

As the brighter light of the lamp hits the solar cell's surface, the same changes as described earlier, but much more dramatically. As the brightness level increased, I had to adjust the axis scaling of the oscilloscope to keep the curves visible. Even before the solar cell was directly underneath the lamp, it became too steep to display. These changes are documented in this video: https://youtu.be/KxmhfwRVGIY

Experiment #3: ***If a solar cell can act as a power source, we should be able to make a graph of V vs I to show how much voltage it provides as the amount of current delivered increases.***

A variable resistor in series with the solar cell can be used to vary the load on the solar cell. By changing the total resistance of the circuit, the amount of current flowing also changes. To measure these changes, the circuit contains a constant-value resistor in series with a variable resistor and a solar cell as a power source.

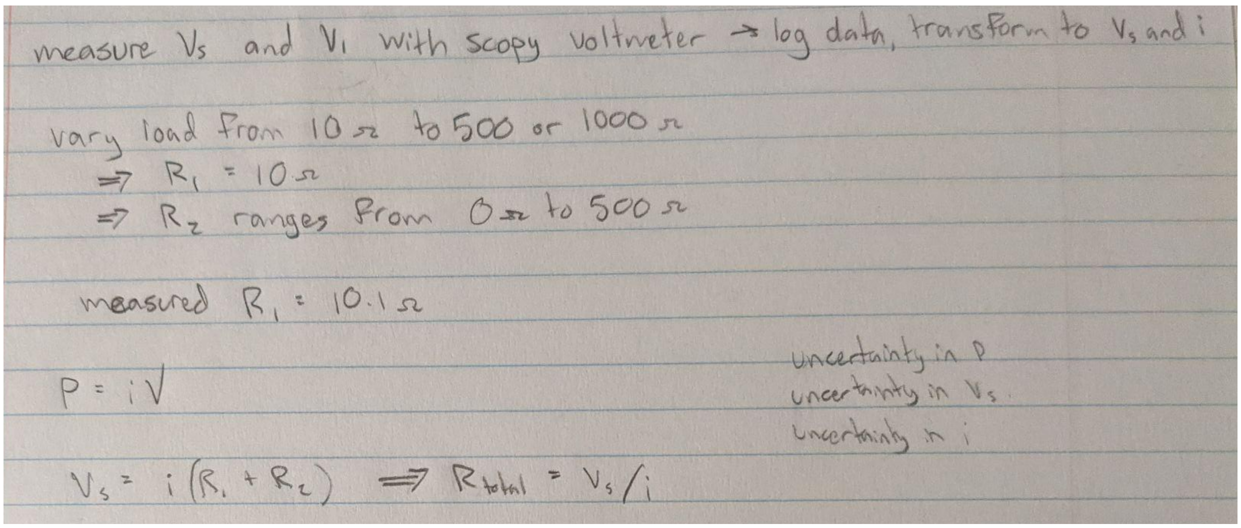
Figure 8. Varying load circuit diagram.



Using the data logging feature of Scopy's voltmeter, V_1 across the constant-value resistor and V_S across the solar cell were measured and recorded as the resistance of the variable resistor was adjusted with a screwdriver.

For R_1=10 Ohms, the minimum total resistance of the circuit = R_1+R_2 = 10 Ohms. For R_1=10 Ohms and R_2 varying up to 500 Ohms, the maximum total resistance of the circuit = R_1+R_2 = 510 Ohms.

Figure 9. Plans for necessary circuit components



measure V_s and V_1 with Scopy voltmeter → log data, transform to V_s and i

vary load from 10 Ω to 500 or 1000 Ω

⇒ $R_1 = 10\ \Omega$

⇒ R_2 ranges from 0 Ω to 500 Ω

measured $R_1 = 10.1\ \Omega$

$P = iV$

uncertainty in P

uncertainty in V_s

uncertainty in i

$V_s = i(R_1 + R_2) \Rightarrow R_{total} = V_s / i$

Figure 10. Built varying-load circuit.

