LAKE FOREST COLLEGE
Department of Physics

Physics 115 **Experiment #5: Ohm's "Law" and Resistors** Spring 2025

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Table:

Preliminary Instructions
Create a folder for you and your lab partner on Teams. Save a copy of these instructions for each student to that folder. Include your name in the filename. As you edit this document put your text in a different color. Save one copy of the Excel template with both your and your partner's name included in the filename.

Pedagogical goal
Explore the ideas of current, voltage, and resistance, their relationships, and how to measure them.

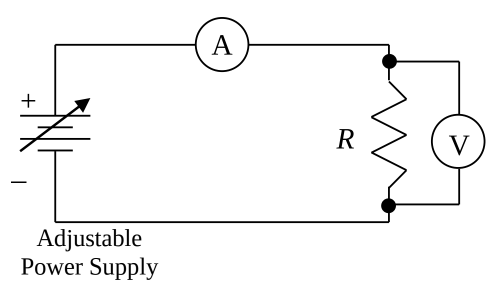
Experimental goal
Measure resistances and test predictions of the equivalent resistance of series and parallel combinations.

Background

Quantity	Description	Variable	Unit
Current	The amount of charge moving past a point per unit time interval.	I	ampere (A)
Potential (Voltage)	The potential energy per unit charge.	V	volt (V)
Resistance	The difficulty with which charges move through an object.	R	ohm (Ω)

Ohm's "Law" describes the *approximate* relationship (therefore "Law") between the voltage across a component, the current through it, and its resistance: $V = IR$. We can measure each of these quantities using a digital multimeter (DMM) on the appropriate setting. For some components, like resistors, the resistance is essentially constant for a range of currents.

Procedure:
Part I: Definition of resistance



1. Use the nominal 560 Ω resistor at your station. Set one DMM to read DC volts and set the other to read DC milliamps. Connect the circuit shown in the diagram using the plastic holders and the patch cords. Employ the positive (+) and negative (-) terminals of the power supply, not the ground terminal. **Include a photograph of your setup here.**

