Lab 1 - Ohm's Law

Your Name (First Last):

Overview

In this lab you will learn about electrical resistance and its connection to Ohm's Law. Ohm's Law simply states when a voltage V is applied to a circuit, a current I will flow through the circuit. The amount of current is directly proportional to the applied voltage.

$$V \propto I \tag{1}$$

The portionally between the voltage and current is the resistance of the circuit. If the resistance R is a constant (it does not change if the applied voltage changes), then resistance obeys Ohm's Law:

$$V = IR \tag{2}$$

The units of resistance are measured (not surprisingly) in ohms (Ω). In this lab you will use resistors, circuit elements with constant resistance, to construct different circuits and test Ohm's law. Since a resistor's resistance is constant, it is said to be *ohmic*. But not all circuit elements are ohmic as you will see in later labs.

Part 1 - Breadboard Connections

The breadboard has MANY holes and so an attempt to try every pairwise combination would be tedious. Instead of trying every pair of holes, you are asked to apply intelligence to the issue and try enough holes that the pattern of connections has become absolutely certain.

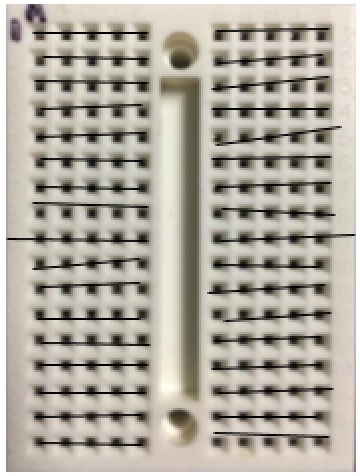
Here is a video to show you how to test the breadboard connections. The breadboard in the video may differ from the one you have, BUT the concept of testing the connection is the same.

Breadboard Connections (https://youtu.be/ERCLIfAnSZ4)

Remember:

- A measurement of 3.3V means the two points you test on the breadboard are connected.
- A measurement of 1.5V means the circuit is open and the two points NOT connected.
- Like in the video, you should use slot A7 on the IOlab to do this question

1. Use the image of the breadboard below and draw lines across all holes you have determined to be connected.

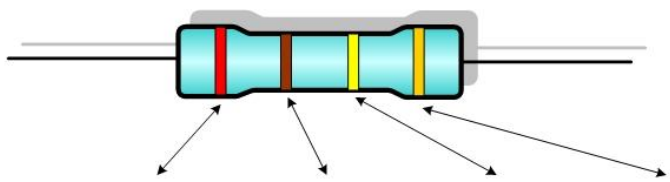


Part 2 - The Voltage Divider

A voltage divider is one the simplest circuit you can construct. I basically consist of two resistors connected in series with each other. You will construct a voltage divider using the breadboard and two 10,000 Ω or 10kΩ. Remember 1kΩ = 1,000 Ω.

From the Electricity and Magnetism Accessory Pack take out two 10kΩ resistors from the pack.You can check if you have the right resistors using the color bands on them. The color bands represent a numerical code for the resistance of the resistor. For at 4-band resistor the color code is:

4-band Resistor



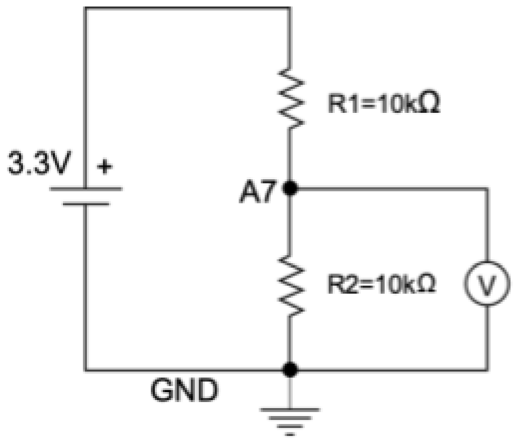
Color	1st band value	2nd band value	Multiplier	Tolerances
Black	0	0	× 1	
Brown	1	1	× 10	± 1%
Red	2	2	× 100	± 2%
Orange	3	3	× 1000	± 3%
Yellow	4	4	× 10,000	± 4%
Green	5	5	× 100,000	± 0.5%
Blue	6	6	× 1,000,000	± 0.25%
Violet	7	7	× 10,000,000	± 0.10%
Grey	8	8	× 100,000,000	± 0.05%
White	9	9	× 1,000,000,000	
Gold			× 0.1	± 5%
Silver			× 0.01	± 10%
No band				± 20%