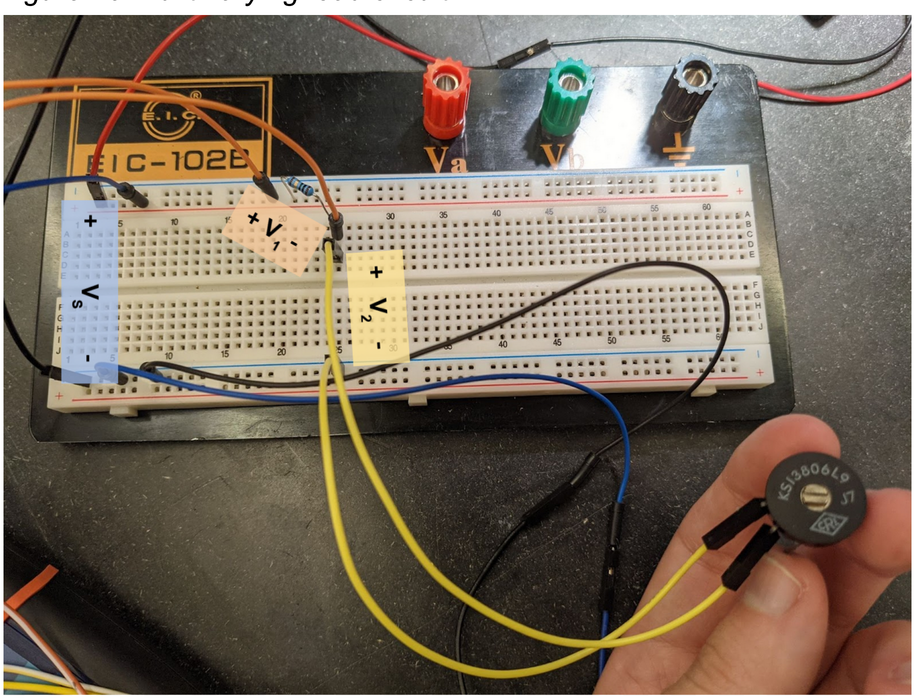
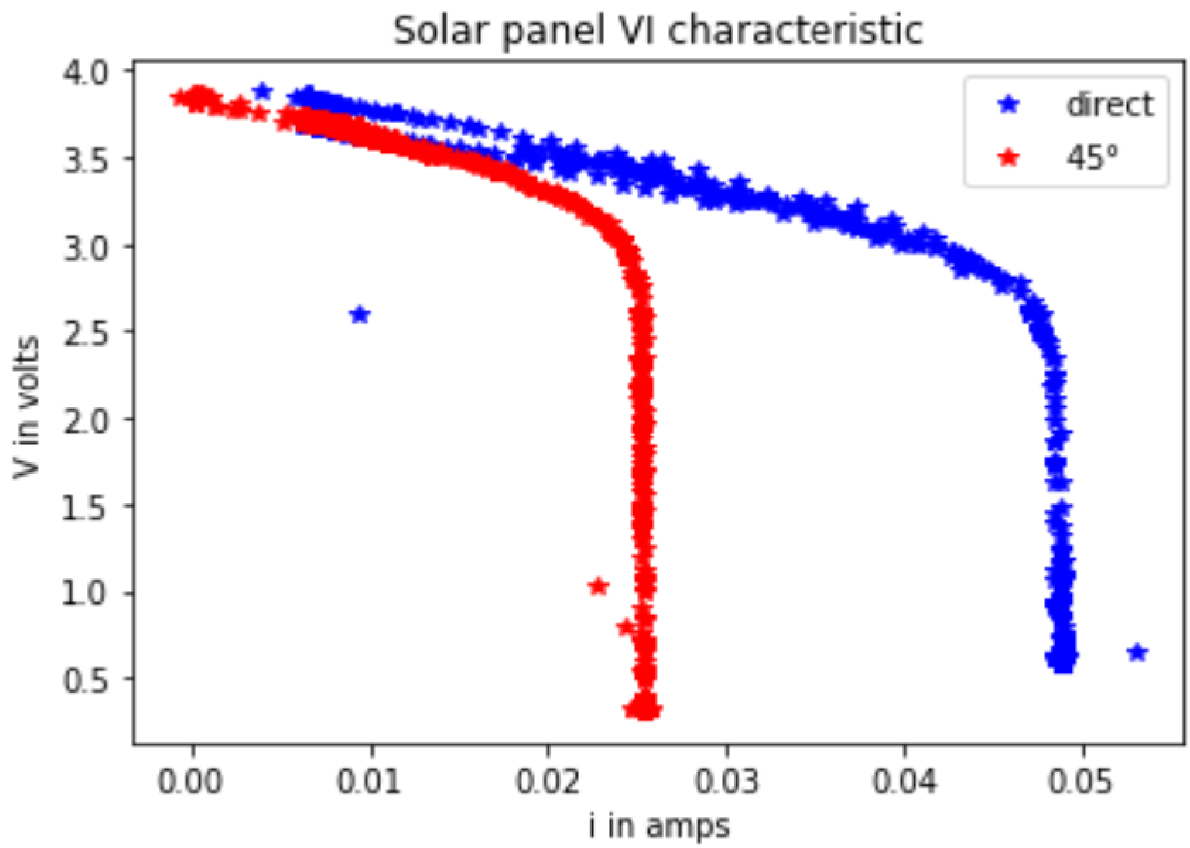
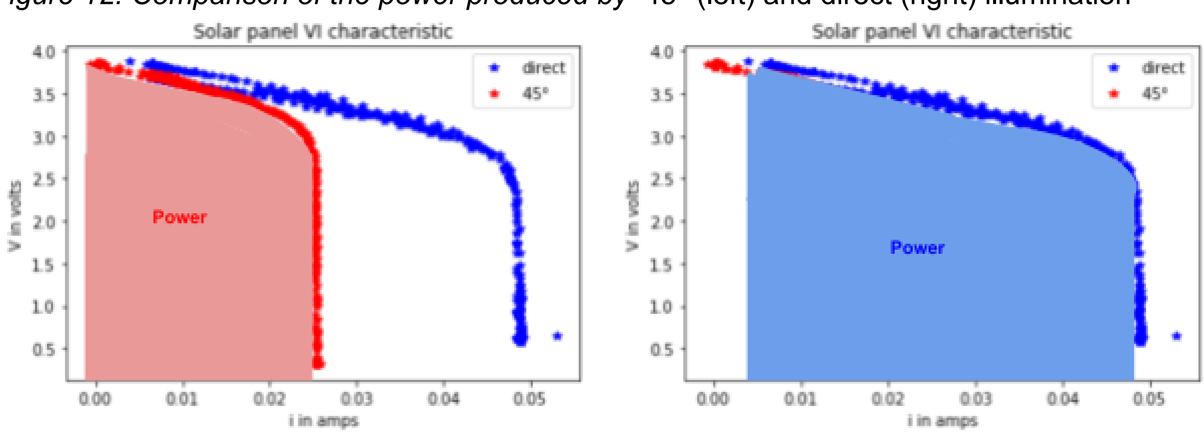


