Name: ___________Ebagnisev Sahiv LopezBorja_____________________

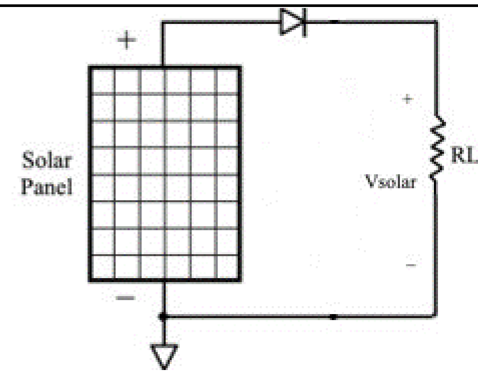
EEE 202 Lab 7 Design Project
DATA SHEET

Part 1 (9 points): Voltage Divider Design

What do you think the purpose of the diode rectifier is in this design?

To make sure we safeguard the controller from being fried if the user connects the solar panel (voltage in) in the reverse direction.

Hand calculations: **consider the circuit as shown (i.e. without R1 and R2). Set the load resistor RL to 1k Ohms and calculate the voltage and current the solar panel can produce over different light conditions. Pick 4 different voltage values; the highest of which corresponds to the Full Sunlight, while the lowest to the Lab Light. Do not forget to consider the voltage drop on the diode.**



Light Condition	Assumed Solar Panel Voltage (V)	Calculated Solar Panel Current (mA)
Full Sunlight	9	9
Shaded Sunlight	5	5
Lab Light Plus Phone Light	3	3
Lab Light	1	1

The CEO of Sparky Solar, Melanie Waters, has told you that the design criteria (in order of importance) are: 1. Availability, 2. Cost, 3. Accuracy. When designing the voltage divider circuit, which set of resistors will you use (1, 2, or 3) and why?

In order to create a safe design that will be able to take a high power rating we will use Set 2. In addition, its accuracy is reasonable and it is available now, thus no delay in production.

Select R1 and R2 to ensure that the value of A1 does not exceed 5V for all light conditions. Calculate the maximum voltage your circuit can feed to Pin A1. Show your work here:

$$V_{Out} = 9V \cdot \frac{R_2}{R_1 + R_2} = 5V \quad \therefore \quad R_1 = 0.80\, R_2$$

Based on our selection of SET 2 we have that R1 = 8k and R2 = 10k

$$V_{Out} = 9V \cdot \frac{10k\Omega}{8k\Omega + 10k\Omega} = 5V$$

R1 (Ohms) (Make sure it is in your stock)	R2 (Ohms) (Make sure it is in your stock)	Max Voltage in to Pin A1 (V)
8k	**10k**	**5V**

Which light condition should be considered when selecting R1 and R2 and why?

Full Sunlight of 9V should be considered as this is when the highest Vout will be produced that will exit to the controller input A1.

In this setup I have ignored the Diode Rectifier's voltage, so this actually means that the max voltage along the Pin A1 will be around 4.61V (considering a 0.7V Diode as 9V-0.7V will result in 8.3V effectively across the Voltage Divider and Rload.)

If your customer asked you to purchase another solar panel with a higher voltage, what is the <u>maximum voltage</u> that such a solar panel can have without exceeding the power rating of your selected R1 and R2? Assume your resistors are ¼ W resistors. ***(Note: If such voltage happens to exceed the voltage corresponding to the Full Sunlight condition you specified above, you will need to reselect your R1 and R2 values to use them with the solar panel you have at hand).***

$V_{R_1} = V_{Solar} - V_{R_2}$ ***and*** $V_{R_2} = V_{A_1}$

For Power across R1 we calculate the following way:

$$P_{R_1} = \frac{\left(V_{solar}\cdot\frac{R_1}{R_1+R_2}\right)^2}{R_1} = 0.25W \therefore$$

$$V_{Solar}^{2} = \frac{0.25\,W\cdot R_1}{\left(\frac{R_1}{R_1+R_2}\right)^2}$$

$$\therefore V_{Solar} = \sqrt{\frac{0.25\,W\cdot 8k\Omega}{\left(\frac{8k\Omega}{8k\Omega+10k\Omega}\right)^2}} = 100.623\,V$$

Similarly for R2 we have:

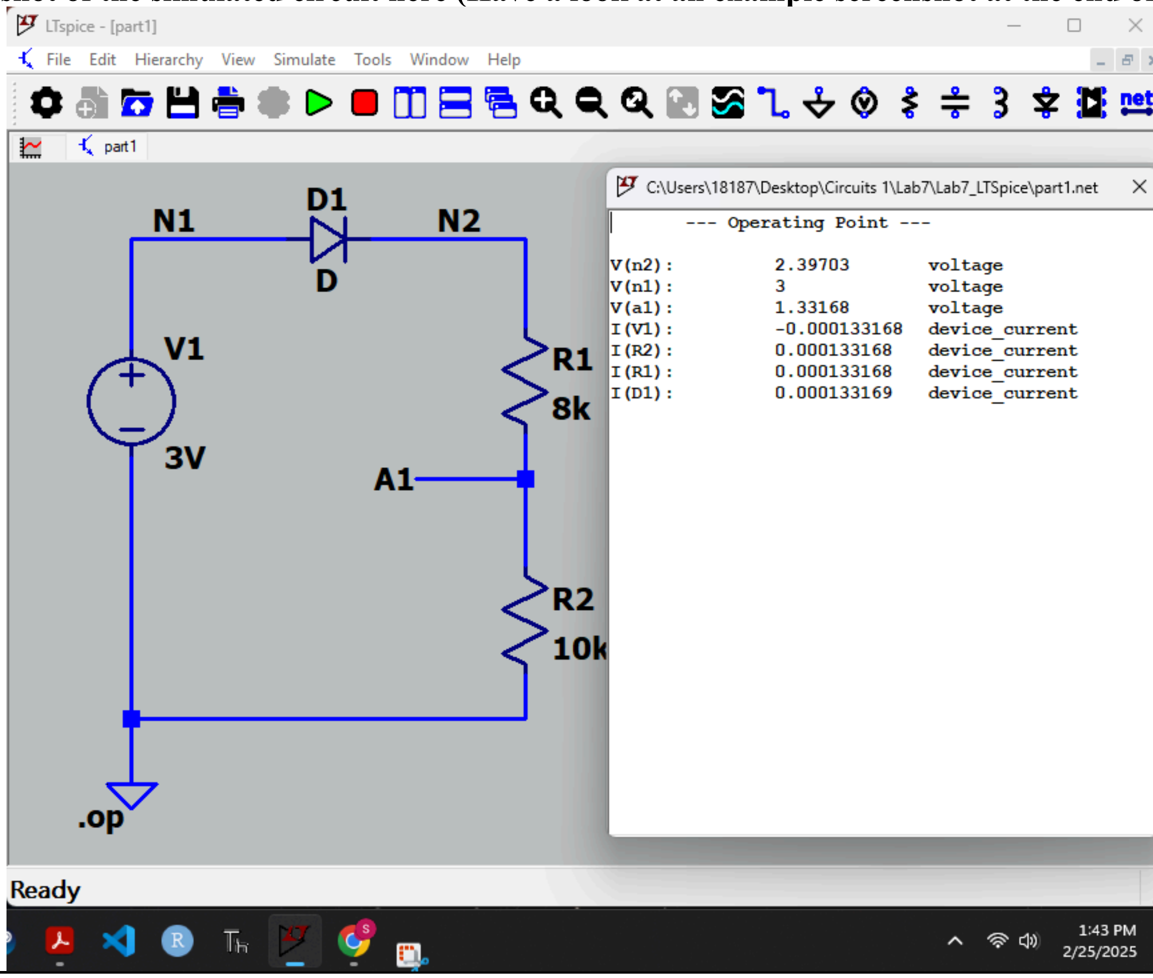
$$V_{Solar} = \sqrt{\frac{0.25\,W\cdot 10k\Omega}{\left(\frac{10k\Omega}{8k\Omega+10k\Omega}\right)^2}} = 90\,V$$