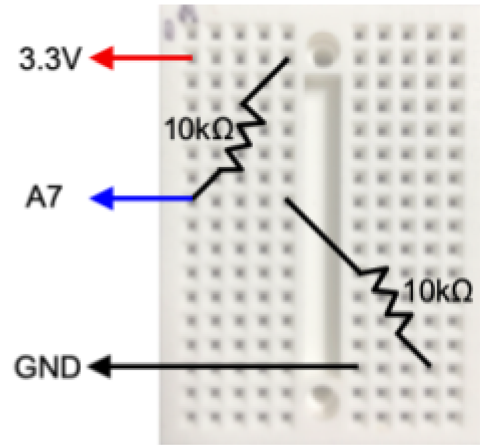
The 10kΩ resistors in your E&M pack have the color bands brown (**1**), black (**0**), orange (**1000**), and gold (**5%**). The color corresponds to either a digit, a multiplier, or a tolerance. So for the case of a 10kΩ, the resistance is:

$$(\mathbf{1}\times 10 + \mathbf{0}\times 1)\times \mathbf{1000} \pm \mathbf{5\%} = 10{,}000\ \Omega \pm 5\%$$

The tolerance means that the manufacturer rates the value of resistance within a percentage of the nominal value. For example, the actual value of the resistance of the 10kΩ with a tolerance of 5% may be between 9.5kΩ and 10.5kΩ.

Now construct a voltage divider. Here is a circuit diagram of what the voltage divider looks like:

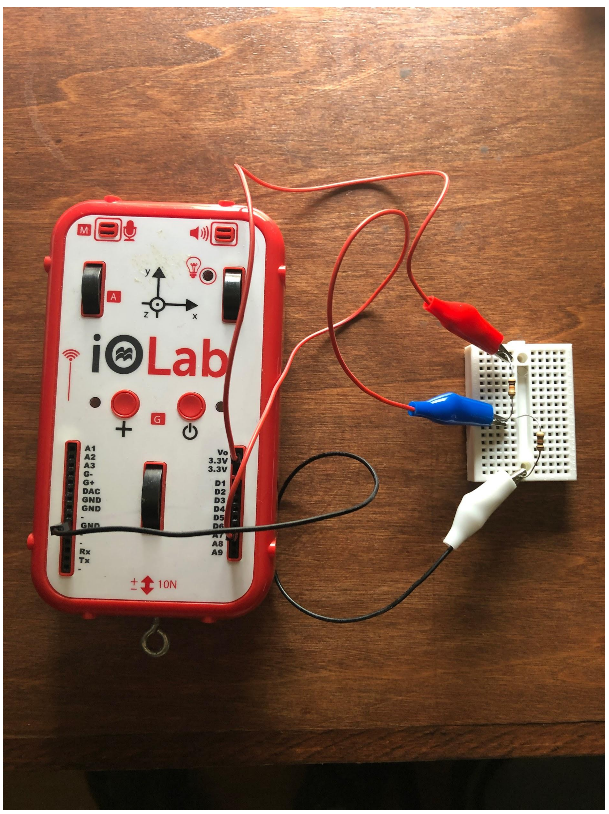




You will also need to connect wires to the iOLab. The iOLab will function as both a voltage source and a voltmeter and ammeter.

- Connect the top end of the first resistor (R1) to the 3.3V voltage source on the iOLab.
- Connect the bottom end of R1 to the A7 input. A7 will function as a voltmeter.
- Connect the bottom end of the second resistor (R2) to the GND on the iOLab.

