LAKE FOREST COLLEGE
Department of Physics

Physics 115 **Experiment #6: Kirchhoff's Rules v3** 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.

Experimental goal
Test Kirchhoff's loop and junction rules:

(1) $\sum_{\substack{\text{around}\\\text{loop}}} \Delta V = 0$

(2) $\sum_{\text{at junction}} I = 0$ (positive for currents going in and negative for currents coming out)

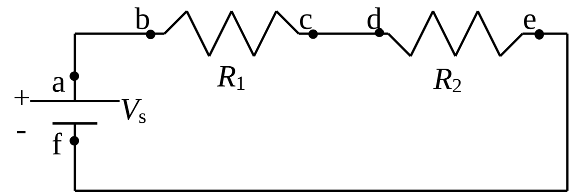
or equivalently $\sum_{\substack{\text{into}\\\text{junction}}} I = \sum_{\substack{\text{out of}\\\text{junction}}} I$ (all positive)

Background
A voltmeter measures the difference in electrical potential (voltage). Recall from Experiment #5 that voltmeters are connected in parallel with circuit elements. Let $\Delta V_{\mathrm{ba}} = V_{\mathrm{b}} - V_{\mathrm{a}}$; this means to connect the voltmeter port (marked "VΩ" and usually connected to a red wire) to point b and the common port (COM) to point a (and usually connected to a black wire). If $V_{\mathrm{b}} > V_{\mathrm{a}}$ then the voltmeter port is at a higher potential than the common port and the reading will be positive.

An ammeter measures the rate at which charge flows past a point in a circuit. If current (defined as moving *positive* charges) enters the ammeter port (marked "300 mA") and exits the common port, then the reading will be positive. Remember, ammeters are connected in series with the circuit elements, hence you must *break* (disconnect) the circuit and insert the ammeter in order to measure current.

Procedure

Part I: Voltage Divider



Circuit #1

1. You have been given two resistors with nominal values of $R_1 = 1.0\ \text{k}\Omega$ and $R_2 = 2.2\ \text{k}\Omega$. Measure each resistance with an ohmmeter. The resistance accuracy is 0.5% of the reading + 1 count in the least significant digit. Example: For a nominal $1.0\ \text{k}\Omega$ resistor, the absolute uncertainty in a typical reading is $\delta R = (0.005)(983\ \Omega) + 1\ \Omega = 6\ \Omega$.

2. Calculate the equivalent resistance for your two resistors in series and its uncertainty. **Insert Table I here. Include a caption.**

			Calculated
	R_1 (Ω)	R_2 (Ω)	R_{series} (Ω)
value	997	2173	3170
abs. unc.	6.0	12	18
rel. unc. (%) (no units)	0.6%	0.5%	0.6%

Table 1. Series Resistance. R_1 has a nominal resistance of 1002 $\pm$ 50Ω. The measured resistance of 997 ±6Ω falls into this region. R_2 has a nominal resistance of 2222±111Ω. The measured resistance of 2170±12Ω falls within this region. The absolute uncertainly came from adding one lowest significant digit to 0.5% of the overall value. R_{series} was calculated by adding the individual resistance since the circuit was a series circuit.

3. Assemble Circuit #1. Use a DMM as a voltmeter to monitor the potential difference of the power supply. The power supply is set so that $V_s = \Delta V_{af} = 5.00$ V. Keep this voltmeter in place throughout this part of the experiment and make sure that the power supply voltage does not drift with time. The voltage accuracy is 0.4% of the reading + 1 count in the least significant digit. Example: $\delta V_s = (0.004)(5.00\ \text{V}) + 0.01\ \text{V} = 0.03\ \text{V}$.

4. Predict the amount of current through the power supply (I) if the power supply has the voltage set in step 3. Find the uncertainty in this predicted current. **Insert Table II here. Include a caption.**

	Measured
	V_s (V)
value	4.90
abs. unc.	0.03
rel. unc. (%) (no units)	0.6%

	Predicted current I_{pred} (mA)
value	1.55
abs. unc.	0.02
rel. unc. (%) (no units)	1%

Table 2. Measured Voltage and Predicted Current for Series Circuit. The voltage, V_s, was measured with a Fluke multimeter. The absolute uncertainty was calculated by adding one lowest significant digit to 0.4% of the overall value. The predicted current, I_{pred}, was calculated by dividing the measured voltage by the calculated resistance. The relative uncertainty was calculated by adding the relative uncertainty of the measured voltage with the relative uncertainty of the calculated resistance. The absolute uncertainty was calculated by multiplying the value by the relative uncertainty.