Max voltage for

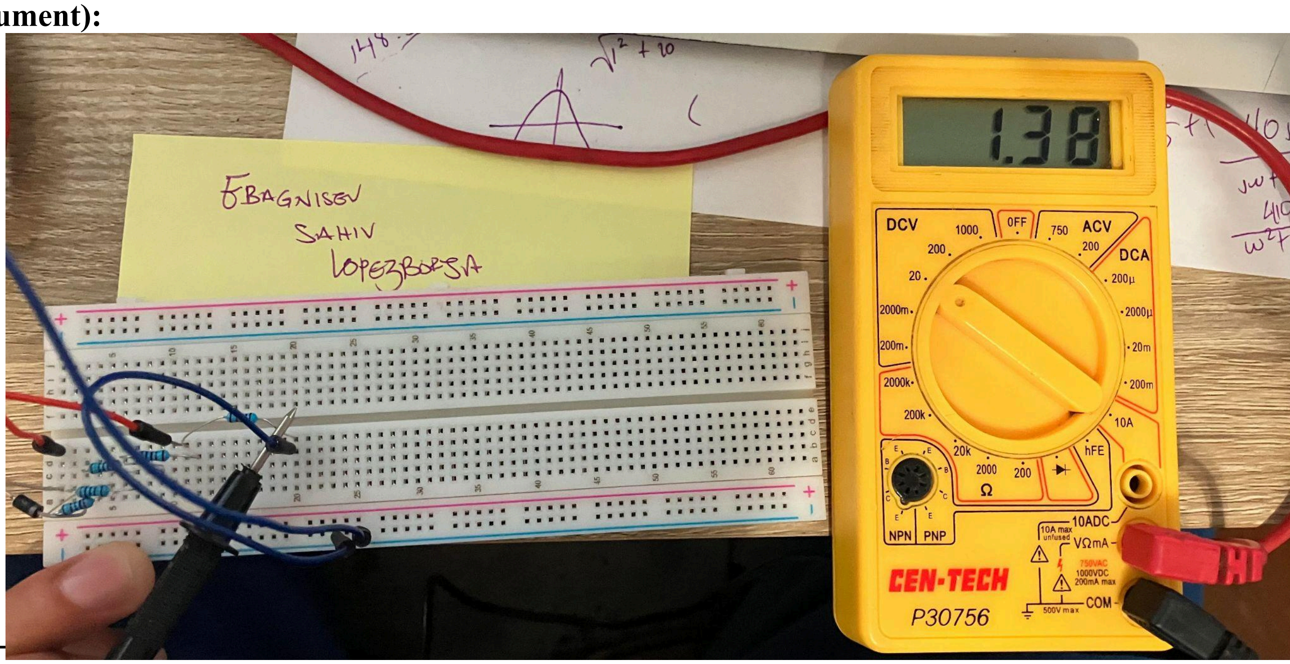
- **R1: 100.623 V**
- **R2: 90 V**
- **V_{solar} (V): 90 V**

Simulations: Create a simulation of your Voltage Divider circuit in LTSPICE or TinkerCAD. Choose one of the sunlight conditions you used above in your simulations. Mention which one you chose.

Include a screenshot of the simulated circuit here (Have a look at an example screenshot at the end of this document):



Hardware: Build the circuit you simulated above.
Include a photo of your hardware circuit here (Have a look at an example photo at the end of this document):



Do your measured Voltage Divider results (V of R2) from your built circuit match your simulated results? How much error are you seeing? What are some possible reasons for the difference in the real and theoretical results? Choose one of the sunlight conditions you used above to compare your results. Mention which one you chose.

Chosen Test Voltage for Comparison: 3V (DC - Supply from V+ using ADK3)

Well, my setup has 4, 20k Ohm resistors in series to account for R1, so these will introduce a certain level of variation overall and when added to the final 100k Ohm resistor for R2, we have a small variation once again. Due to this, I am seeing an error of 0.05V.

Part 2 (9 points): Op-Amp Design

****** Remember, when measuring current the portable multimeters have current limits (check the multimeter). If your calculations show you will be above the limit of the current input, use the 10A terminal!!! Failure to use the correct terminal will result in blowing the fuses of the multimeter. ******

a) **What is the <u>maximum current</u> that the load resistor RL can take. Hint: The resistors provided are ¼ W resistors. Show your calculations.**

$$I_{max} = \sqrt{\frac{P}{R}} = \sqrt{\frac{0.25\ W}{1000\ \Omega}} = 15.811\ mA$$

*Max current of RL=*______$15.811\ mA$____________

If your solar panel can exceed this current value, you will need to use a load resistor with a higher power rating. Thus, also calculate the current your solar panel outputs at the maximum lighting conditions.

Hints:

1- ***You will need the value of RL.***
2- ***Neglect R1 and R2 if you have chosen their values to be large compared to RL (i.e., if the current flowing through them would be negligible).***

Show your calculations.

$$I_{solar} = \frac{V}{R_L} = \frac{8.3\ V}{1000\ \Omega} = 8.3\ mA$$

Max current that the Solar Panel can supply=______$8.3\ mA$___________

Do you need to use a different resistor that has a higher power rating? Yes/No.

No.

b) **Why do you think the current measurement needs to be done using an Op-amp rather than how we measured the voltage in Part 1?**

In part one, we used a physical multimeter which required us to break the circuit when measuring current. Meanwhile with our current setup we only need a small voltage (taken from R_sh) and then the op-amp amplifies the voltage to a readable level for an Arduino. This gives us a method to continuously measure without breaking the circuit as well as minimal interference as the voltage drop is within the margin of error due to it being 5 ohms and the op-amp has a high input impedance, so no current is lost.

c) Using your <u>highest</u> load current, determine the maximum voltage into the + terminal of the Op-amp (i.e. the voltage over R_{sh}):

Max I_{load} (mA)	R_{sh} (Ohms)	Max V^+ (mV)
8.3	**5**	**41.5**

d) The CEO of Sparky Solar, Melanie Waters, has told you that the design criteria (in order of importance) are: 1. Temp, 2. Cost, 3. Availability. When designing the op-amp circuit, which set of resistors Rf and Ri will you use (1, 2, or 3) and why?

Since we need a heat tolerance of at least 155°C, we cannot move forward with Set 3, and although Set 1 is cheaper we will need to wait 2 weeks, which will cause delays in production. So we will elect Set 2. Despite the extra dollar in price per part it is immediateness that makes it the clear one to choose.

e) Select Ri and Rf to boost the output voltage, but ensure that the Op-Amp output voltage does not exceed 5V for all light conditions. (show your work here):

$$V_{out} = V_{+}(1 + \frac{R_f}{R_i})$$

$$5V = 41.5\, mV\,(1 + \frac{R_f}{R_i})$$

$$\therefore 120.4819 = (1 + \frac{R_f}{R_i}) \text{ and } \frac{R_f}{R_i} = 119.4819$$

As we chose Set 2 we will see that if we set $R_i = 1k\Omega$, then R_f must be 119.5kΩ or less.