When you are done you voltage divider may look like this:

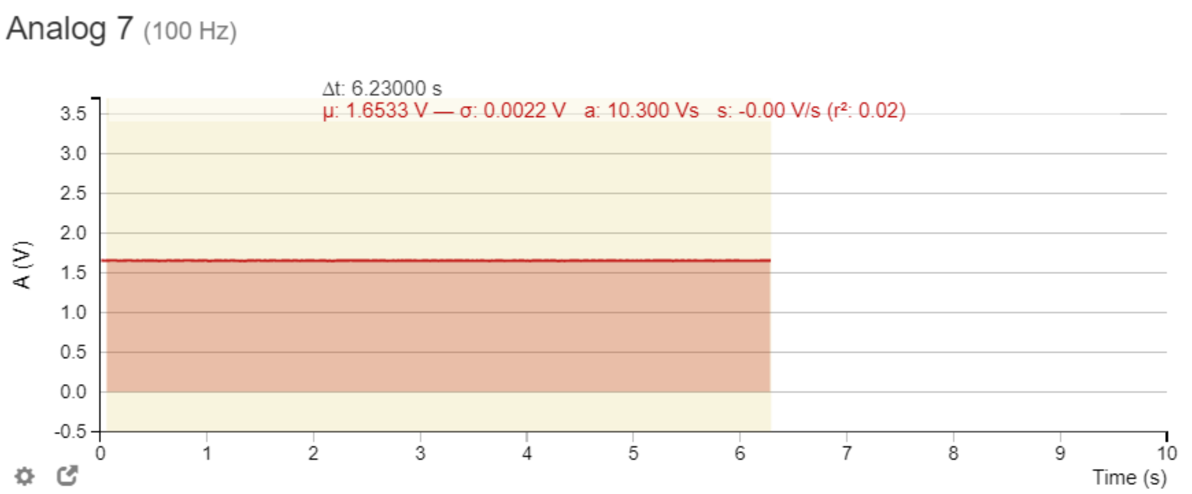


- Red alligator clip is connected to 3.3V
- Blue alligator clip is connected to A7.
- White alligator clip is connected to GND.

Now let's measure the voltage of the voltage divider. Setup the iOLab and iOLab app:

- Connect the dongle to the USB port on your computer.
- Turn on the iOLab.
- Launch the iOLab app and select Analog 7 (A7) from the list of sensors.
- Click Record and record the voltage measured by Analog 7. Allow the recording to run for 5 to 10 seconds.
- Click the Analog Mode button (bar chart button) on the toolbar in the app. Click and hold the mouse arrow and drag the arrow across a segment of the data in the graph.

2. Take a screenshot of the iOLab app with the data of the voltage divider and paste it here:



3. Record the average voltage (μ) +/- the uncertainty (σ) measured by A7 in the table below:

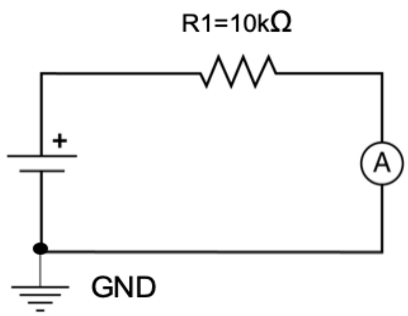
Average Voltage (V)
1.6533 +/-.0022

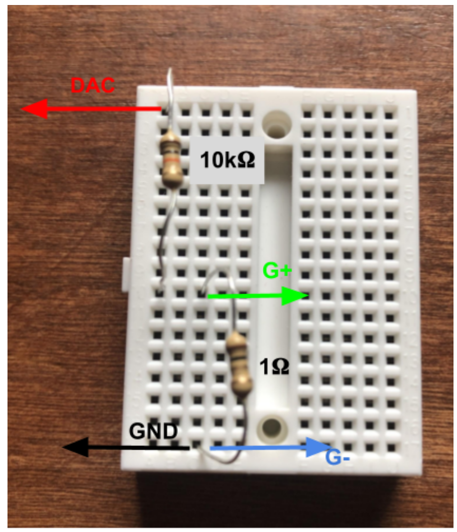
4. How does the value of the average voltage compare to the voltage supplied by the iOLab? Explain how the voltage divider "divides" the voltage in terms of the resistance of the resistors.

The average voltage is about half of the supplied voltage of 3.3 V, the voltage divider takes the supplied voltage and divides it by about 2. The system does this by establishing a gradient of voltage across the resistors, because we know there are 2 resistors and we also know that at GND there is 0 voltage, right in the middle of the 2 resistors must be half the voltage at 1.65V