Figure 11. VI characteristic for solar cell under direct lamplight and lamplight at a 45° angle



P = IV. So a power source like this will produce maximum power in conditions where the product of I and V, or the area under the VI characteristic, is greatest. The area under the VI characteristic increases as the current range increases. For the cell illuminated by light at a 45° angle, there's a sharp drop-off point at about 0.025 amps. It does not supply voltage for currents higher than that. For the cell under direct illumination, the drop-off point is just under 0.05amps. It supplies voltage for a wider range of currents.

Figure 12. Comparison of the power produced by 45° (left) and direct (right) illumination



The solar cell will produce the most power when illuminated directly.

Python code was used to calculate the power and equivalent resistance of the circuit under each illumination condition, direct and tilted. Using the definition of power, P = IV. The current has already been calculated, and the power across the cell was measured.

Figure 13. Python code for calculations and plots.

```python
# import statements
import matplotlib.pyplot as plt
import numpy as np
```

```python
# collected data
data_d = np.loadtxt('direcct_illumination_data.csv', skiprows=1, delimiter=',')
vr_d = data_d[:,0]    # volts
vs_d = data_d[:,1]    # volts

data_t = np.loadtxt('tilted_illumination_data.csv', skiprows=1, delimiter=',')
vr_t = data_t[:,0]    # volts
vs_t = data_t[:,1]    # volts
```

```python
# calculataions
i_d = vr_d / 10.1     # amps
p_d = i_d * vs_d      # watts
Req_d = vs_d / i_d    # ohms

i_t = vr_t / 10.1     # amps
p_t = i_t * vs_t      # watts
Req_t = vs_t / i_t    # ohms
```

```python
# VI characteristic plot
plt.title('Solar panel VI characteristic')
plt.ylabel('V in volts')
plt.xlabel('i in amps')
plt.plot(i_d,vs_d, 'b*', label='direct')
plt.plot(i_t,vs_t, 'r*', label='45$\degree$')
plt.legend()
```

```python
# Power vs resistance plot
plt.title('Solar panel P vs R')
plt.xlabel('R in Ohms')
plt.ylabel('P in Watts')
plt.semilogx(Req_d,p_d, 'b*', label='direct')
plt.semilogx(Req_t,p_t, 'r*', label='45$\degree$')
plt.legend()
```

Figure 14. P vs R for solar cell under direct lamplight and lamplight at a 45° angle.