(Even if we choose to round up to 120kΩ, the voltage out will be 5.02 V.)

We will elect 110kΩ which outputs 4.61 V – safely under 5V.

Max Vo (V)	Gain (V/V)	Rf (Ohms)	Ri (Ohms)
4.61 V	**111**	**110k**	**1k**

f) Why is a rail-to-rail Op-Amp required for this design? A rail-to-rail Op-Amp costs more than a standard Op-Amp, what value to the stakeholder does this extra feature add to the design? [Explain the benefits of rail-to-rail Op-Amps in your own words]

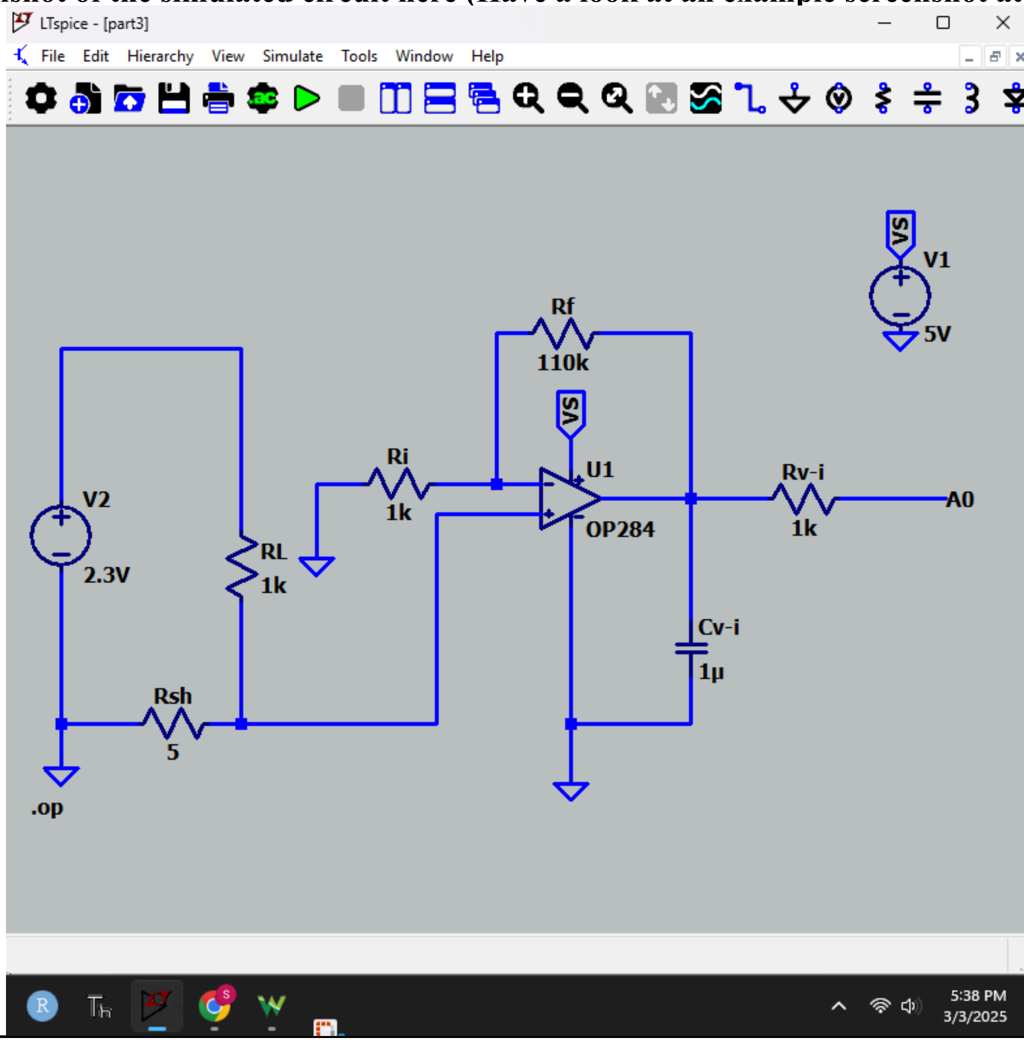
We want an accurate reader that will be able to detect a small input voltage (from the shunt resistor). We are asked to ensure that the output can reach close to the power supply rails of 0V and 5V. Since the input voltage is in the millivolt range a rail to rail Op-Amp ensures that we amplify linearly without distortion in between.

g) Do the values of Ri and Rf you proposed in part (e) need to be extremely accurate for your current measurement to be precise? Explain why or why not.

There is some wiggle room for the values of Ri and Rf. These small variations will change the gain amount by a small amount as well. The Arduino also will assist in reading accurately.

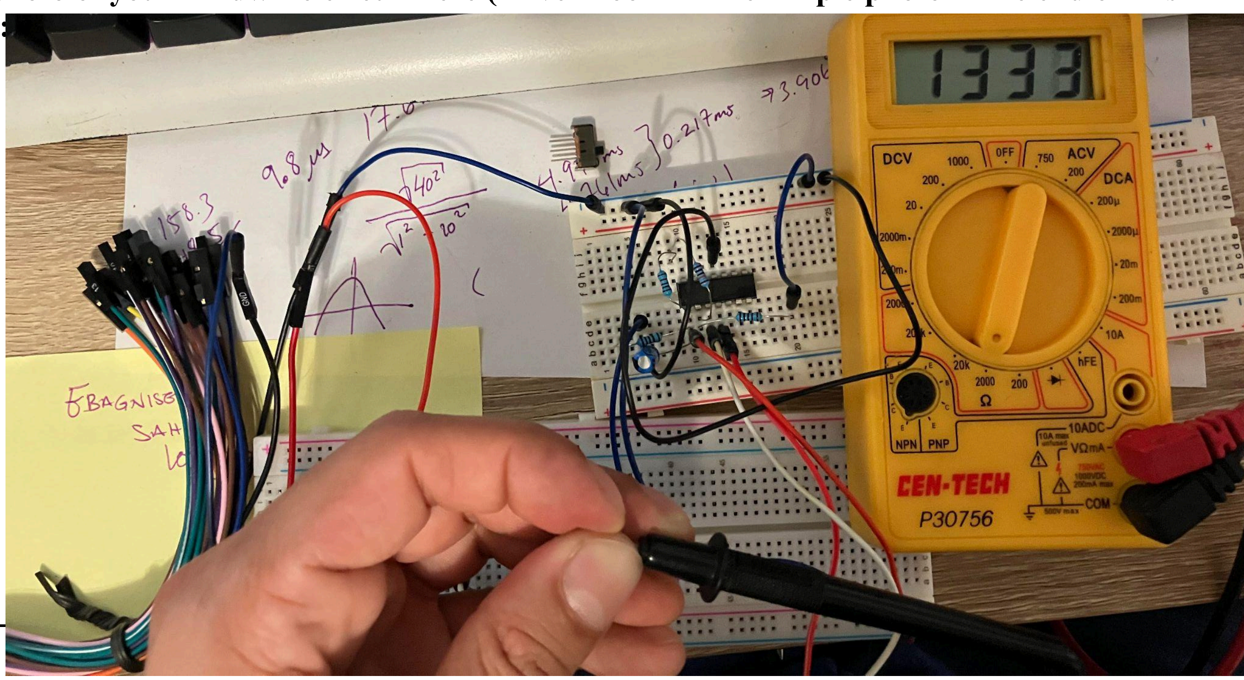
h) Create a simulation of your Op-Amp circuit in LTSPICE or TinkerCAD.