Part 3 - Ohm's Law

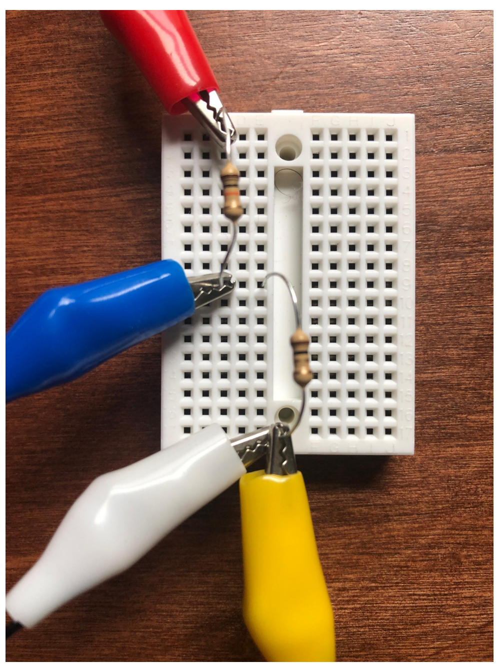
Now let's test Ohm's Law. You will construct a circuit and measure both the voltage across and current through the circuit using the iOLab. First you will construct a circuit that looks like this:





- Replace the second resistor R2 with a 1Ω resistor.
- A 1Ω resistor has band colors brown(**1**), black(**0**), gold(**0.1**), and gold(**5%**).

Your circuit should look like this:



- Red alligator clip is connected to DAC.

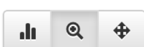
- Blue alligator clip is connected to G+.
- Yellow alligator clip is connected to G-.
- White alligator clip is connected to GND.

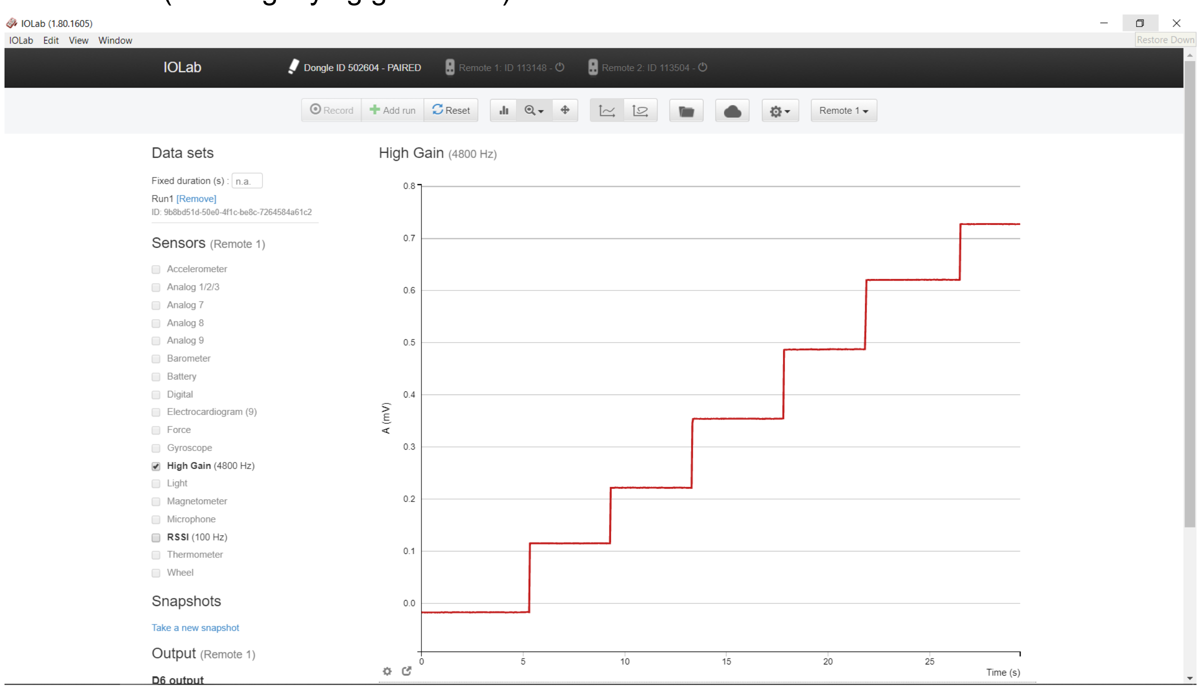
Now you need to setup the iOlab app:

- Uncheck Analog 7 and check High Gain sensor.
- On the toolbar click the settings button (cog) > Expert Mode > Output configuration.
- At the bottom of the iOLab app window the DAC Output should appear.
- In the DAC Output menu select 0.0V then click On.

