EE 236: Experiment No. 4
Temperature Dependence of Solar Cell Characteristics

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1 Overview of the experiment

1.1 Aim of the experiment

The following were the aims of the experiment:

- To plot and measure the I-V and P-V characteristics of a solar cell under different temperatures and find *fill factors*.
- To plot and measure the I-V characteristics of a solar cell for different values of series and shunt resistances.

1.2 Methods

The method overview includes constructing circuit netlists according to the given circuits in the previous handouts for each part, simulating them using *dc* analysis and calculating required parameters for all parts. The first two parts required us to plot the I-V Characteristics of a solar cell while the second part also required us to plot the Power-voltage characteristics and calculating fill factors. Third part included plotting I-V and P-V characteristics for different values of series and shunt resistances and calculating fill factors.

2 Design

2.1 Part 1

The netlist for each of the five cases: temperature = {35°C, 45°C, 55°C, 65°C, 75°C}, described below, included a dedicated 100Ω resistor, and the solar cell with the input voltage and was written according to the following circuit.

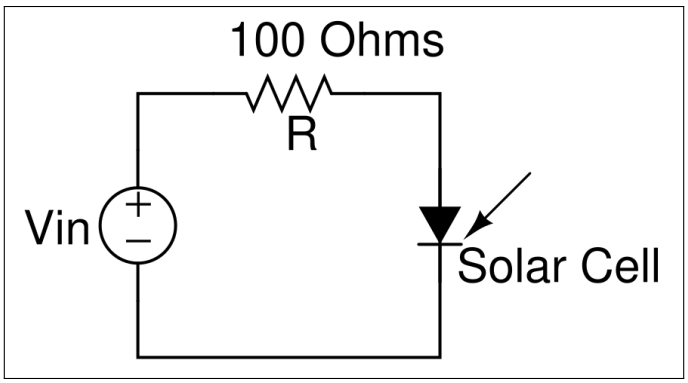


Figure 1: The I-V Characterization Circuit

DC analysis was performed by varying V_{in} from -2V to 2V in steps of 0.01V to obtain the I-V characteristics. The ideality factor, η, was found using the following equation:

$$\frac{ln(I_{D2}) - ln(I_{D1})}{V_{D2} - V_{D1}} = \frac{1}{\eta V_T}$$

2.2 Part 2

In this part, the solar cell was used as the power source. The illumination level was chosen as $IL = 8$ mA. The netlist is simple with just the solar cell and load resistor.

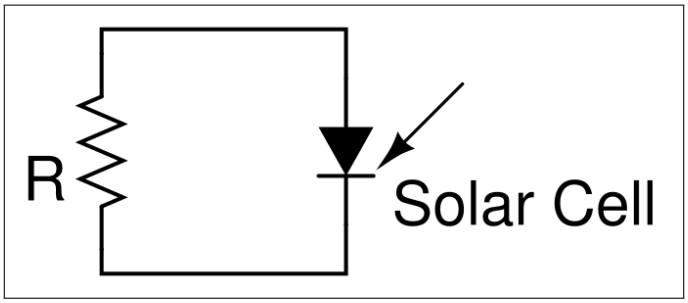


Figure 2: I-V Characterization Circuit

DC analysis was performed by varying the load resistance from 1 to 500 Ω in steps of 0.1 Ω. $I_D - V_D$ and $P_R - V_D$ characteristics were plotted, where $P_R = I_R * V_R$. The short-circuit current, I_{SC}, and open-circuit voltage, V_{OC}, were obtained from the former graph.
Max-power current and voltage, I_{MP} and V_{MP} respectively, were obtained from the graphs. The fill-factor, FF was obtained according to the relation:

$$FF = \frac{I_{MP} * V_{MP}}{I_{SC} * V_{OC}}$$

2.3 Part 3

The circuit used was same as in Part 2. Here, the series resistance, R_S and shunt resistance, R_{SH} were varied in {0, 10, 30} and {500, 1k, 5k} Ω respectively.