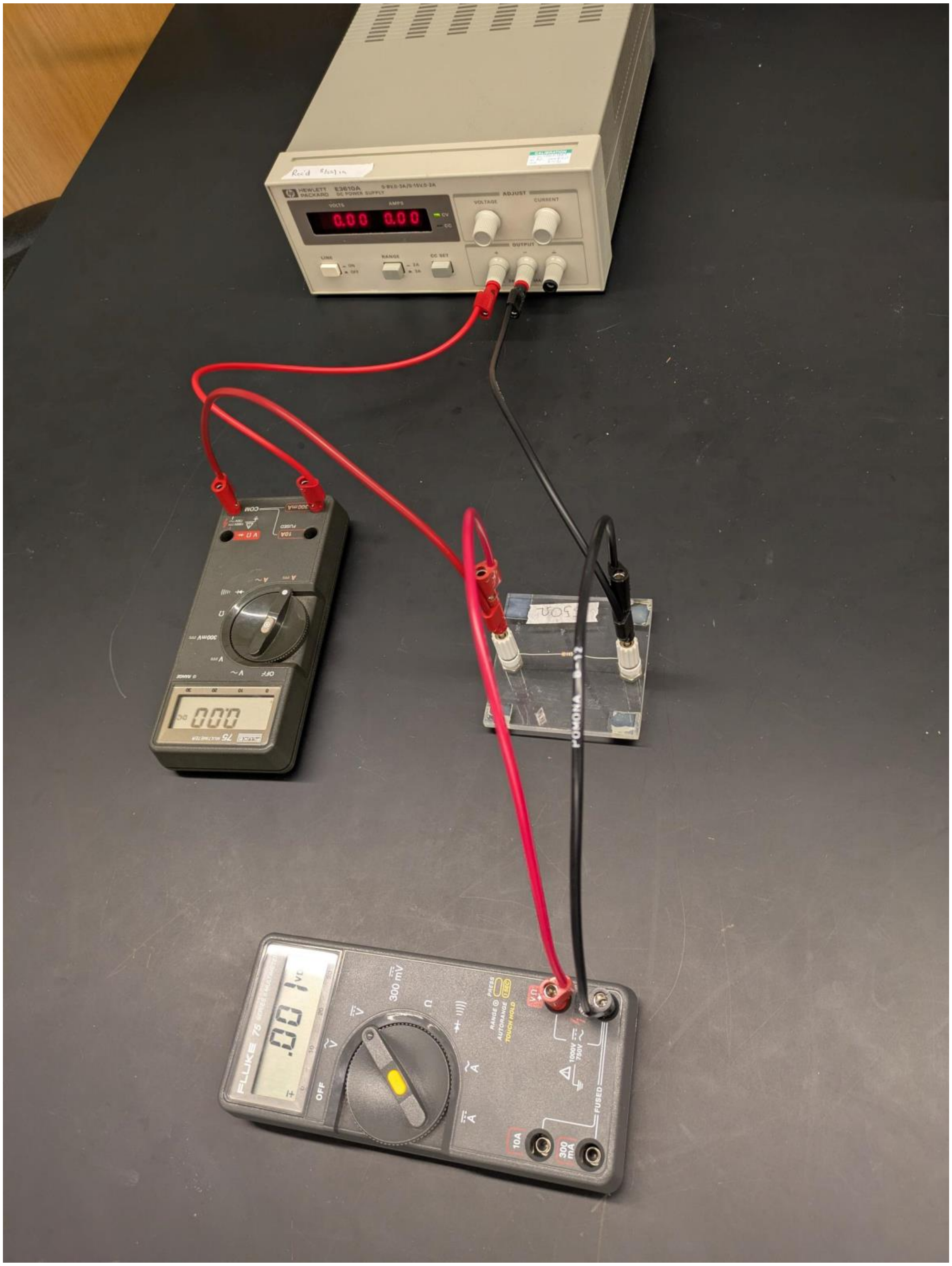


Figure 1. Resistance Apparatus. The Hewlett Packard DC power supply acts as a power supply. The red patch cords indicate the flow of 'positive' charge and the black patch cords indicate the flow of 'negative' charge. The Fluck multimeters measure the voltage (V) and current (mA). The multimeter with two red cords measures the current and the multimeter with a red and black cord measures the voltage. The resistor connected to the circuit has a resistance of 550Ω.

2. Measure the current through the resistor with the voltage across the resistor ranging from 0.00 V to 5.00 V in roughly 0.50 V increments. Record the values in a table. Convert the current in milliamps to amps and **paste the table here**. **Include a table caption.**

V (V)	I (mA)	I (A)
0	0	0
0.496	0.89	0.00089
0.993	1.79	0.00179
1.487	2.69	0.00269
1.980	3.58	0.00358
2.473	4.48	0.00448
2.970	5.38	0.00538
3.450	6.28	0.00628
3.95	7.17	0.00717
4.44	8.07	0.00807
4.94	8.97	0.00897

Table 1. Measured Current and Voltage. The voltage and current were measured by Fluke multimeters in a circuit with a 550Ω resistor. The current was measured in miliamps (mA) and converted to amps (A) by dividing by 1×10^{-3}. The multimeter always measured a voltage slightly lower than the voltage set on the power supply.

3. Plot a graph of the voltage (in volts on the vertical axis) as a function of the current (in amps on the horizontal axis) using Logger Pro. Fit your data to a proportional function (y=Ax). Use the fitted slope as a measure of the resistance. Use the fitting uncertainty as the uncertainty in the resistance. **Explain why the slope of the graph is equal to the resistance of the resistor. Paste the graph here. Include a caption.**