Include a screenshot of the simulated circuit here (Have a look at an example screenshot at the end of this document):



i) Physically build and test your design.

Include a photo of your hardware circuit here (Have a look at an example photo at the end of this document):



Do your measured results from your built circuit match your simulated results?

Yes.

How much error are you seeing?

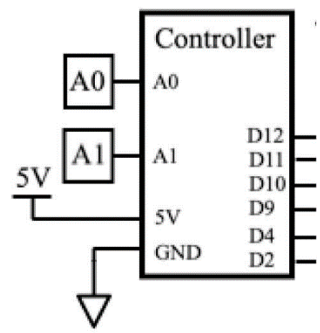
Not much.

What are some possible reasons for the difference in the real and theoretical results?

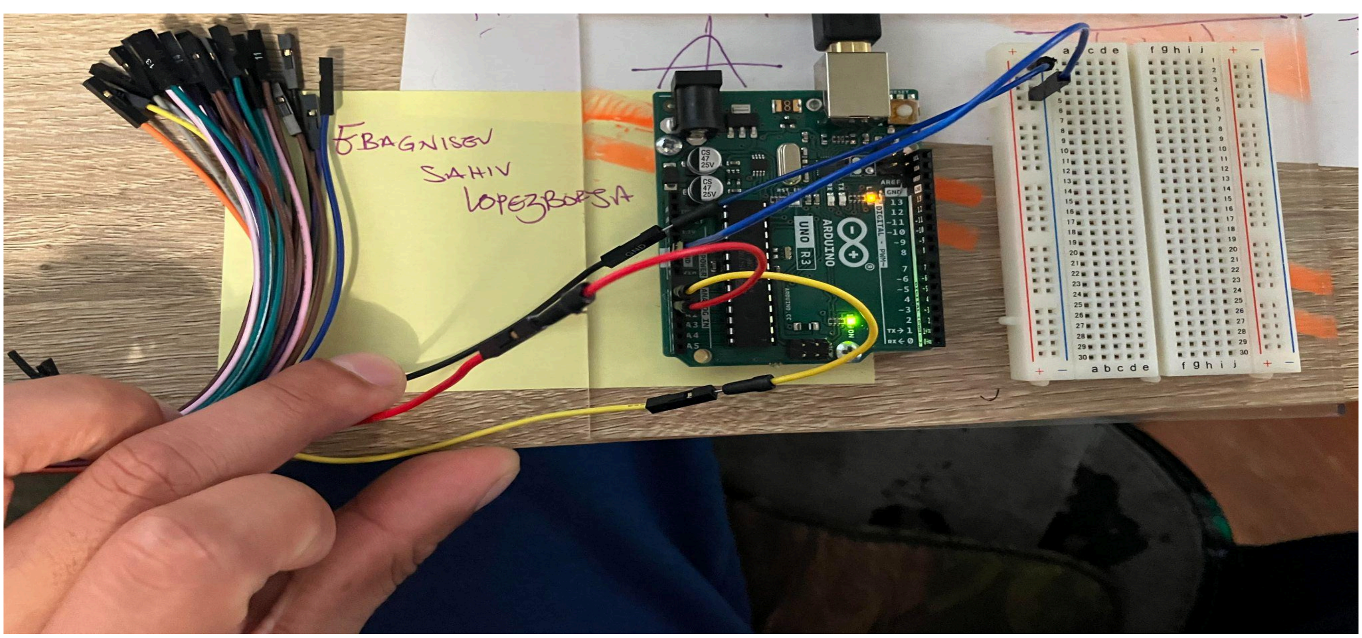
There are a lot of parts interconnected with varying resistance and tolerances.

Part 3 (9 points): Controller Circuit Design – Hardware Implementation
For each question in Part 3, you are supposed to simulate the circuit using TinkerCad or LTSpice before implementing it on hardware. However, this is optional due to time limitations.

Build your Controller circuit on hardware. For this question, you will need to build only the following circuit (i.e. controller without the voltage divider or any other part of the original circuit). You will need to supply voltage manually directly from the V1 and W1 of your AD2 to each of A0 and A1, respectively, to be able to answer the following questions.



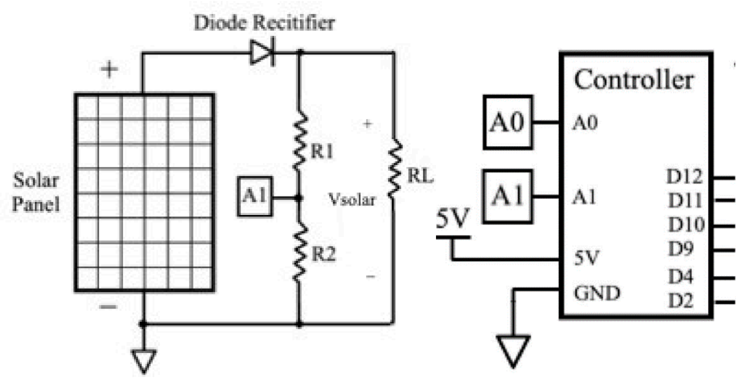
Include a photo of your hardware circuit here (Have a look at an example photo at the end of this document):



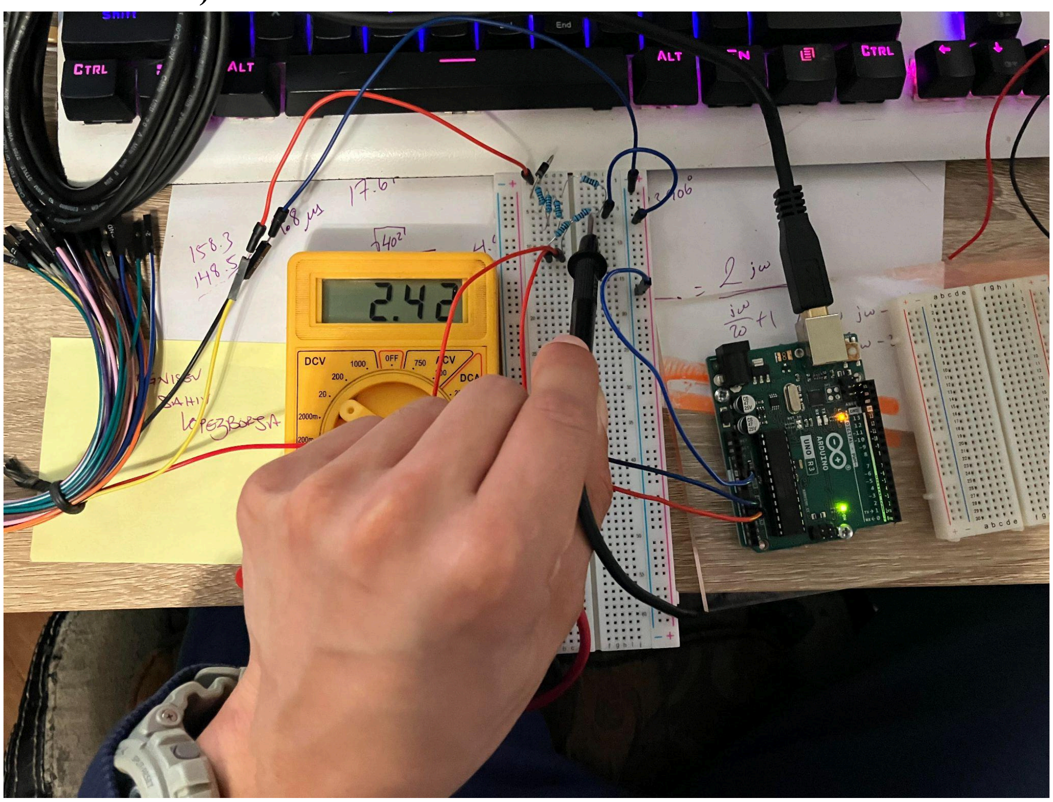
Physical Results:

A1 (V)	Voltage (V) (From Serial Port reading)	A0 (V)	Serial Port Current (mA) (From Serial Port reading)	Serial Port Power (mW) (Calculated)
1	8.27	1	8.29	68.54
2	8.26	2	8.29	68.47
3	8.29	3	8.3	68.76

Now, build your Voltage Divider on hardware and connect it to the Controller circuit. Use a voltage source to replace your Solar Panel. For this question, you will test the voltage coming out of the voltage divider with a voltmeter and compare it to the reading the controller is providing via the serial port.



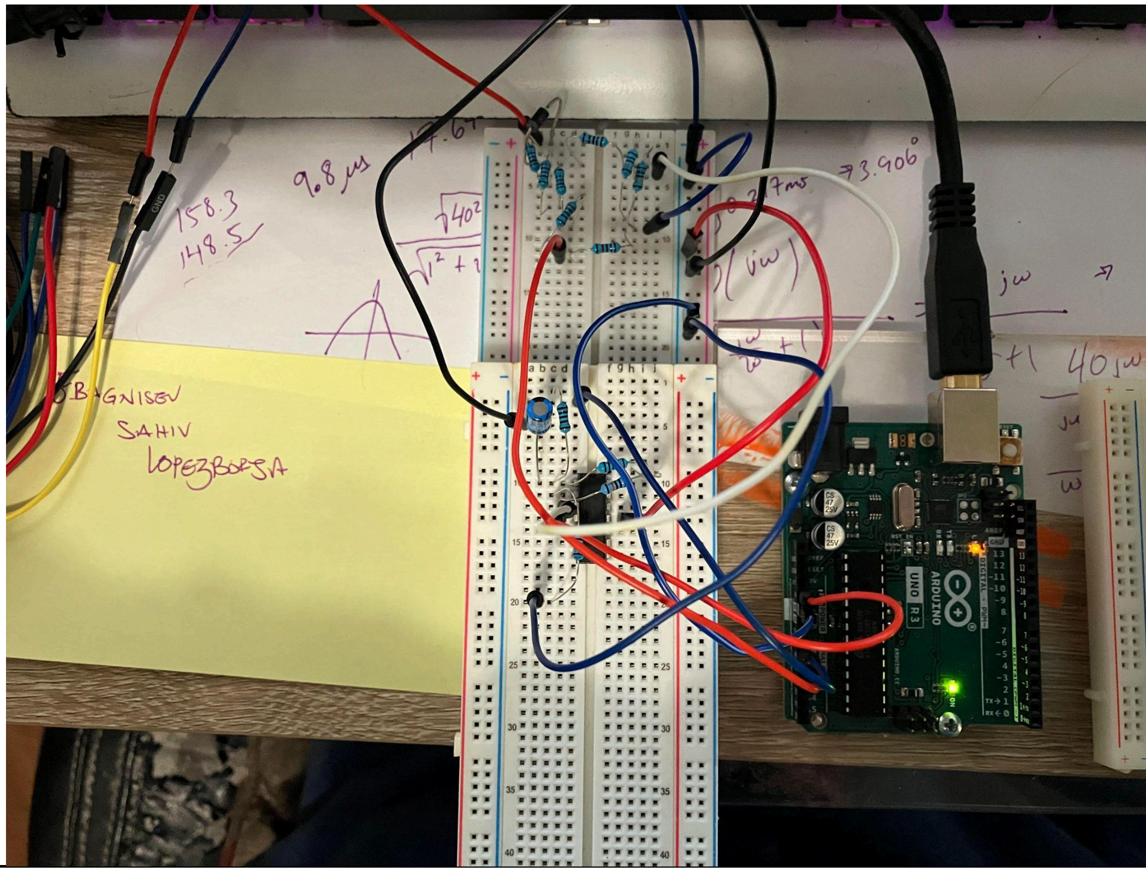
Include a photo of your hardware circuit here (Have a look at an example photo at the end of this document):



Physical Results:

V_{solar} max (V) (Voltmeter reading)	Voltage (V) (from serial port reading)
4.39 V	4.32 V

Do your measured results from your voltmeter and serial port match? How much error are you seeing? What are some possible reasons for the difference in the real and theoretical results? There is an error of 0.07 V (1.6% error).
Now build your Op-Amp Circuit on hardware and connect it the Controller subcircuits while leaving the voltage divider subcircuit connected. For this question, you will test the current flowing in the RL with an ammeter and compare it to the current reading the controller is providing via the serial port. **Include a photo of your hardware circuit here (Have a look at an example photo at the end of this document):**



Physical Results:

Vsolar (V) (Voltmeter)	Load Current (mA) (Voltmeter)	Power (mW) (Calculated)	Voltage (V) (Serial port)	Current (mA) (Serial Port)	Power (mW) (Serial Port)
8.83	8.80	77.704	8.89	8.86	78.72

Do your measured results from your voltmeter match your results from serial port? How much error are you seeing? What are some possible reasons for the difference in the real and theoretical results?

There are minor fluctuations that the multimeter is not reading due to its own limitations that the controller/computer can read and detect. The error is very minor compared to the serial port readings. The reason can be due to the Arduino and its limitations in readings. We can better this by stabilizing the value by taking averages of a period of time (i.e samples).

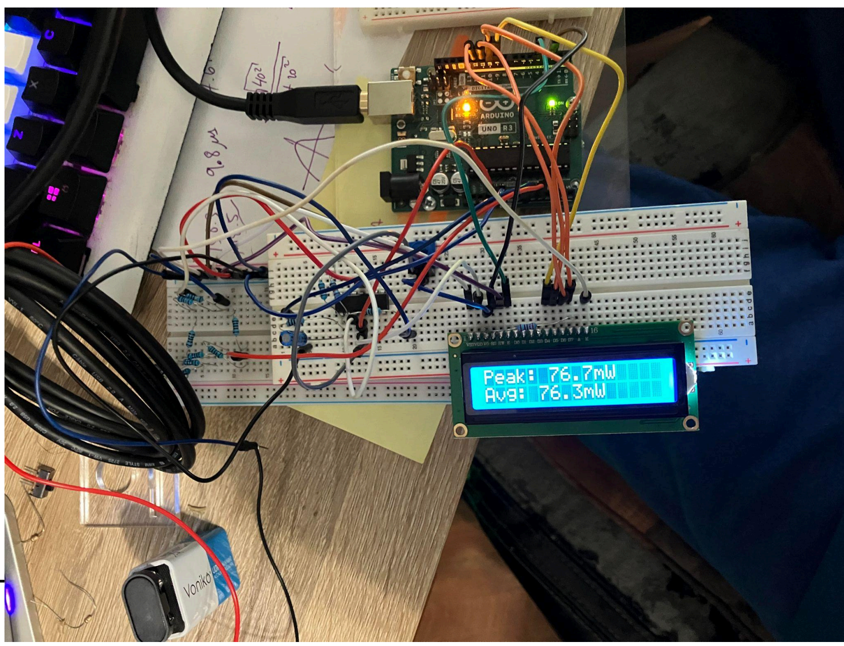
What adjustments can you suggest to the code to increase the accuracy of the voltage, current, and power that display in the serial port? For this question, only provide suggestions without needing to implement them. Hints: which resistors do you think are not provided in the code accurately? Any other potential source for errors?