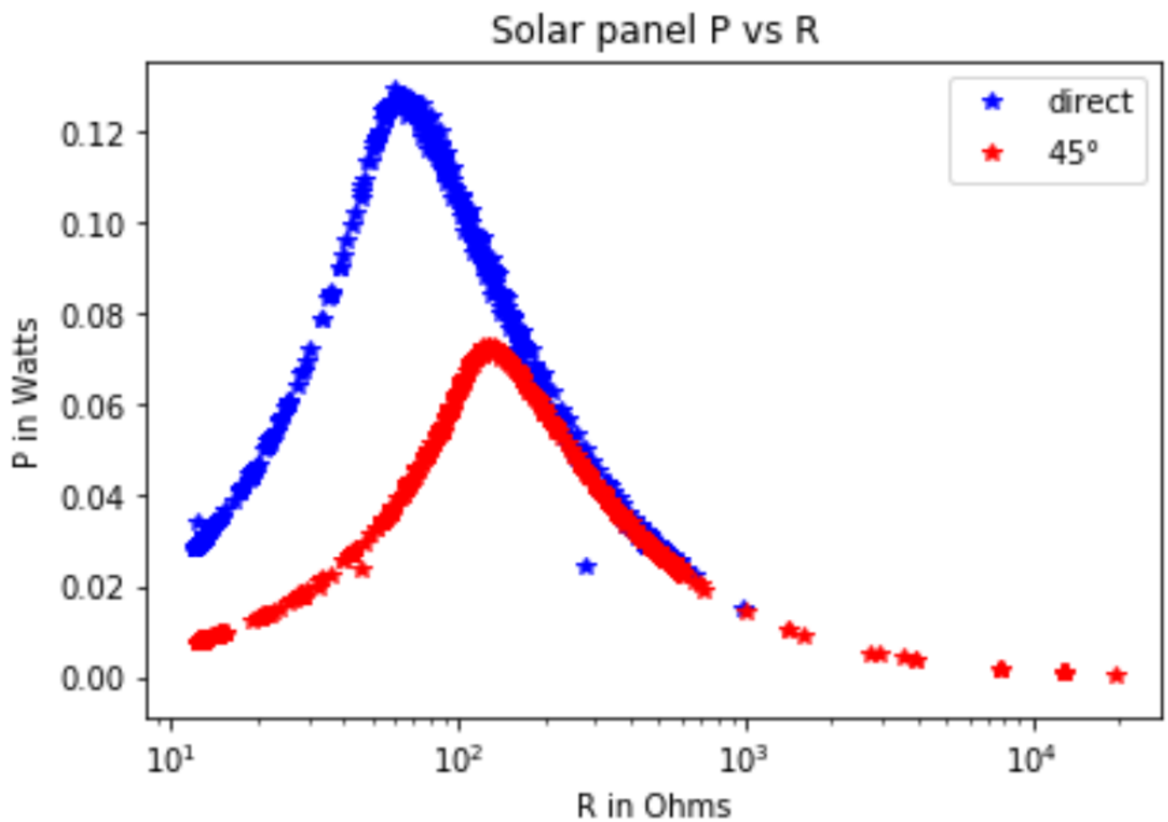


Figure 15. Python code calculating peak power and required resistance values.

```
peak_power_d = np.max(p_d)
peak_index_d = np.where(p_d == peak_power_d)
peak_res_d = float(Req_d[peak_index_d])
print('peak power, direct illumination:', np.round(peak_power_d,3), 'W at R =', np.round(peak_res_d,3), 'Ohms')

peak_power_t = np.max(p_t)
peak_index_t = np.where(p_t == peak_power_t)
peak_res_t = float(Req_t[peak_index_t])
print('peak power, 45 deg. illumination:', np.round(peak_power_t,3), 'W at R =', np.round(peak_res_t,3), 'Ohms')
```

```
peak power, direct illumination: 0.129 W at R = 59.59 Ohms
peak power, 45 deg. illumination: 0.073 W at R = 133.697 Ohms
```

The plot and the calculations support the prediction that maximum power is produced when the solar cell is under direct illumination rather than illuminated from an angle. This makes sense. It means that every diode in the cell is receiving all possible energy, so the conductivity of the cell increases the most. This matches the trend shown on the P vs R graph - the higher peak power value is associated with a lower resistance value. Lower resistance means more current flowing, and since power is proportional to current, more current means more power.