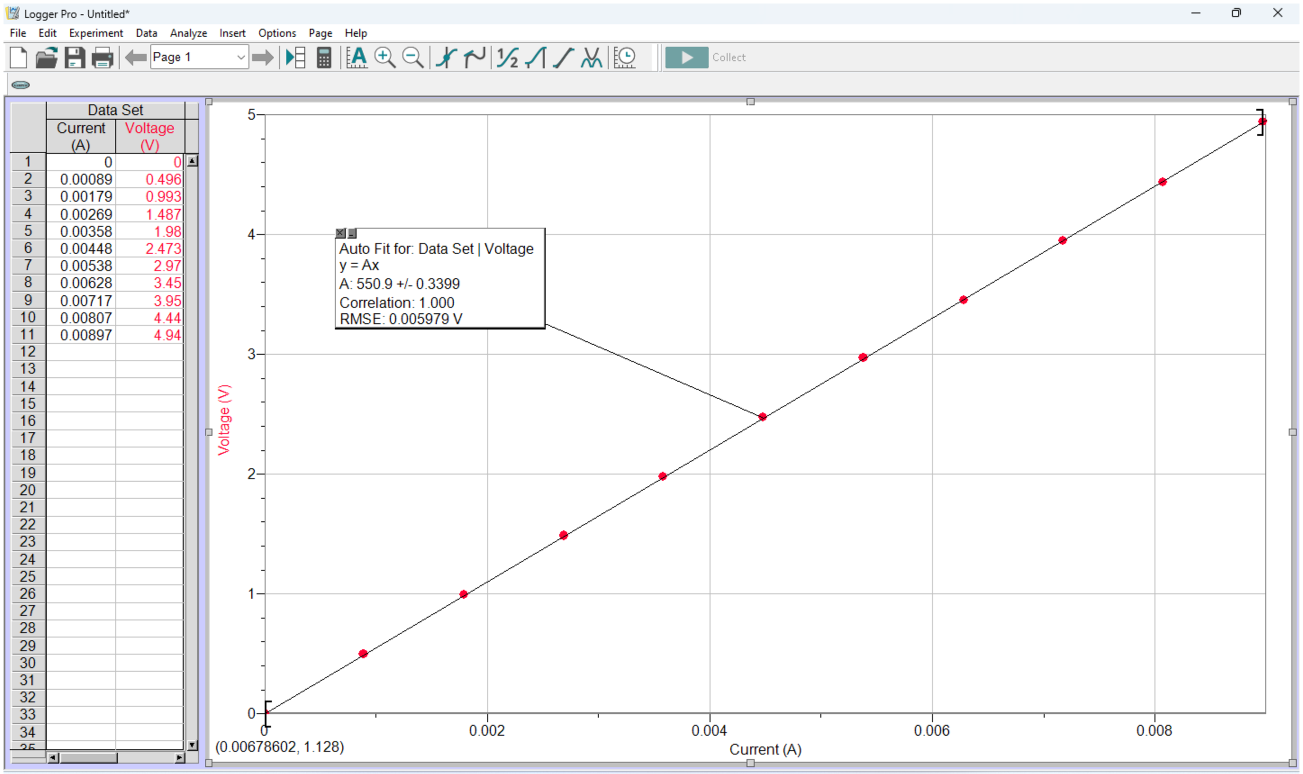


Figure 2. Voltage Current Graph. The measured voltage (V) is on the y-axis and the measured current (A) is on the x-axis. The slope of the graph, 550.9 V/A, represents the calculated resistance of the resistor in the circuit. The uncertainty of the slope, 0.3399 V/A, is the calculated uncertainty of the resistance.

4. Measure the resistance of the resistor by disconnecting it from the circuit and connecting it to a DMM set to read resistance. Record the value in your table.

5. Calculate the uncertainty of the resistance reading. The uncertainty of the Fluke 75 for resistance is 0.5% of the reading plus one unit of the least significant digit (except for the most sensitive scale, <320 Ω, where the manual says to add 2×LSD). Here are some examples.

Fluke 75 Reading	LSD	Formula
97.1 W	0.1 W	(0.005*97.1 W) + 0.2 W = 0.686 W
1189 W	1 W	(0.005*1189 W) + 1 W = 6.945 W
12.64 kW	0.01 kW	(0.005*12640 W) + 10 W = 73.20 W

6. Calculate the relative uncertainties in the two determinations of resistance. Use the ratio test to compare the resistance obtained from the graph to the resistance measured by the DMM. **Paste the comparison table here. Include a table caption.**

Step 6

Resistance from slope		
R (Ω)	abs unc R (Ω)	rel unc R (%)
550.9	0.3	0.06%

Resistance from DMM		
R (Ω)	abs unc R (Ω)	rel unc R (%)
551	3.8	1%
	Ratio Test	0.0244

Table 2. Calculated and Measured Resistance Comparison Table. The calculated resistance, or slope resistance, comes from the slope of a line made from measured voltage and current. The measured resistance, or resistance from DMM, comes from the value measured by a multimeter. The absolute uncertainty of the measured resistance is the lowest significance digit plus 0.5% of the measured resistance. The calculated and measured resistances agree according to the ratio test.

7. In the spreadsheet, record the *nominal value* and *manufacturing tolerance* (which is the relative uncertainty) indicated by the color-coding on the resistor. (From the side with the color closest to the end of the resistor, the four colors give the first digit, the second digit, the number of zeros, and the tolerance: green, blue, brown, gold means 560 ± 5% ohms.) Calculate the absolute uncertainty and use the ratio test to compare these values to the resistance measured by the DMM. **Paste the comparison table here. Include a table caption.**

Nominal Resistance		
Color R (Ω)	rel unc (%)	abs unc R (Ω)
561	5%	28.05
	Ratio test Nomial vs. DMM	0.31

Table 3. Measured and Nominal Resistance Comparison Table. The nominal resistance comes from the colored band on the resistor. The resistor has a green, blue, and brown band indicating that is has a resistance of 561Ω. It has had a gold band indicating that it has a relative uncertainly of 5% of the total resistance. The nominal resistance and the measured resistance agree according to the ratio test.