We can better this by stabilizing the value by taking averages of a period of time (i.e samples).

[Optional] Bonus Opportunity – 5 Points – Read the Manual. Make sure to include your modified code and any screenshots that show that the added features work:

```
if (Power > peakPower)
peakPower = Power;
totalPower += Power;
readings++;
int displayMode = (millis() / 5000) % 3; // Changes every 5 seconds

if (displayMode == 0) {
    // Display Voltage and Power
    lcd.setCursor(0, 0);
    lcd.print("V="); lcd.print(Voltage, 2); lcd.print("V ");
    lcd.setCursor(0, 1);
    lcd.print("P="); lcd.print(Power, 1); lcd.print("mW ");
}
else if (displayMode == 1) {
    // Display Current and Power
    lcd.setCursor(0, 0);
    lcd.print("I="); lcd.print(Current, 2); lcd.print("mA ");
    lcd.setCursor(0, 1);
    lcd.print("P="); lcd.print(Power, 1); lcd.print("mW ");
}
else {
    // Display Peak and Average Power
    lcd.setCursor(0, 0);
    lcd.print("Peak: "); lcd.print(peakPower, 1); lcd.print("mW ");
    lcd.setCursor(0, 1);
    lcd.print("Avg: "); lcd.print(totalPower / readings, 1); lcd.print("mW ");
}
```



Part 4 (4 points): Complete Automated Solar Panel Power Meter Design

On your hardware circuit, mimic the change in the lighting conditions of your solar panel by changing the voltage of your voltage source and record the corresponding measurements in the following table. Include screenshots for your Serial Port Readout at the end of this part.

Solar Panel Light Condition Voltage (V)	Solar Panel Supplied Voltage (V) (Voltmeter)	Solar Panel Supplied Current (mA) (Ammeter)	Serial Port Voltage Readout (V)	Serial Port Current Readout (mA)	Serial Port Power Readout (mW)
Full Sunlight	8.83	8.80	8.80	8.84	77.79
Shaded Sunlight	4.36	4.64	4.35	4.60	20.02
Lab Light Plus Phone Light	2.40	2.50	2.39	2.53	6.06
Lab Light	0.48	0.52	0.47	0.53	0.25

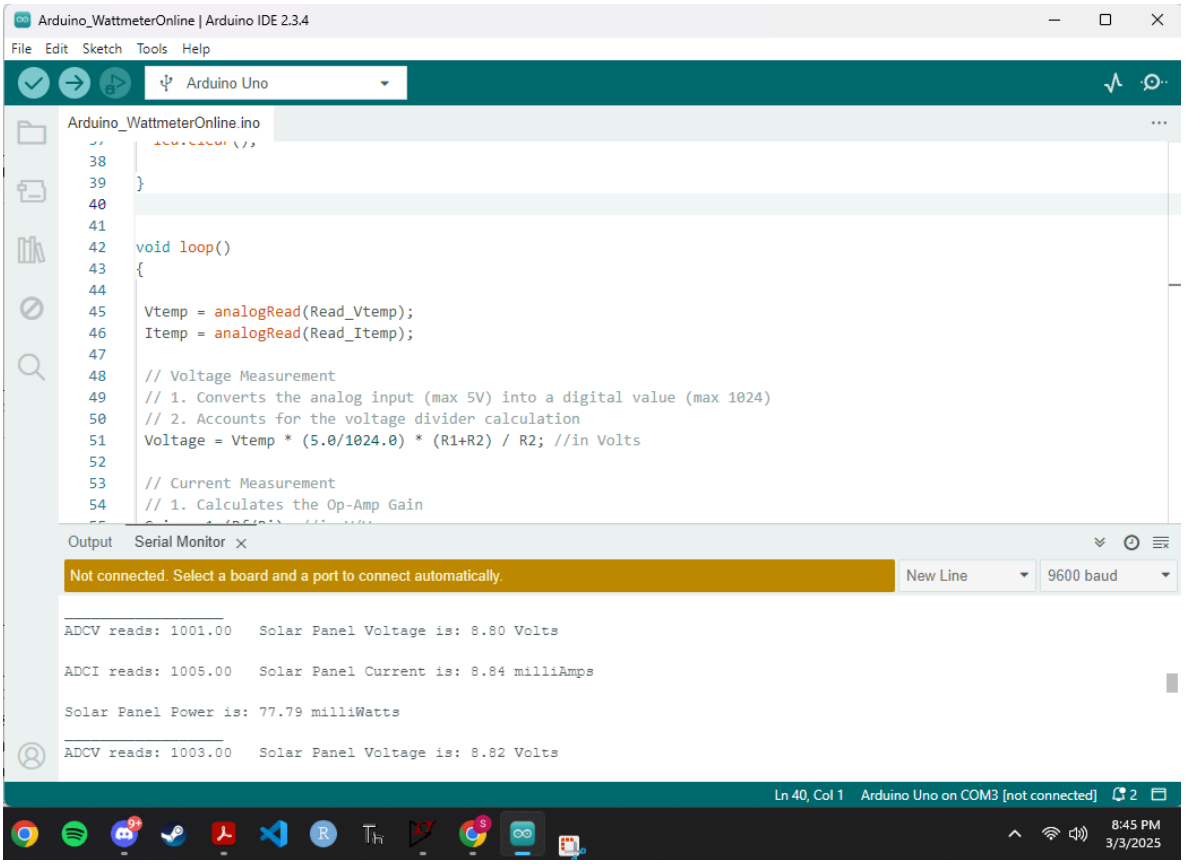
Did you have to make any component or code changes? If so, what changes were made? If not, comment on how you changed the lighting conditions on your solar panel to reach the voltage values on the voltage column in the previous table.