3 Simulation results

3.1 Code snippets

3.1.1 Part 1

```
Vinamra Baghel 190010070 IV Characteristics Part 1
.include Solar_Cell.txt
*Netlist
r1 in out1 100
X1 1 gnd solar_cell IL_val = 0
Vd1 out1 1 0
Vin in gnd 0

*Analysis
.dc Vin -2 2 0.01
*.dc Vin -2 2 0.01 temp 35 75 10
.temp 75

.control
run
plot I(Vd1) vs V(1)
meas dc v1 find V(1) when I(Vd1) = 1m
meas dc v2 find V(1) when I(Vd1) = 2m
meas dc v3 find V(1) when I(Vd1) = 5m

meas dc i11 find I(Vd1) when V(1) = 505m
meas dc i12 find I(Vd1) when V(1) = 495m
let il11 = log(abs(i11))
let il12 = log(abs(i12))
let e1 = 10m/(((273+75)/298)*26m*(il11-il12))

meas dc i21 find I(Vd1) when V(1) = 105m
meas dc i22 find I(Vd1) when V(1) = 95m
let il21 = log(abs(i21))
let il22 = log(abs(i22))
let e2 = 10m/(((273+75)/298)*26m*(il21-il22))

print e1 e2
.endc
.end
```

3.1.2 Part 2 and 3

```
Vinamra Baghel 190010070 IV Characteristics Part 2 and 3
.include Solar_Cell.txt
*Netlist
r1 2 1 1
X1 1 gnd solar_cell IL_val = 8e-3
Vd1 2 gnd 0

```

```
*Analysis
.dc r1 1 500 0.01
*.dc r1 1 500 0.01 temp 35 75 10
.temp 35

.control
run
plot I(Vd1) vs V(1)
let Vr = V(2)-V(1)
plot I(Vd1)*Vr vs V(1)
plot I(Vd1)*Vr vs I(Vd1)
let Pr = I(Vd1)*Vr
let P_max = minimum(Pr)
meas dc Vmp find V(1) when Pr = P_max
meas dc Imp find I(vd1) when V(1) = Vmp
.endc
.end
```

3.2 Simulation results

3.2.1 Part 1

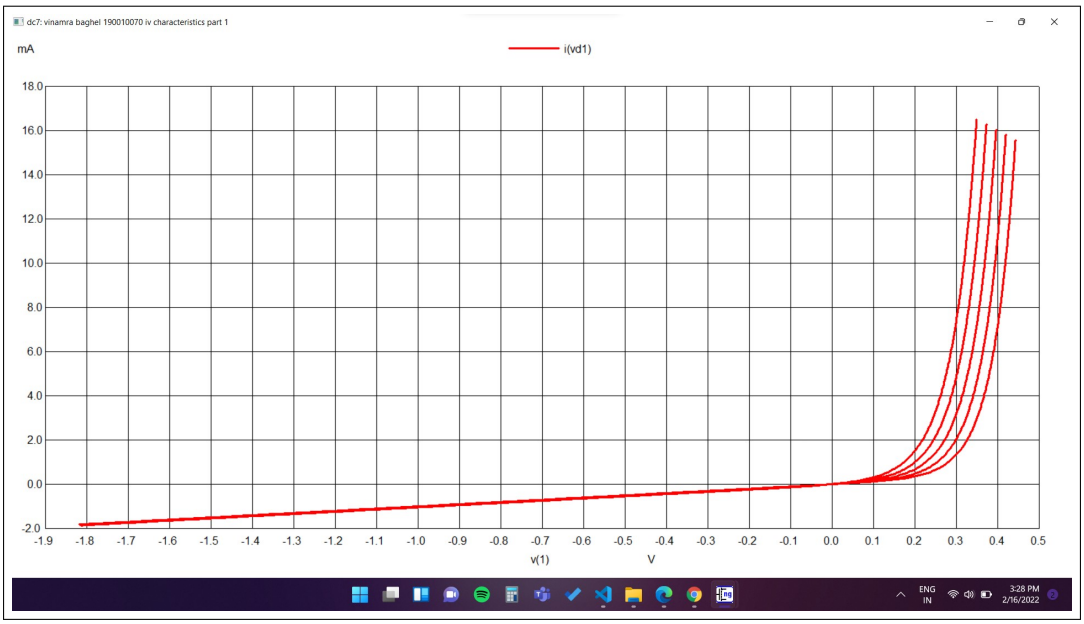
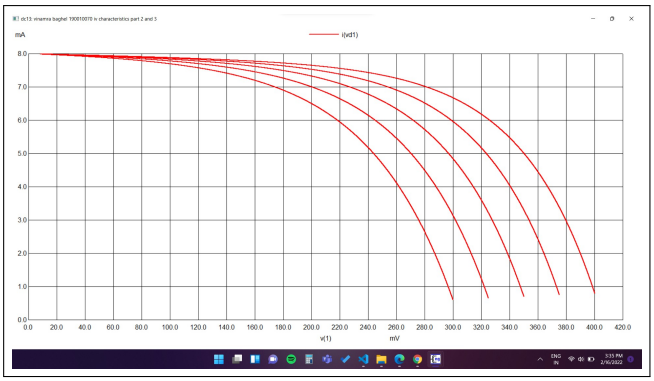