<u>Part II: Series and Parallel Combinations</u>

8. Look at the color codes and identify one 100 Ω, two 1 kΩ and one 10 kΩ resistor. Attach the resistors in the holders and label each resistor with a piece of drafting tape.

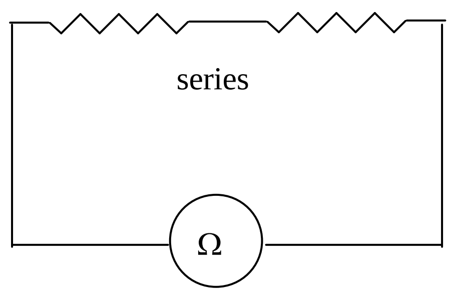
9. Use the DMM to measure the actual resistance of each of these four resistors (DMM on Ω setting). Calculate the uncertainty in these measurements as in step 5. Record the resistance and the uncertainty in proper tables of the spreadsheet. **Paste the individual resistances table here. Include a table caption.**

Individual Resistances	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	R_4 (Ω)
Nominal (from color codes)	100	1000	1000	10000
Measured value (from DMM)	98.8	992	1000	9980
abs uncertainty	0.694	5.96	6	59.9
rel uncertainty (no units) (%)	0.7%	0.6%	0.6%	0.6%

Table 4. Individual Resistance. The nominal values come from the colored band on the resistors. The measured value came from the value shown on the multimeter. The measured values were usually slightly lower than the nominal values. The absolute uncertainty was calculated by taking the lowest significance digit plus 0.5% of the measured value. If the total measured value was below 320Ω then 2 times the LSD was used.

Series

10. Connect the 100 Ω resistor in <u>series</u> with one of the 1 kΩ resistors.



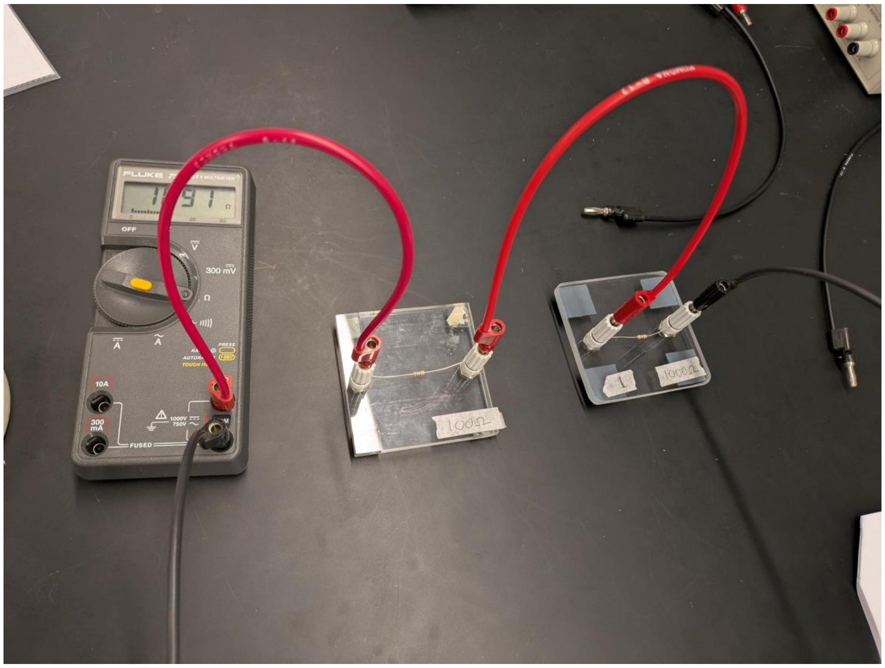


Figure 4. Series Circuit. The series circuit connects a multimeter set to measure resistance to multiple resistors. The resistors are connected by the red path cords and the black patch cord connects the multimeter to the final resistor of the series. In this example the series connects a 100Ω and a 1000Ω resistor.

11. The results of steps 12-16 will all end up in your Excel tables for resistors in series. <u>Display all measured values as shown by the DMM and the absolute uncertainty to the same number of decimal places</u>.