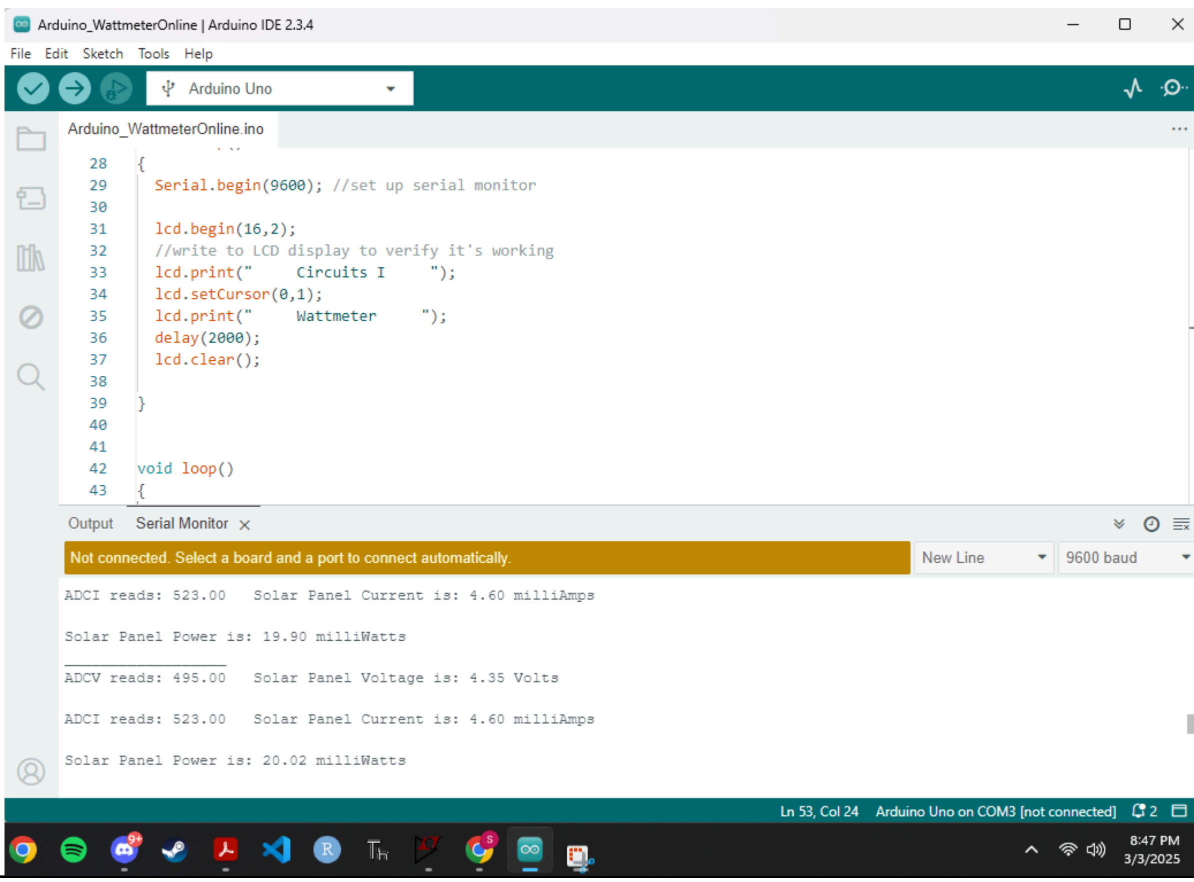
Used an Alkaline 9V and then used ADK3 to output the values on the first page using V+.

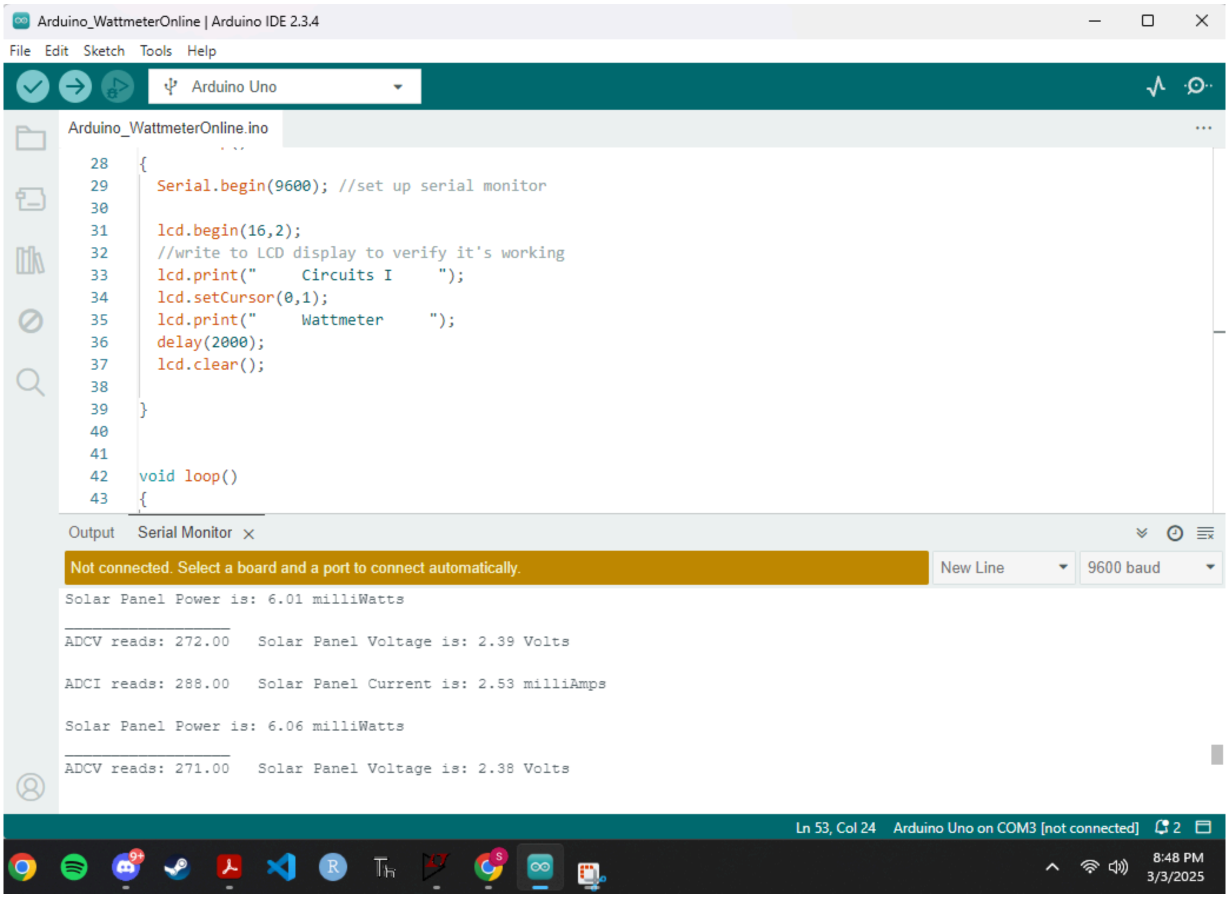
Do your measured results from your multimeter current and voltage match your Serial Port Readout results? How much error are you seeing? What are some possible reasons for the difference in the real and theoretical results?