Now it is time to take some data:

- Click the Record button and record the High Gain voltage for about 5 seconds.
- If you cannot see any line at all, it is because the line is too high off the graph, so we can't see it. To fix this, click the settings wheel in the bottom left corner of the graph and increase the maximum y value.
- While still recording, change the DAC Output voltage menu to 0.5V. Record for 5 more seconds.
- Change the DAC Output voltage in 0.5V steps up to 3.0V. With each change in voltage record the High Gain voltage for about 5 seconds.

When you are done your data should look like this. You may have to use the the Zoom Mode  (the magnifying glass icon) to zoom in on the data :



Each jump in the DAC Output voltage means the voltage across the 1Ω resistor jumps. But what about the current flowing through the circuit? How can we measure that? It turns out the 1

Ω IS the ammeter! Because we measure the voltage across the 1Ω, and we know the resistor is 1Ω, then using Ohm's Law the current through the resistor is simply voltage divided by 1Ω .

Now you will need to measure the current for each 0.5V step in your data. Open the Google Sheet Ohm's Law - Student Data to record your measurements:

Ohm's Law - Student Data

Make sure you make a copy of the spreadsheet for yourself. Click the menu File > Make a copy. Your copy will be in your UMass Google Drive. You can edit your copy by entering data, making graphs and performing calculations.

5. Measure the current for each 0.5V step in your data.
    a. Use the Analysis Mode to measure the current for each flat segment of data.
    b. Record the values of current in the Google Sheet.

6. Make a scatter plot of Voltage vs. Current:
    a. Click on the top of the column with the values of Current (mA) (Column A).
    b. Press and hold the Ctrl key and click on the top of the column with the Voltage (V) values (Column B).
    c. Release Ctrl key and open the Insert menu and select Chart.
    d. The Charter Editor will open. In Setup choose Chart Type > Scatter Chart,
    e. Make sure the X-axis indicates Current (mA).
    f. Make sure the Series indicates Voltage (V). If Current (mA) is in the Series, remove it.
    g. In Customize > Chart & axis titles add axes titles with units to your graph.
    h. Copy and paste your plot into this document below here:

7. Look closely at your graph of Voltage vs. Current and you will see it should be linear. What does the slope of Voltage vs. Current *physically* represent? Hint: look back at Ohm's Law Equation 2.

Voltage vs current is exactly the same as ohm's law formula of V=IR, which is a linear relationship.

In the spreadsheet there is a built-in function called LINEST. LINEST estimates the best fit line $y = mx + b$ (the slope m and intercept b) for a set of data. LINEST will return a table with results of the slope and intercept and the uncertainties of slope and intercept of a line that best fits the relationship between Voltage and Current. The table of results is organized like this:

LINEST	
Best Slope	Best Intercept
Uncertainty of Slope	Uncertainty of Intercept

Correlation Coefficient R2	Standard Error
F Statistics	Degrees of Freedom
Sum of Square Regression	Sum of Square Residuals

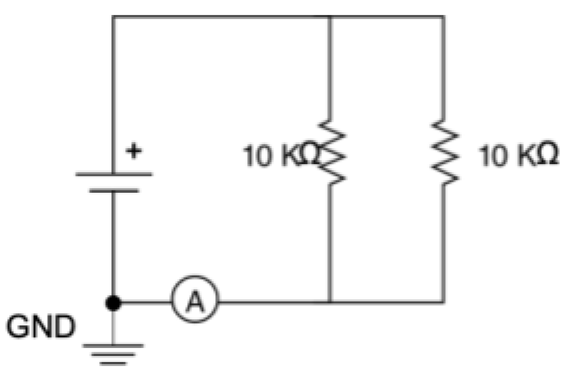
8. Use the built in function LINEST to determine the best slope of Voltage vs. Current.
    a. In an empty cell E2 enter =LINEST(range of y,range of x,1,1).
    b. The range of y should be the range of cells with the values of Voltage in Column B (B2:B8).
    c. The range of x should be the range of cells with the values of Current in Column A (A2:A8).