12. We predict that the equivalent resistance of two resistors in series should be given by $R_{\text{series}} = R_1 + R_2$. Use your measured values of the individual resistances to calculate the predicted equivalent resistance of this combination and propagate the uncertainties from R_1 and R_2. Because the individual resistances are added, the predicted absolute uncertainty is the sum of the individual absolute uncertainties.

13. Use the DMM to measure the equivalent resistance of the series combination and its absolute uncertainty, using the method of step 5.

14. For the series combination, compare your predicted value and experimental measurements using the ratio test. **Paste the tables for the measurements, uncertainties, and comparisons here.**

Nominal 100 Ω & 1 kΩ	Measured		Calculated	Measured
	R_1 (Ω)	R_2 (Ω)	$R_{series12}$ (Ω)	$R_{series12}$ (Ω)
value	98.8	992	1090.8	1091
abs uncertainty	0.7	6	6.7	6.455
rel uncertainty (no units) (%)	0.70%	0.60%	0.61%	0.59%
			Ratio test	0.0153

Table 5. 100Ω and 1000Ω Series Resistance. The measured values were calculated from the measured resistance of the individual resistors. The calculated series resistance was calculated by adding the values of the individual resistors. $R_T = R_1 + R_2$. The absolute uncertainty of the series resistance was calculated by adding the absolute uncertainty of the individual resistors. The measured series resistance was measured by a multimeter. The measured and calculated values agree according to the ratio test. Similar results were observed for series with 1000Ω and 10000Ω resistors as well as two 1000Ω resistors.

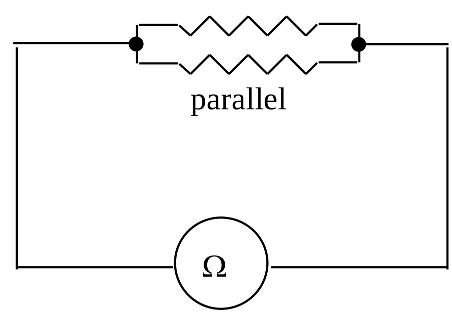
15. Repeat steps 12-14 with 1 kΩ & 10 kΩ resistors.

Nominal 1 kΩ & 10 kΩ	Measured		Calculated	Measured
	R_2 (Ω)	R_4 (Ω)	$R_{series24}$ (Ω)	$R_{series24}$ (Ω)
value	992	9980	10972	10890
abs uncertainty	6.0	60	65.9	64.45
rel uncertainty (no units) (%)	0.60%	0.60%	0.60%	0.59%
			Ratio test	0.629

16. Repeat steps 12-14 with 1 kΩ & 1 kΩ resistors.

Nominal 1 kΩ & 1 kΩ	Measured		Calculated	Measured
	R_2 (Ω)	R_3 (Ω)	$R_{series23}$ (Ω)	$R_{series23}$ (Ω)
value	992	1000	1992	1993
abs uncertainty	6.0	6	12.0	10.965
rel uncertainty (no units) (%)	0.60%	0.60%	0.60%	0.55%
			Ratio test	0.0436

Parallel



17. Connect the 100 Ω resistor in parallel with one of the 1 kΩ resistors. We predict that the equivalent resistance should be given by $\frac{1}{R_{\text{parallel}}} = \frac{1}{R_1} + \frac{1}{R_2}$. Use your measured values of the individual resistances to calculate the predicted equivalent resistance of this combination and its absolute uncertainty. *The 8 cells for the relative and absolute uncertainties for the calculated values have been preloaded with formulas for you.* Display two significant figures for the absolute and relative uncertainties. Display the values to the same number of decimals places as the absolute uncertainty. Display all of the absolute uncertainties to one significant figure or to the nearest integer value of resistance (for example, 65 Ω) and the final results to the same number of decimal places. Display two significant figures for the relative uncertainties and the ratio test. Note that all of the entries with units involve ohms, not kilo-ohms.

18. Use the DMM to measure the equivalent resistance of the parallel combination and its uncertainty, using the method of step 5.