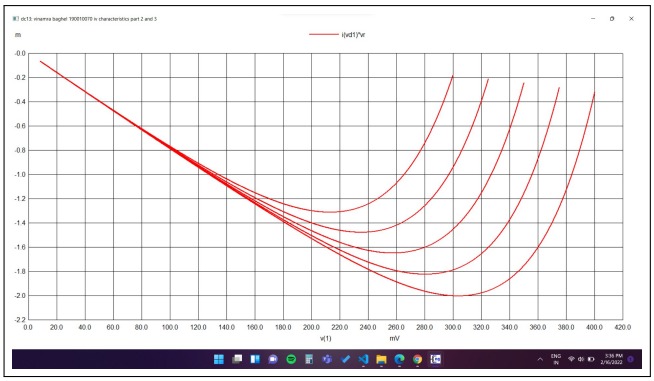
Figure 3: I-V Characteristics

Shown above were the I-V characteristics obtained for the solar cell for the five different temperature levels.

3.2.2 Part 2



(a) $I_D - V_D$ characteristics



(b) $P_R - V_D$ characteristics

Figure 4: Characteristic Plots of Part 2 for different temperature levels

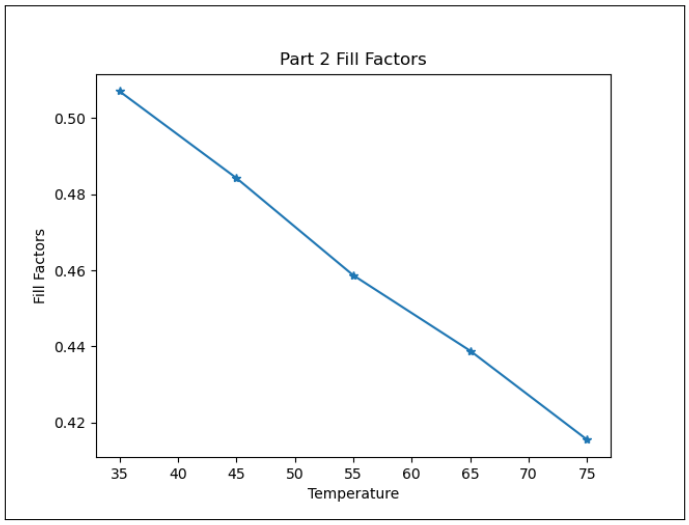
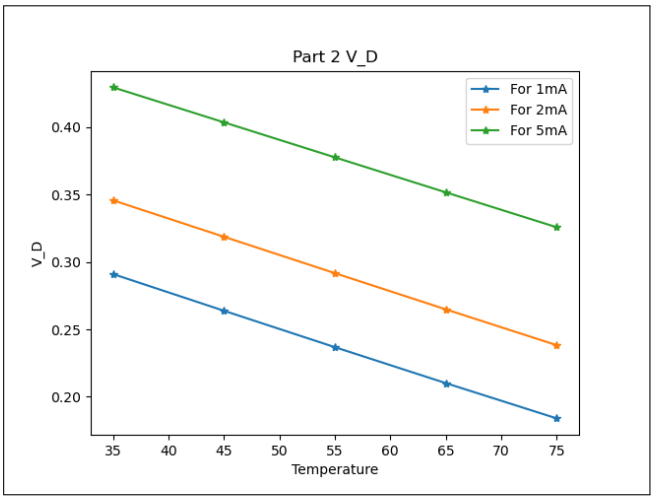