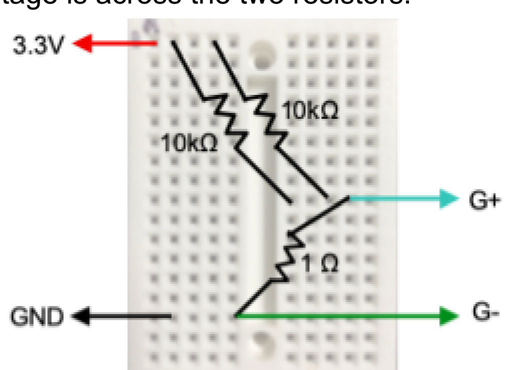
Part 4 - Resistors in Series and Parallel

Real electrical circuits have complex networks of all kinds of circuit elements. Let's consider some basic combinations of circuit elements, namely [resistors in series and parallel].

Parallel Resistors

Let's start by analyzing the two resistors connected in parallel. Construct a circuit with two 10kΩ in parallel. Two resistors are in parallel with each other if the ends of the resistor are connected to the same potentials. That means the same voltage is across the two resistors.





When two resistors are in parallel, there are two paths for the electric current to travel through. The two resistors combined act as a single resistor with resistance R_p.

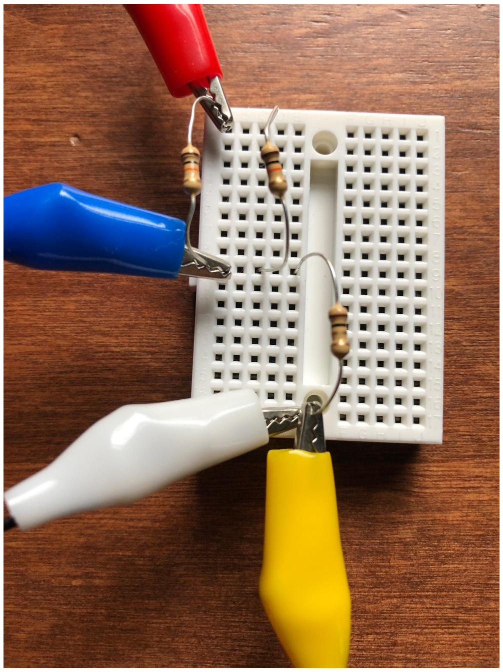
9. Do you think the combined resistance R_p of the two resistors in parallel will be greater than or less than the individual resistance of each resistor? Explain your answer.

I predict that the resistance will be half of the resistance with 2 parallel resistors instead of 1 resistor. I predict that because it is 2x the amount places for the current to go.

10. Based on your answer to question 9, will more or less current flow through the two resistors in parallel than an individual resistor? Explain your answer.

Based on the response to question 10, more current should flow through the 2 combined resistors than 1 individual resistor. This is because the overall resistance is lower so more current flows.

Your circuit should look like this:



- Red alligator clip is connected to 3.3V.
- Blue alligator clip is connected to G+.
- Yellow alligator clip is connected to G-.
- White alligator clip is connected to GND.

When two or more resistors are connected in parallel, the combined resistance is:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \tag{3}$$

11. Using the resistance of two 10kΩ resistor, calculate the combined resistance R_p if the resistors are connected in parallel.

R_p (Ω)
5k Ω

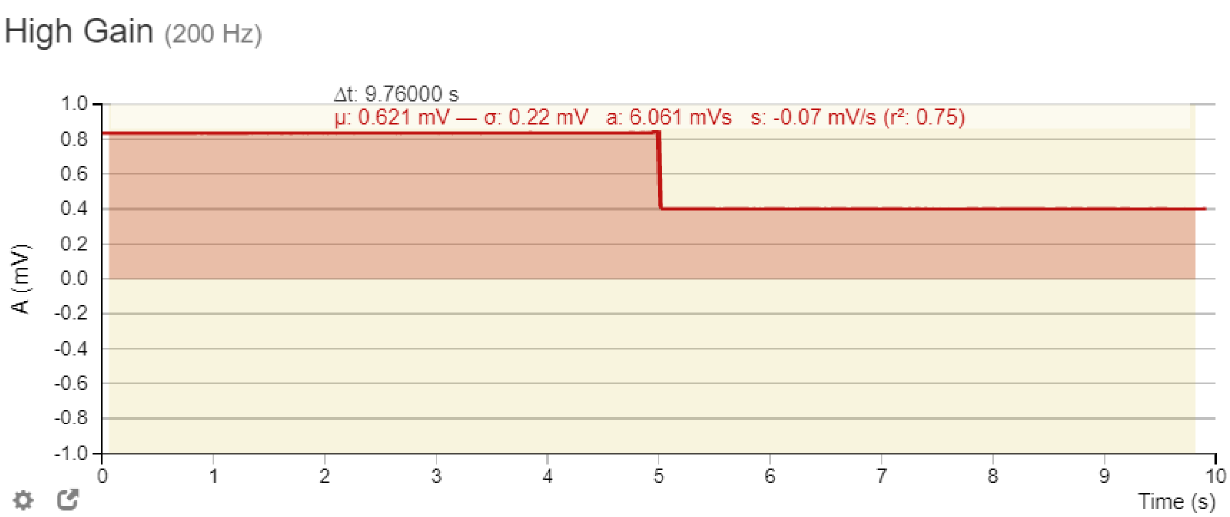
12. If 3.3V is applied to the two resistors in parallel, calculate the amount of current flowing through the circuit.