5. Use a second DMM as an ammeter to measure the current at various points in the circuit. Measure the current at points *a*, *c*, and *e* (i.e. I_a, I_c, and I_e) shown in Circuit #1. Use the sign of the ammeter readings to determine the direction of the currents. The current accuracy is 1.5% of the reading + 2 counts in the least significant digit. Example: For $I = 1.56 \text{ mA}$, $\delta I = (0.015)(1.56 \text{ mA}) + 0.02 \text{ mA} = 0.04 \text{ mA}$. Compute the ratio test between predicited and measured currents for each current. **Draw a circuit diagram with arrows indicating the direction for each of your measurements. Insert Table III and the circuit diagram here. Include a caption.**

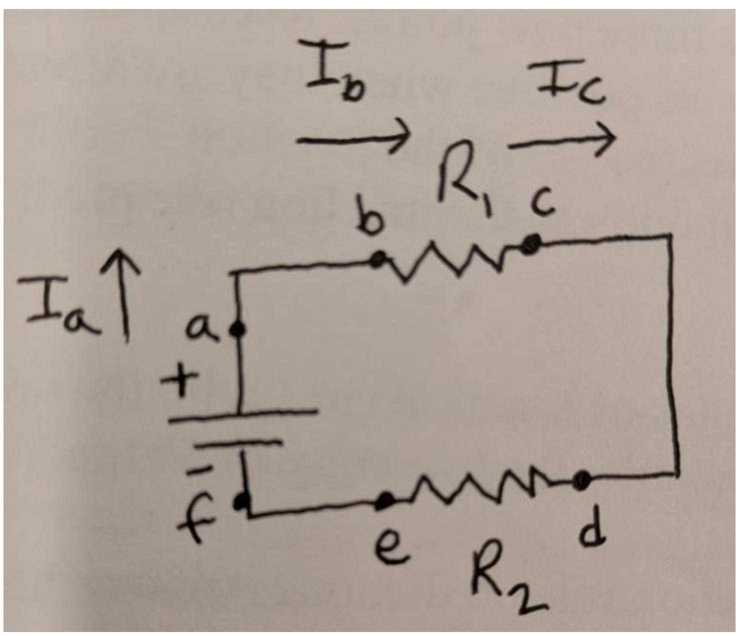


Figure 1. Series Circuit Diagram. The power supply was set to an output of 5.00V. A multimeter connected to the power source, not pictured in the diagram, measured an output The points, a, b, c, d, e, and f represent points where current and voltage were measured. R_1 had a resistance of 997 ±6Ω and R_2 had a resistance of 2170±12Ω.

	Measured		
	I_a (mA)	I_c (mA)	I_e (mA)
value	1.56	1.56	1.56
abs. unc.	0.04	0.04	0.04
rel. unc. (%) (no units)	3%	3%	3%

Ratio Test	
I_{pred} and I_a	0.23
I_{pred} and I_c	0.23
I_{pred} and I_e	0.23

Table 3. Measured current around a series circuit. The current was measured at points a, c, and e. The current had a value of 1.56 ±0.04A at all measured points. The absolute uncertainty of the measurement was calculated by adding 0.02A to 1.5% of the total value. The measured values agree with the predicted values according to the ratio test.

6. Are your measurements consistent with the idea that the current should be the same everywhere in this circuit? Do your measurements agree with your predicted current? **Answer here**.

The measurements were consistent with the idea that current should be the same at all points along the circuit. The current was the same at all points measured along the circuit. The measurements agree with the predicted value according to the ratio test. The idea that all the measurements are the same is also cemented by all the ratio tests having the same value.

7. Use the second DMM as a voltmeter to measure the following potential differences ΔV_{ba}, ΔV_{cb}, ΔV_{dc}, ΔV_{ed}, and ΔV_{fe}. These potential differences may be positive, negative, or zero. See step 3 for uncertainties in voltage readings. Use absolute values to ensure that uncertainties are positive.

8. Calculate the sum of the potential differences around the loop (including ΔV_{af}). Is your sum of the potential differences within uncertainty of zero? Perform the ratio test. **Answer here**. **Insert Table IV here. Include a caption.**

	Measured					
	ΔV_{ba} (V)	ΔV_{cb} (V)	ΔV_{dc} (V)	ΔV_{ed} (V)	ΔV_{fe} (V)	ΔV_{af} (V)
value	0.00	-1.56	0.00	-3.42	0.00	4.99
abs. unc.	0.01	0.00	0.01	0.00	0.01	0.03

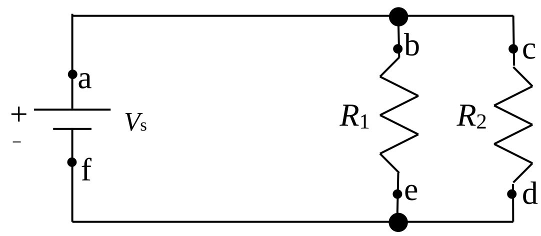
	$\Sigma\Delta V$ (V)
value	0.01
abs. unc.	0.06

Ratio Test
$\Sigma\Delta V$ and 0 V
0.17

Table 4. Voltage across a series circuit. The voltage was measured with a Fluke multimeter. The first letter in the subscript indicated the positive point of the measurement. ΔV_{cb} and ΔV_{ed} are negative since they cross resistors. ΔV_{af} is positive since it crosses the power supply. The absolute uncertainty of the current was calculated by adding one lowest significant digit to 0.4% of the total value. The measured value agrees with 0 according to the ratio test.