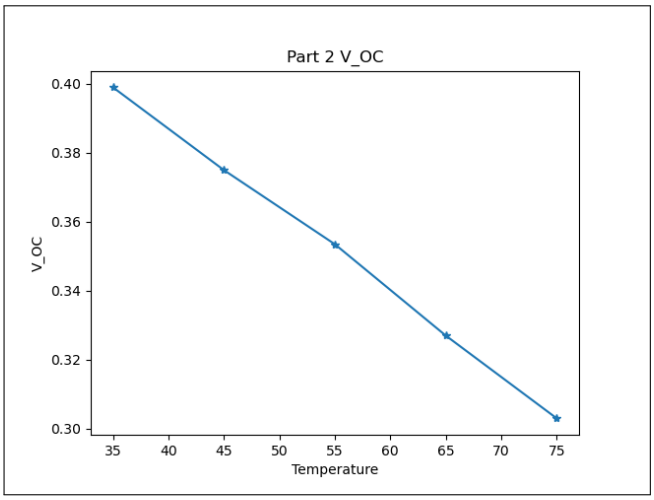


Figure 5: Fill Factors vs Temperature



(a) V_D vs Temperature

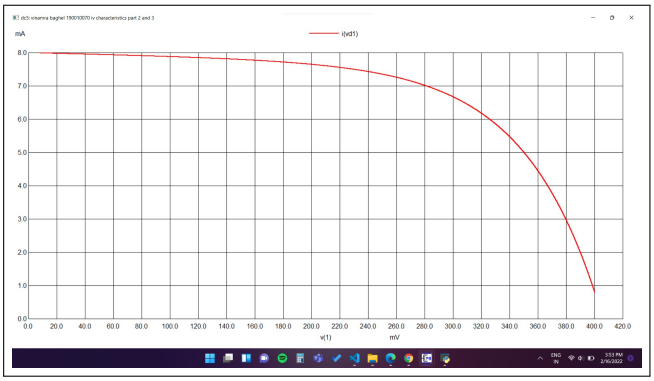


(b) V_{OC} vs Temperature

Figure 6: Voltage vs Temperature

Above are characteristic plots obtained for the circuit in Part 2. The first plot was used to obtain I_{SC} and V_{OC}. Next are the plots of Fill Factors, V_D, and V_{OC} vs Temperature.