Current (A)
6.6 mA

Make sure the iOlab app is setup and ready to record data:

- Check High Gain sensor.
- Click the Record button and record the High Gain voltage for about 5 seconds.
- As the data is recording, *carefully* remove the second 10kΩ resistor.
- Continue recording for about 5 more seconds then click Stop.

13. Take a screenshot of the iOLab app with the data of the two resistors in parallel and paste it here. If you cannot see any line at all, it is because the line is too high off the graph, so we can't see it. To fix this, click the settings wheel in the bottom left corner of the graph and increase the maximum y value.



14. When you removed the second 10kΩ resistor, did the current change (increase, decrease or stay the same? Is this consistent with your answer to question 10? Explain your answer.

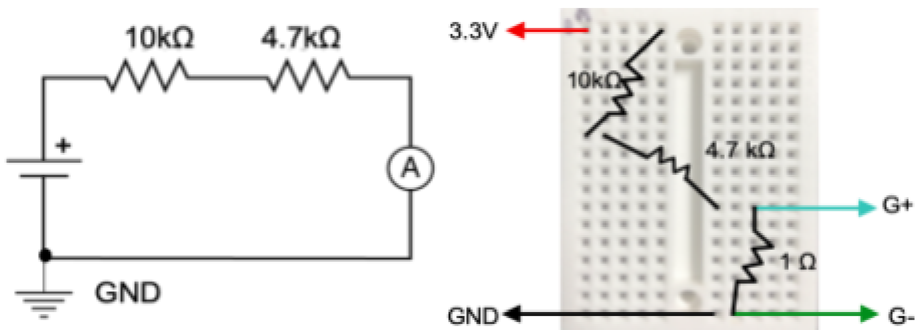
When the 10k resistor was removed, the voltage halved, just as expected. The overall resistance increased by 2x. In the formula $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ **, 1/r=1/10000+1/10000;**

r=5000, but after 1 resistor is removed, 1/r=1/10000; r=10000. The voltage with 1 resistor vs 2 in parallel is a factor of 2.

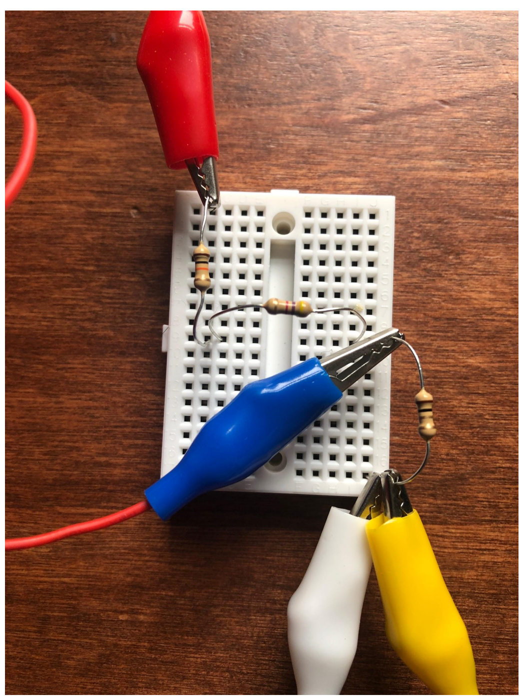
Series Resistors.