Part II: Current Divider

9. Take the data from step 1 and calculate the equivalent resistance for your two resistors in parallel. Calculate the equivalent resistance. Formulas for the uncertainty calculations are pre-filled in the spreadsheet. **Insert Table V here. Include a caption.**



Circuit #2

	Measured		Calculated			
	R_1 (Ω)	R_2 (Ω)	$1/R_1$ (1/Ω)	$1/R_2$ (1/Ω)	$1/R_{parallel}$ (1/Ω)	$R_{parallel}$ (Ω)
value	997	2173	0.00100	0.000460	0.001463	683.4
abs. unc.	6.0	12	0.0000060	0.0000025	0.0000085	4.0
rel. unc. (%) (no units)	0.6%	0.5%	0.6%	0.5%	0.6%	0.6%

Table 5. Parallel Resistance. R_1 has a nominal resistance of $1002 \pm 50\Omega$. The measured resistance of 997 ±6Ω falls into this region. R_2 has a nominal resistance of 2222±111Ω. The measured resistance of 2170±12Ω falls within this region. The absolute uncertainly came from adding one lowest significant digit to 0.5% of the overall value. $R_{parralel}$ was calculated using the equation $R_{parallel} = (1/R_1 + 1/R_2)^{-1}$ for a total of 683.4±4.0Ω.

10. Assemble Circuit # 2. Use the first DMM as a voltmeter to measure the potential difference of the power supply.

11. Predict the amount of current through the power supply (I_{pred}) if the power supply has the voltage measured in step 10. Find the uncertainty in this predicted current. **Insert Table VI here. Include a caption.**

	Measured V_s (V)
value	4.90
abs. unc.	0.030
rel. unc. (%) (no units)	0.6%

	Predicted current through power supply I_{pred} (mA)
value	7.17
abs. unc.	0.09
rel. unc. (%) (no units)	1%

Table 6. . Measured Voltage and Predicted Current for Parallel Circuit. The measured voltage was the same as the voltage for part one. The predicted current, I_{pred}, was calculated by dividing the measured voltage by the calculated resistance. The relative uncertainty was calculated by adding the relative uncertainty of the measured voltage with the relative uncertainty of the calculated resistance. The absolute uncertainty was calculated by multiplying the value by the relative uncertainty.

12. Use the DMM as an ammeter to measure I_a, I_b, and I_c at the points shown in Circuit #2. *This will require you to unplug some of the wires*. Determine the direction of each the currents based on the sign of the ammeter reading. Draw a circuit diagram with arrows indicating the direction of the current at each of these three points. Record the currents in Table VII of your Excel sheet. Indicate the currents as positive when they are directed into the top junction and negative when they are directed out of the junction. Perform a Ratio test comparing the sum of currents at the top junction to the junction rule prediction of zero.

13. Use the DMM as an ammeter to measure I_d, I_e, and I_f at the points shown in Circuit #2. *This will require you to unplug some of the wires.* Determine the direction of each the currents based on the sign of the ammeter reading. Draw arrows on your previous circuit diagram indicating the direction of the current at each of the three new points. Record the currents in Table VII of your Excel sheet. Indicate the currents as positive when they are directed into the bottom junction and negative when they are directed out of the junction. Perform a Ratio test comparing the sum of currents at the bottom junction to the junction rule prediction of zero.

14. Perform ratio tests to determine if your measurements of I_a and I_f agree with the predicted current I? Include these in Table VII of your Excel table. **Paste a copy of Table VII here**.

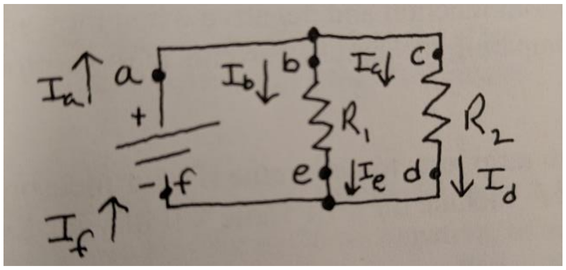


Figure 2. Parallel Circuit Diagram. The power supply was set to an output of 5.00V. A multimeter connected to the power source, not pictured in the diagram, measured an output The points, a, b, c, d, e, and f represent points where current and voltage were measured. R_1 had a resistance of 997 ±6Ω and R_2 had a resistance of 2170±12Ω. There are two junctions in this circuit. J_{abc} has current from point a going in and going out to points b and c. J_{def} has currents from points d and e going in and out to point f.