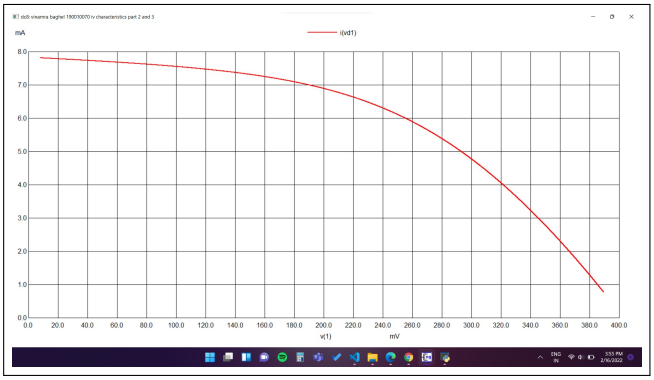
3.2.3 Part 3



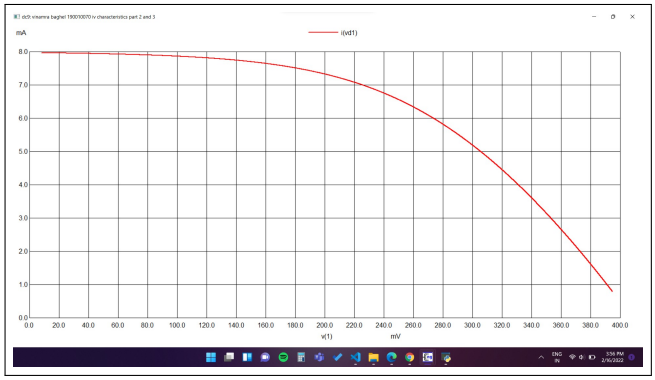
(a) $R_S = 0$ and $R_{SH} = 1k$

(b) $R_S = 30$ and $R_{SH} = 1k$

Figure 7: I-V Characteristics of Part 3 for different series resistance



(a) $R_S = 10$ and $R_{SH} = 500$



(b) $R_S = 10$ and $R_{SH} = 5k$

Figure 8: I-V Characteristics of Part 3 for different shunt resistance

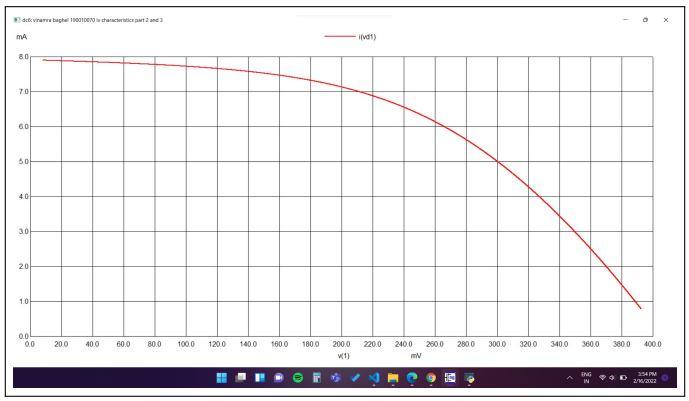
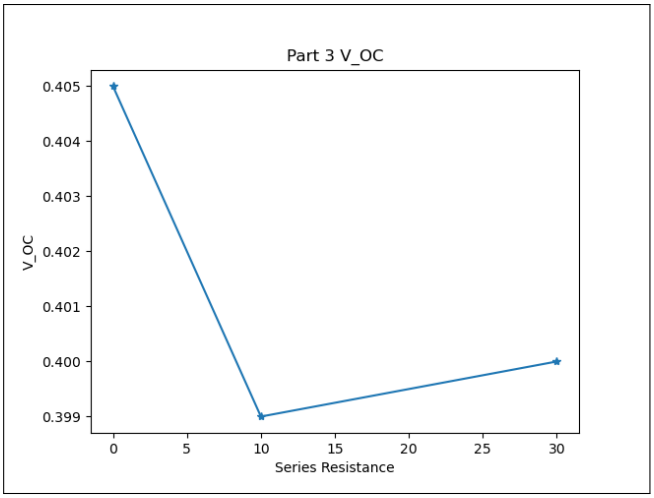
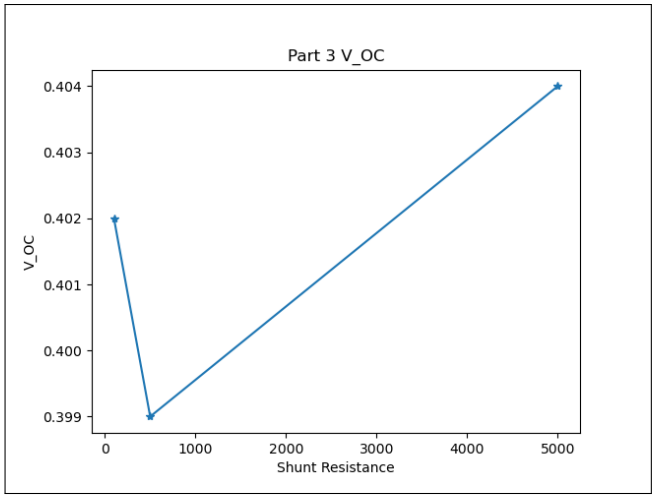


Figure 9: I-V Characteristics of Part 3 for $R_S = 10$ and $R_{SH} = 1k$

Above are plots for I-V Characteristics for different series and shunt resistor values. Below are plots for V_{OC}, I_{SC} and Fill Factors vs resitance.