Now let's observe what happens when two resistors are connected in series. Two or more resistors are in series if there is only one path the current can flow through the circuit. The current flows sequentially through each resistor. Construct a circuit with a 10kΩ resistor and a 4.7kΩ resistor in series. The 4.7kΩ resistor in your E&M pack is in the packet. The color bands on the 4.7kΩ resistor are yellow(4), purple(7), red(**100**), and gold(5%). Based on the bands the nominal resistance is:

$$(4\times 10+7\times 1)\times \mathbf{100}\pm 5\% = 4{,}700\Omega\ \pm 5\%$$



Your circuit should look like this:



- Red alligator clip is connected to 3.3V.
- Blue alligator clip is connected to G+.
- Yellow alligator clip is connected to G-.
- White alligator clip is connected to GND.

When two resistors are in series, there is only one path for the electric current to travel through. The two resistors combined act as a single resistor with resistance R_s.

15. Do you think the combined resistance R_s of the two resistors in series will be greater than or less than the individual resistance of each resistor? Explain your answer.
The combined resistance should be higher than the individual resistance because when you put them in line together, the 2 resistors act as one.
16. Based on your answer to question 15, will more or less current flow through the circuit with two resistors in series, compared to the circuit with only one resistor? Explain your answer.

Based on the prediction made in question the current flowing through the whole circuit should be less than that of any of the 2 individual resistors. This is because together, the resistors have a higher resistance than each of them alone, so the current should be reduced.

When two or more resistors are connected in series, the combined resistance is:

$$R_s = R_1 + R_2 + \cdots \tag{3}$$

17. Using the resistance of two resistors, calculate the combined resistance R_s if the resistors are connected in series.

R_s (Ω)
14.7kΩ

18. If 3.3V is applied to the two resistors in series, calculate the amount of current flowing through the circuit.

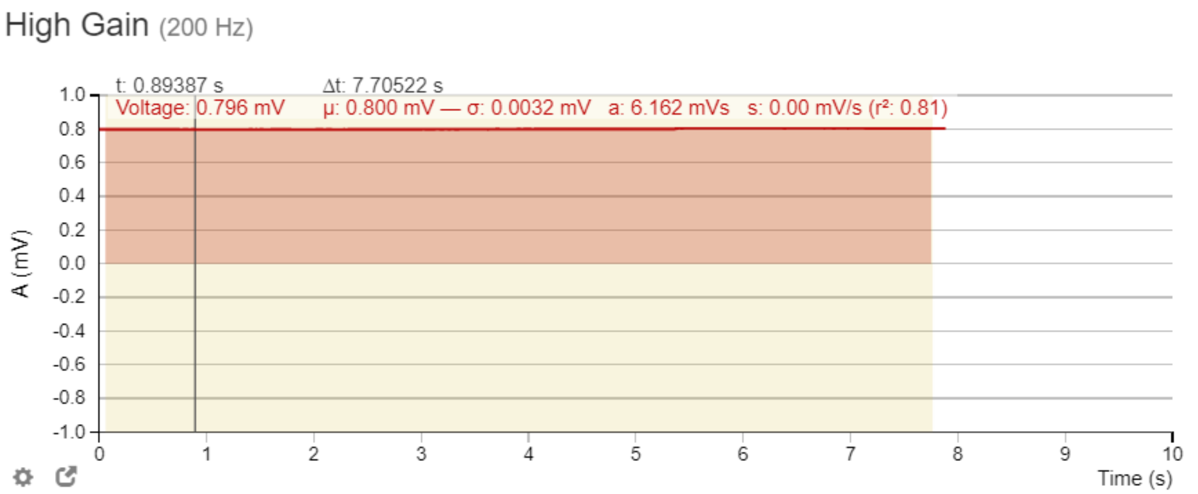
Current (A)
.22 mA

Now record data:

- Check High Gain sensor.
- Click the Record button and record the High Gain voltage for about 5 seconds then click Stop.

- Click the Analog Mode button on the toolbar in the app. Click and hold the mouse arrow and drag the arrow across a segment of the data in the graph.

19. Take a screenshot of the iOLab app with the data of the two resistors in series and paste it here:



20. Record the average current (μ) +/- the uncertainty (σ) measured by High Gain in the table below:

Current (A)
0.800 +/- 0.0032

21. How does the value of the average current compare to the current calculated in question 17?

The average current is a lot higher than the calculated value in question 17, the difference is about 4 times higher.