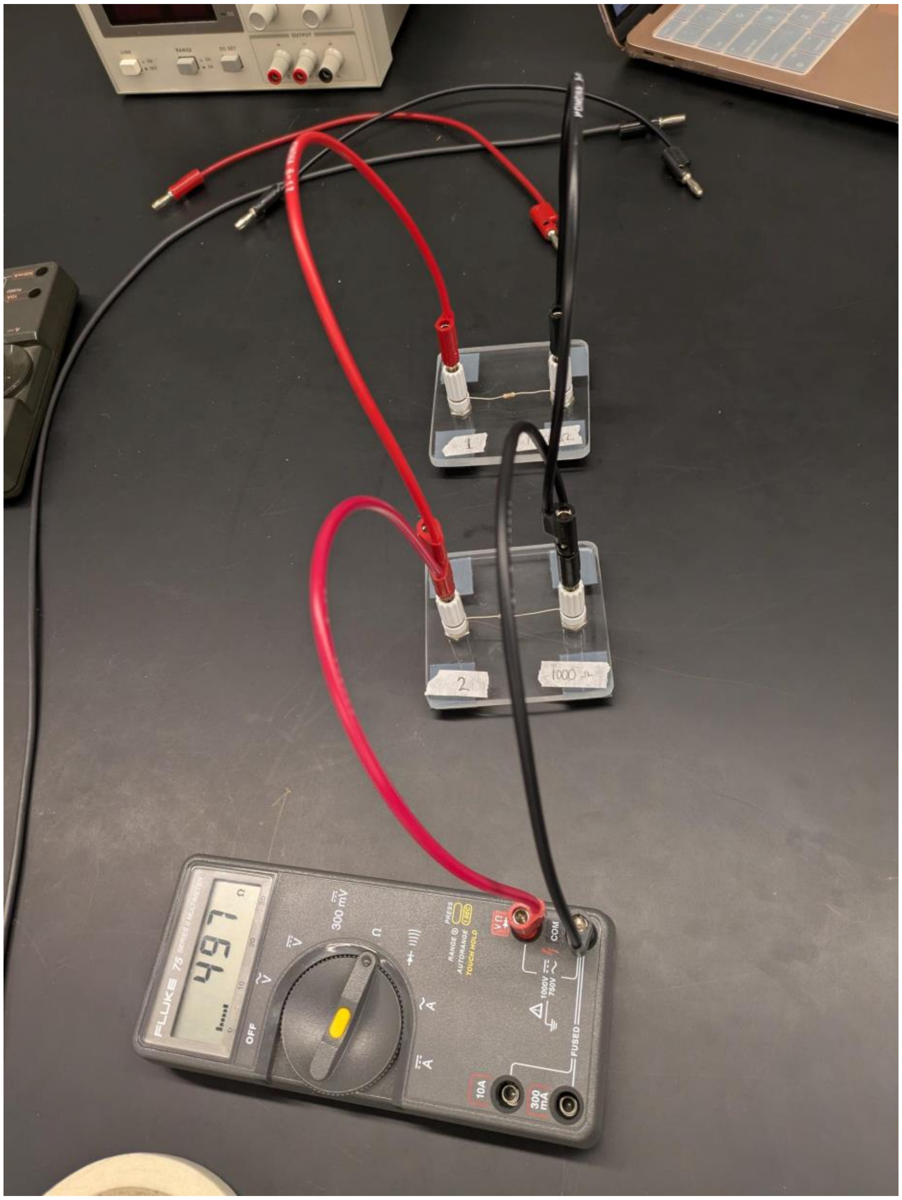


Figure 3. Parallel Circuit. The parrel circuit connects multiple connected resistors to a multimeter. The resistors are connected by red patch cords and black patch cords. In this example, two 1000Ω resistors are connected.

19. For the parallel combination, compare your predicted value and experimental measurements using the ratio test. **Paste the tables for the measurements, uncertainties, and comparisons here.**

Nominal 100 Ω & 1 kΩ	Measured	
	R_1 (Ω)	R_2 (Ω)
value	98.8	992
abs uncertainty	0.7	6
rel uncertainty (no units) (%)	0.70%	0.60%

Calculated				Measured
$1/R_1$ (1/Ω)	$1/R_2$ (1/Ω)	$1/R_{parallel12}$ (1/Ω)	$R_{parallel12}$ (Ω)	$R_{parallel12}$ (Ω)
0.0101	0.00101	0.0111	89.9	89.9
7E-05	6E-06	8E-05	0.6	0.6
0.70%	0.60%	0.69%	0.69%	0.72%
			Ratio test	0.038

Table 6. 100Ω and 1000Ω Parallel Resistance. The measured values were calculated from the measured resistance of the individual resistors. Using the equation $1/R_T = 1/R_1 + 1/R_2$. The absolute uncertainty was calculated accordingly. The measured series resistance was measured by a multimeter. The measured and calculated values agree according to the ratio test. Similar results were observed for parallel circuit with 1000Ω and 10000Ω resistors as well as two 1000Ω resistors.