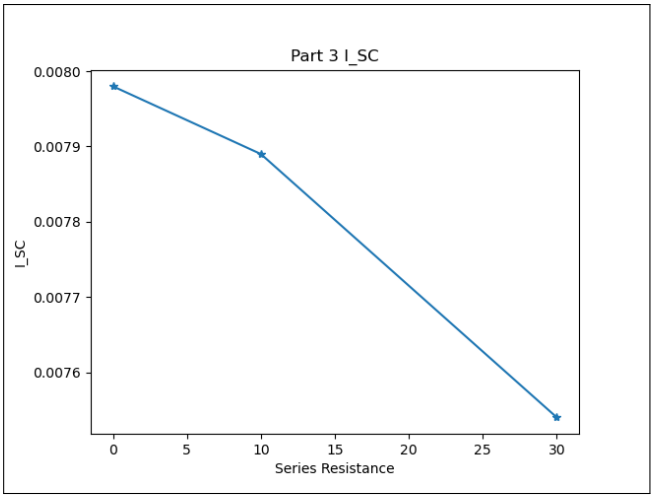


(a) V_{OC} vs Series Resistance

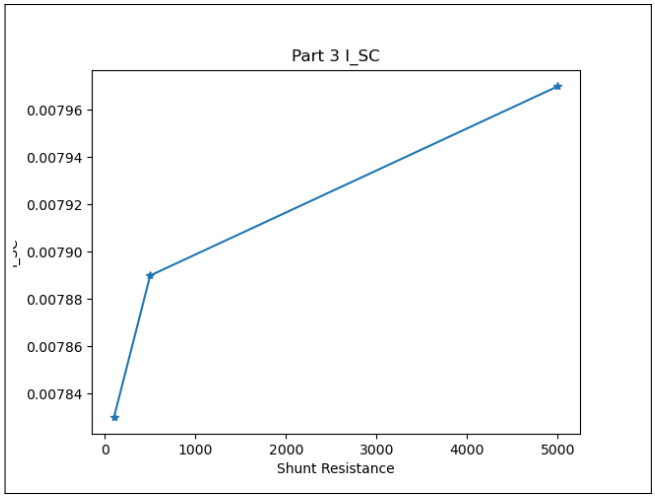


(b) V_{OC} vs Shunt Resistance

Figure 10: V_{OC} vs Resistance

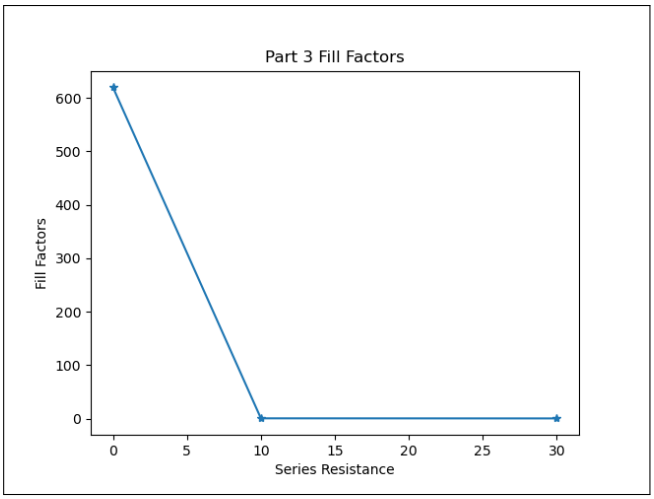


(a) I_{SC} vs Series Resistance

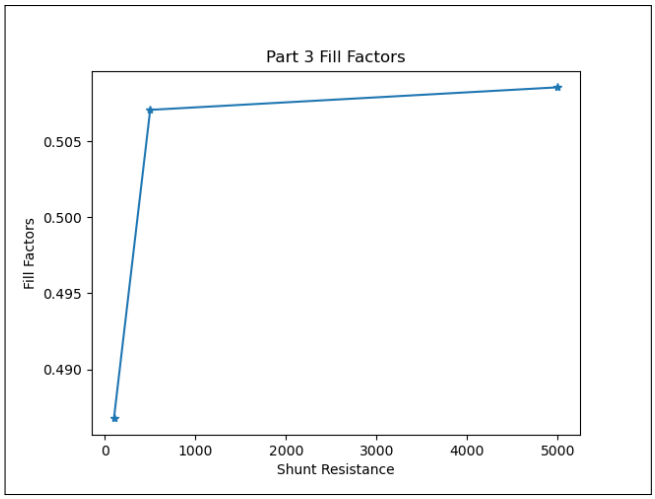


(b) I_{SC} vs Shunt Resistance

Figure 11: I_{SC} vs Resistance



(a) Fill Factor vs Series Resistance



(b) Fill Factor vs Shunt Resistance

Figure 12: Fill Factor vs Resistance

4 Experimental results

Part 1: Voltage and Ideality Factor values vs temperature.

Temperature (in °C)	**V at 1mA** (in mV)	**V at 2mA** (in mV)	**V at 5mA** (in mV)	η **at 1mA** (in V^{-1})	η **at 5mA** (in V^{-1})
35	291.09	345.84	429.68	5.348	3.109
45	263.85	318.77	403.71	5.796	2.759
55	236.81	291.75	377.71	6.241	2.415
65	210.13	264.88	351.72	6.678	2.182
75	183.93	238.28	325.79	6.754	1.996

Part 2: Maximum point voltage and current, open circuit voltage, short circuit voltage, and fill factor vs temperature.

Temperature (in °C)	V_{MP} (in mV)	I_{MP} (in mA)	V_{OC} (in mV)	I_{SC} (in mA)	Fill Factor
35	261.07	6.115	399	7.89	0.507
45	240.47	5.958	375	7.89	0.484
55	220.35	5.784	353.5	7.86	0.459
65	200.85	5.587	327	7.82	0.439
75	182.04	5.366	303	7.76	0.415

Part 3: Maximum point voltage and current, open circuit voltage, short circuit voltage, and fill factor vs resistance.