	Measured			Calculated
	I_a (mA)	I_b (mA)	I_c (mA)	ΣI at top junction (mA)
value	-7.10	4.90	2.20	0.00
abs. unc.	0.09	0.094	0.053	0.23
rel. unc. (%) (no units)	1%	2%	2%	#DIV/0!
	Ratio test comparing ΣI to zero			0
	Ratio test comparing I_a to I_{pred}			0.41

	Measured			Calculated
	I_d (mA)	I_e (mA)	I_f (mA)	ΣI at bottom junction (mA)
value	-2.20	-4.97	7.24	0.07
abs. unc.	0.01	0.05	0.13	0.20
rel. unc. (%) (no units)	0.6%	1%	2%	280%
	Ratio test comparing ΣI to zero			0.36
	Ratio test comparing I_f to I_{pred}			0.33

Table 7. Current across a parallel circuit. The currents going into the junctions are negative and the current coming out of the junctions are positive. The sum of the current at J_{abc} is 0.00±0.23A. Since the values of the current is 0, we get an error when calculating the

relative uncertainty. The current at J_{def} is 0.07±0.20A. Since the absolute uncertertainty is very large in comparison to the values, the relative uncertainly is very large. The sum of the currents at each junction agrees with 0 according to the ratio test. The current at the power supply, I_a and I_f agree with the predicted current according to the ratio test.

15. Do your current measurements agree with the junction rule prediction? **Answer here.**
Kirchhoff's junction rule states that the sum of the currents at each circuit will be 0A. The measurements agree with this rule because, although the resulting current may not have been exactly 0A, the values agree with 0 according to the ratio test.

16. Do your current measurements at points *a* and *f* agree with the predicted current through the power supply? **Answer here.**
The measured current at points a and f agree with the predicted current according to the ratio test.

17. Use the DMM as a voltmeter to measure ΔV_{be}, ΔV_{cd}. Perform the ratio tests. Are these voltages within uncertainty of ΔV_{af} ? **Answer here**. **Insert Table VIII here. Include a caption.**

	ΔV_{be} (V)	ΔVcd (V)	ΔV_{af} (V)
value	4.90	4.90	4.90
abs. unc.	0.03	0.03	0.03
rel. unc. (%) (no units)	0.6%	0.6%	0.6%

	Ratio test
ΔV_{be} & ΔV_{af}	0.00
ΔV_{cd} & ΔV_{af}	0.00

Table 8. Voltage across a parallel circuit. The voltage was measured across each resistor, from b to e and c to d, and across the power supply, from point a to f. the current had a value of 4.90±0.03V at all measured points. The measured values agree with each other according to the ratio test.

Discussion questions

1. **Why is the circuit in Part 1 called a voltage divider?**
The series circuit is a voltage divider because the voltages changes along the circuit. Unlike a parallel circuit, it is not constant at all points in the circuit.

2. **For the voltage divider, which potential differences were positive, which were negative, and which were zero? Explain.**

The potential difference was negative when the voltage was measured across a resistor and was positive when the voltage was measured across the power supply. The voltage decreases because of the resistor and increased because of the power supply.

3. **As a charge travels around the circuit, its potential energy decreases. Where does that energy go?**

As the potential energy decreases, it becomes heat energy in the resistors. It also becomes some heat energy in the wires and multimeters but it is an insignificant amount so we consider out wires and multimeters to be ideal.

4. **Why is the circuit in Part 2 called a current divider?**

The parallel circuit is a current divider because the current changes along the circuit. Unlike a series circuit, a parallel circuit does not have constant current at all points.

5. **For the current divider, why are some of the currents that you measured equal and others are not equal?**

The currents that were equal travel on the same path but others were not equal because they took a different path. This is because the resistors did not have equal resistance.

Analysis

Did all of your predictions agree with your measurements?

All predictions agreed with the measurements according to the ratio test.

Conclusion

Summarize what you conclude from the results of your experiment.

Series circuits have constant current. This series circuit had a current of 1.56 ±0.04A at all points in the circuit. The sum of all the voltages around a series circuit is 0 according to Kirchhoff's rule. The series circuit had a voltage of 0.01±0.06Vwhich agrees with 0 according to the ratio test.

Parallel circuits have constant voltage. This parallel circuit has a voltage of 4.90±0.03V at all points in the circuit. The sum of all the currents in a junction will be 0 according to Kirchhoff's rule. The parallel circuit had a current of 0.00±0.23A at one junction and 0.07±0.20A at the other junction. Both of these values agree with 0 according to the ratio test.

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.