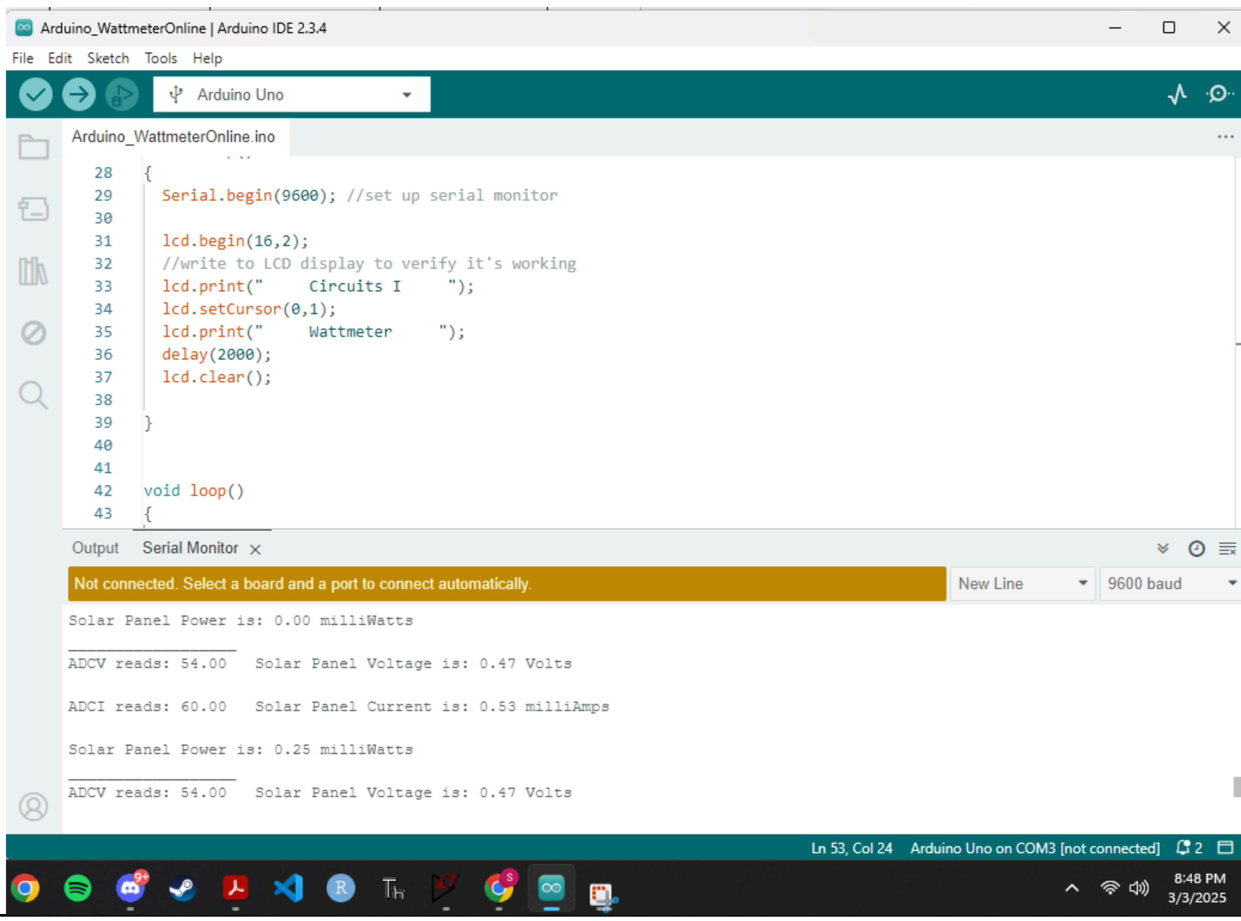
The amount of error is within under 1% for the first two cases and around 2% for the final two cases. This is mostly due to the difference in current but this can be attributed to the difficulty in using an ammeter to measure at such small voltages.

Serial Port Readout screenshots for all 4 lighting conditions (1 screenshot for each condition – make sure your computer's date and time are showing up in your screenshot):






Arduino_WattmeterOnline | Arduino IDE 2.3.4
File Edit Sketch Tools Help
Arduino Uno
Arduino_WattmeterOnline.ino
{
Serial.begin(9600); //set up serial monitor
lcd.begin(16,2);
//write to LCD display to verify it's working
lcd.print("   Circuits I   ");
lcd.setCursor(0,1);
lcd.print("   Wattmeter   ");
delay(2000);
lcd.clear();
}
void loop()
{
Output
Serial Monitor
Not connected. Select a board and a port to connect automatically.
New Line
9600 baud
Solar Panel Power is: 6.01 milliWatts
ADCV reads: 272.00   Solar Panel Voltage is: 2.39 Volts
ADCI reads: 288.00   Solar Panel Current is: 2.53 milliAmps
Solar Panel Power is: 6.06 milliWatts
ADCV reads: 271.00   Solar Panel Voltage is: 2.38 Volts
Ln 53, Col 24   Arduino Uno on COM3 [not connected]   2
8:48 PM
3/3/2025


Arduino_WattmeterOnline | Arduino IDE 2.3.4
File Edit Sketch Tools Help
Arduino Uno
Arduino_WattmeterOnline.ino
{
Serial.begin(9600); //set up serial monitor
lcd.begin(16,2);
//write to LCD display to verify it's working
lcd.print("   Circuits I   ");
lcd.setCursor(0,1);
lcd.print("   Wattmeter   ");
delay(2000);
lcd.clear();
}
void loop()
{
Output
Serial Monitor
Not connected. Select a board and a port to connect automatically.
New Line
9600 baud
Solar Panel Power is: 0.00 milliWatts
ADCV reads: 54.00   Solar Panel Voltage is: 0.47 Volts
ADCI reads: 60.00   Solar Panel Current is: 0.53 milliAmps
Solar Panel Power is: 0.25 milliWatts
ADCV reads: 54.00   Solar Panel Voltage is: 0.47 Volts
Ln 53, Col 24   Arduino Uno on COM3 [not connected]   2
8:48 PM
3/3/2025

Part 5 (2 point): Load Resistor Discharge Rate

Using the First Order Differential method or First Order Step-by-Step method, determine the size of the load capacitor to meet the design specifications - determine an appropriate capacitor value (from your available parts) to ensure the load will discharge in about 0.1sec with a solar panel supply of 9V and 50mA. You will still assume the load resistance (RL) of 1k Ohms.
(Show your work here. Calculations only. No simulations or hardware implementations needed.)

$$V(t) = V_0 e^{-t/(R_L C_L)}$$

Given that RL = 1k and V(t) is 9V, so we have:

$$ln(\frac{V(t)}{V_0}) = -\frac{t}{R_L C_L}$$

so after rearranging we have:

$$C_L \approx 11\ \mu F$$

Part 6 (7 points): Report

Briefly answer the following questions. Your answers should be qualitative in nature to demonstrate your understanding. This part of the project trains you on how to write a report to the stakeholders of this project showing your contributions, how your design is useful and how it could be further improved for more advanced use-cases:

1. **Who is this device designed for and what considerations were made for the user(s)?**
This device design was intended for a solar installer or electronics hobbyist who would like to monitor the capabilities of a solar panel source. This current design prioritizes availability, portability, and customizability.

2. **How does the final design work - give a detailed description with images?**
The final design consists of a voltage divider to control how the input going into the controller (<5V). A shunt resistor was then used to send the voltage measurement thru an op-amp and then optimized to be readable via the controller's Serial Port and later thru a LCD screen for ease of access.
3. **What components did you specifically determine and explain your reasoning for your choices?**
The first choice made was the resistor values for R1 and R2 as based on the considerations of output and power needed to be capable enough to withstand the required minimal specs, but also leave a bit of safety when using a higher resistance. Secondly we needed to create the op-amp to decide the values that would fully optimize our voltage value on the output of the op-amp without exceeding the limit of 5V. Lastly, a controller (Arduino Uno 3) and an LCD display were used due to their ease of use and customizability.

4. **What trade-offs were made in this design?**
Cost was a minor trade off to this design as this could have been built with lower rated resistors but overall availability was the motivating factor to overlook this when creating the product.

5. **What did you learn about theoretical design versus physical design?**
Theoretical calculations assume that we have ideal components and that the variation is very very minor, but in reality resistor tolerance, op-amp design and noise can affect accuracy when building a physical design.

6. **If this design were scaled up for large solar panel systems, what environmental, technological, societal, and/or financial considerations would need to be made?**
If this design were to be scaled up for a larger production, we would need to consider adding a more rugged design with higher rated instrumentation amplifiers to handle temperature sways and regular use and abuse. In terms of societal, we have to be aware of how this design can be implemented in different sectors.

7. **What skills have you developed in working on this project that will help you in your future career?**
This made me feel more confident in circuit design – both simulated and also physical design. I was also able to make decisions about the design that were based on mathematical calculations and then had to create using the resources in my inventory. This required a distinct type of problem solving applying engineering principles to improve accuracy.