Resistance (in Ω)	V_{MP} (in mV)	I_{MP} (in mA)	V_{OC} (in mV)	I_{SC} (in mA)	Fill Factor
$R_S = 0$, $R_{SH} = 1k$	303.57	6.597	405	7.98	0.619
$R_S = 30$, $R_{SH} = 1k$	219	4.620	400	7.54	0.335
$R_S = 10$, $R_{SH} = 500$	259.31	5.909	402	7.83	0.487
$R_S = 10$, $R_{SH} = 5k$	262	6.250	404	7.82	0.518
$R_S = 10$, $R_{SH} = 1k$	261.07	6.115	399	7.89	0.507

5 Experiment completion status

I could complete all the parts of the lab. There was no hardware involvement as it was all simulation based. The results were shown to the TA and then submitted.

6 Questions for reflection

Question 1. Comment on the dependence of V_{OC}, I_{SC}, and FF. (Part 2)
From the graphs and observations, it is easy to see that all V_{OC}, I_{SC}, and FF **decrease** with an increase in temperature.

Question 2. How the I/V characteristics of solar cell is affected by the series resistance R_S? (Part 3)
The characteristic plots flatten out as series resistance increases; while the Fill Factor decreases drastically with an increase in series resistance.

Question 3. What is effect of larger values of shunt resistance on the performance of the solar cell? (Part 3)
The difference isn't large but the plot curves more, opposite to the case with series resistance. The Fill Factor increases with increasing shunt resistance, although the change is not as drastic.