20. Repeat steps 17-19 with 1 kΩ & 10 kΩ resistors.

1 kΩ & 10 kΩ	R_2 (Ω)	R_4 (Ω)
value	992	9980
abs uncertainty	6.0	60
rel uncertainty (no units) (%)	0.60%	0.60%

Calculated				Measured
$1/R_2$ (1/Ω)	$1/R_4$ (1/Ω)	$1/R_{parallel24}$ (1/Ω)	$R_{parallel24}$ (Ω)	$R_{parallel24}$ (Ω)
0.00101	0.000100	0.00111	902	901

6E-06	6E-07	7E-06	5	5.5
0.60%	0.60%	0.60%	0.60%	0.61%
			Ratio test	0.12

21. Repeat steps 17-19 with 1 kΩ & 1 kΩ resistors.

Nominal 1 kΩ & 1 kΩ	Measured	
	R_2 (Ω)	R_3 (Ω)
value	992	1000
abs uncertainty	6.0	6
rel uncertainty (no units) (%)	0.60%	0.60%

Calculated				Measured
$1/R_2$ (1/Ω)	$1/R_3$ (1/Ω)	$1/R_{\text{parallel23}}$ (1/Ω)	$R_{\text{parallel23}}$ (Ω)	$R_{\text{parallel23}}$ (Ω)
0.00101	0.001	0.00201	498	497
6E-06	0.000006	1E-05	3.0	3.485
0.60%	0.60%	0.60%	0.60%	0.70%
			Ratio test	0.153200431

Part III: Design a more complicated combination

22. Using one, two, three, or four of the four resistors used in part II, design a combination that you expect to have an equivalent resistance of approximately 600 Ω.

23. Draw the circuit diagram and use your measured values of the individual resistances from step 9 to calculate the expected equivalent resistance. Record the measured resistances and the calculated equivalent resistance in a table. You do not need to find the uncertainty of the equivalent resistance for this calculation. **Paste a picture of your circuit diagram here. Include a caption.**

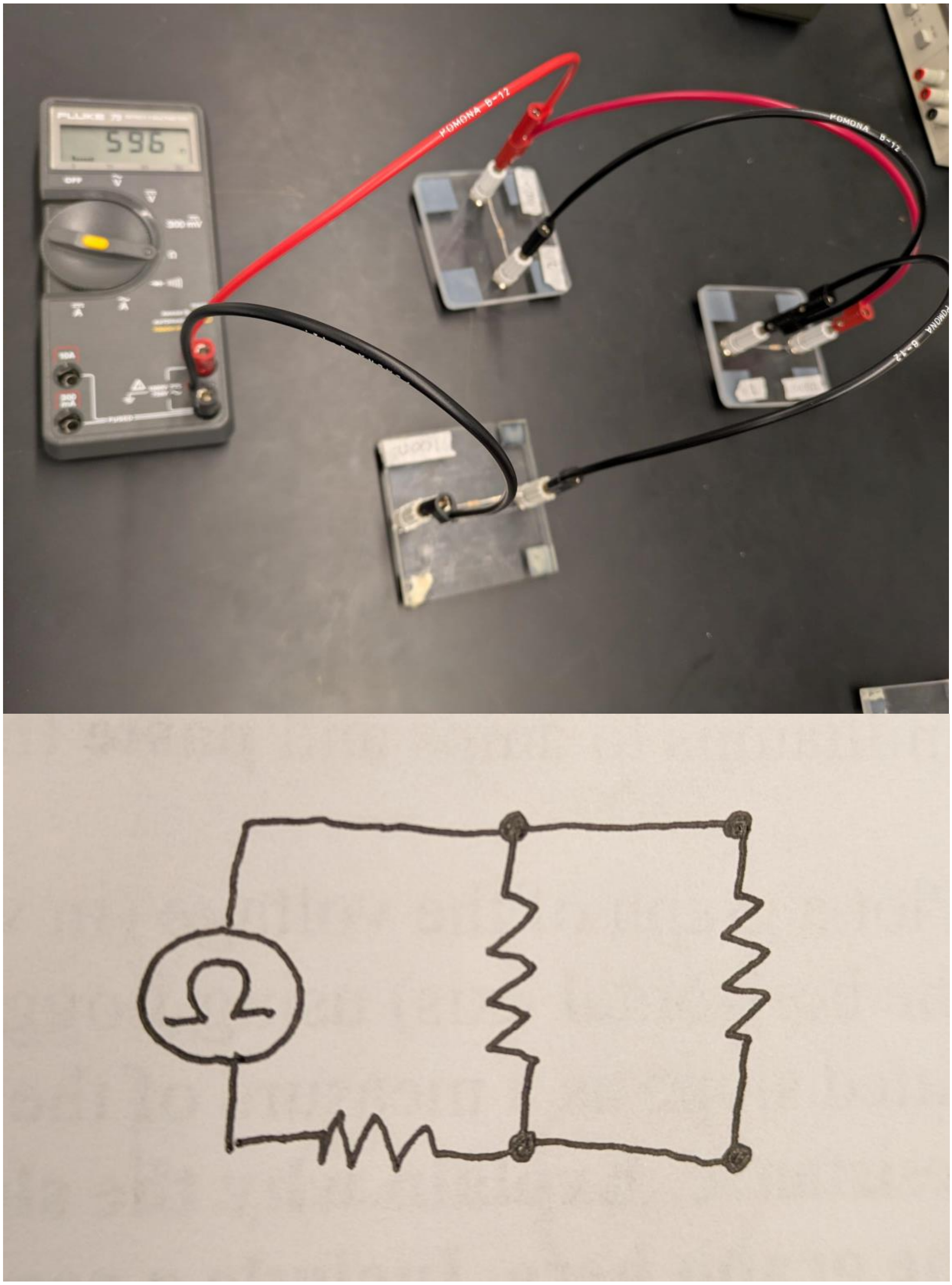


Figure 4. Complex Circuit. A circuit with a resistance of approximately 600Ω was created by having two 1000Ω resistors in parallel and a 100Ω resistor in series. The resulted in a resistance of 596Ω as measured by the multimeter.

24. Build the circuit and use the DMM to measure the equivalent resistance directly. Comment <u>qualitatively</u> on the agreement between calculated and measured equivalent resistances.

Propagation of uncertainty and the ratio test are not required. **Paste your table here. Include a table caption.**

Measured R's used (Ω)	Calculated $R_{combination}$ (Ω)	Measured $R_{combination}$ (Ω)
1000	597	596
992		
98.8		

Table 7. Complex Circuit Resistance. Three resistors were used to create a circuit with a resistance of approximately 600Ω. Two resistors with 1000Ω and 992Ω resistance were in parallel, resulting in a resistance of 497Ω and a 98.8Ω resistor was added in parallel to create a circuit with a measured resistance of 596Ω. The calculated resistance was calculated by adding the total previously measured resistance for a total of 597Ω. The calculated resistance and measured resistance have a 1Ω difference.

Discussion questions:

1. If two resistors are combined in series is the equivalent resistance greater than the largest individual resistance, less than the smallest individual resistance, or in between the two resistances?
2. If two resistors are combined in parallel is the equivalent resistance greater than the largest individual resistance, less than the smallest individual resistance, or in between the two resistances?

   1. If two resistors are combined in series then the resulting resistance will be the total of the two resistance. So it will be greater than the individual resistance of the strongest resistor in the series.
   2. When two resistors are combined in parallel the resulting resistance will be $1/R_T = 1/R_1 + 1/R_2$. So it will be below the resistance of the weakest resistor.

Analysis:

Write a brief analysis of the experiment focusing on any systematic and/or random errors.

All results agreed according to the ratio test. The absolute uncertainty of resistance is relatively high, so it is relatively easy to make the values agree. Combining a 100Ω and 1000Ω resistor in a series circuit results in a circuit with a resistance of 1091±6Ω while combining them in a parallel circuit results in a circuit with a resistance of 89.9±6Ω. This follows the logic that $R_{series} = R_1+R_2$ and $1/R_{parallel} = 1/R_1 + 1/R_2$. Similar results can be observed for circuit with 1000Ω and 10000Ω resistors and two 1000Ω resistors.

Conclusion:

Write a brief sentence or two stating the main results of the experiment.

Resistance can be calculated from the current and voltage using the equation R = V/I. Combining resistors in a series circuit increases the resistance while connecting them in a parallel circuit decreases resistance. By combining the two types of circuits you can create a

circuit with a specified resistance. I really enjoyed trying to create a circuit with a specific resistance and would like to do more work with that.

Final remarks
Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page. Double check that your Excel sheet, graphs, and Logger Pro files are saved in your folder on the Team. Clean up your lab station. Put the equipment back where you found it. Make sure that you logout of Moodle and your email, then log out of the computer. Check with the lab instructor to make sure that they received your submission before you leave.