Report for Experiment #17

DC Circuits

Nicholas DePatie

Lab Partners: Ryan Polesovsky, Samantha Yip, Thomas Bell, Thomas Richmond

TA: Benjamin Sung

March 2, 2021

Abstract

In this lab, Ohm's Law and Kirchhoff's Rules are explored through the measuring of voltages and currents within several circuit configurations. In particular, two EMFs were arranged in series and in parallel to determine how the EMFs behave. The actual resistance value was also calculated in multiple ways to prove the validity of Ohm's Law. The Loop and Junction Rules were used as well to sum voltages and currents in a circuit and further prove Ohm's Law. It was found that resistors in series are additive, while resistors in parallel are reciprocally additive, and EMFs in series are additive, too.

Introduction

This lab explored the various elements of DC circuits, such as basic resistors, voltmeters, and ammeters. These were arranged in various ways to understand the circuit elements used, gain experience with DC circuits in general and their various configurations, and to learn how to apply Kirchoff's rules in a practical application. In particular, we utilized the loop and junction rules listed below:

$$Equation\ 1, Loop\ Rule: \sum V = 0\ \ in\ a\ loop$$

$$Equation\ 2, Junction\ Rule: I_{in} = I_{out}\ at\ a\ junction$$

The loop rule states that the voltages of all components in a closed loop will sum to 0, while the junction rule states that the current flowing into a junction in a circuit must equal the total current flowing out. We also explored Ohm's Law, which states the voltage is proportional to the current and resistance:

$$Equation\ 3, Ohm's\ Law: V = IR$$

The equipment used in this lab consisted of two flashlight batteries, one variable DC power supply, two digital multimeters (DMM), circuit element box that will only be used for the resistors, 8 patch cables, and 4 alligator clips. The investigations covered two different yet related topics: investigation 1 dealt with the various configurations of EMFs on a circuit and the implications of those configurations (e.g. batteries in series vs parallel), while investigation 2 verified the tolerance value of the resistors and investigation 3 dealt with the implications of different configurations of resistors and verifying Ohm's law.

In investigation 1, the quantities being measured were the voltages of one battery and two batteries in series and in parallel. In investigation 2, the quantities being measure were the experimental resistance of the 100-ohm resistor, and the current and voltage across the resistor were used to calculate a theoretical value of the resistance. In investigation 3, the experimental resistance of the 470- and 1000-ohm resistors were found, and the voltage and current over the resistors in parallel and in series were found to calculate a theoretical resistance value for each to verify Ohm's law. Also, in investigation 3, the power over each resistor was calculated for each configuration.

Investigation 1

Investigation 1 deals with measuring the strength of the EMF of the battery used, as well as how the strength changes when the batteries are put in series or in parallel. The setup of this investigation requires 2 flashlight batteries, the patch cables, and the DMM set to the voltmeter mode and involves recording the voltages of the batteries (Circuit diagram in Figure 1), as well as recording them in series (Figure 2) and in parallel (Figure 3).

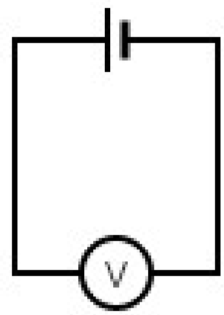

Figure 1

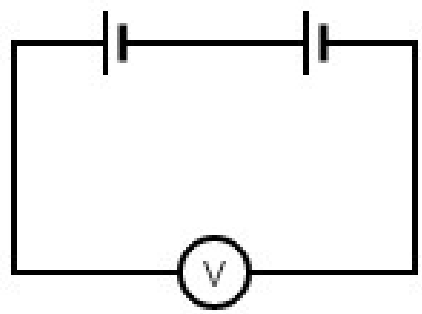

Figure 2

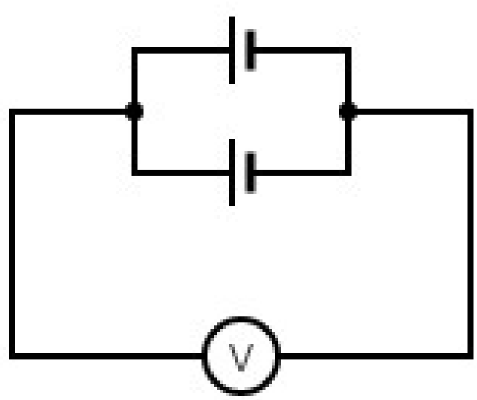

Figure 3

First, the DMM is switched to measure voltage and the first battery is connected to the DMM using the patch cables so the voltage across the battery is measured just as in Figure 1. Next, the battery is flipped so that the negative terminal of the battery is connected to the positive patch cable. This process is then repeated for the second battery. Then, the two batteries are connected in series just as in Figure 2 and the voltage is recorded. The batteries are also put in parallel, after, just as in Figure 3 to record the voltage. The data collected is shown in the data table below (Data Table 1).

Trial	Configuration	Voltage (V)	δVoltage(V)
Trial 1	Figure 1, Battery 1	1.5547	0.015547
Trial 2	Figure 1, Battery 1 Reversed	-1.5590	0.015590
Trial 3	Figure 1, Battery 2	1.4875	0.014875
Trial 4	Figure 1, Battery 2 Reversed	-1.4888	0.014888
Trial 5	Figure 2, Batteries in Series	2.8940	0.028940
Trial 6	Figure 3, Batteries in Parallel	1.4420	0.014420

Data Table 1 – The resulting voltages of batteries 1 and 2 in various configurations

The data in the table does make sense. Trials 2 and 4 are just the negative value of Trials 1 and 3, respectively, which makes logical sense since the batteries are just reversed. Trial 5's voltage value is equal to the sum of the two batteries voltages due to the additive nature of EMFs in series. Trial 6's voltage is equal to the voltage of just one battery which is in line with what is expected with EMFs in parallel.

When comparing Trial 1 and Trial 3, the batteries should be within a 1% difference margin of each other due to the meter having a precision of 1%. The values are close to each other but no within the 1% error margin given. This difference might be caused by the batteries possibly having had some use. This source of error is somewhat systematic, although we do not know if the batteries were recharged before the lab.

One real world application of using EMFs in series are increasing the total voltage in a circuit by adding more power. One real world application of using EMFs in parallel are charging batteries in parallel to charge them more efficiently. Using batteries in parallel might also result in longer lasting discharge of energy.

Investigation 2

Investigation 2 deals with measuring the resistance value of a 100-ohm resistor and verifying Ohm's Law. The materials used are two DMMs that act as a voltmeter and ammeter, 1 flashlight battery, patch cables, and jumper cables. The setup of the investigation is recording the resistance value, current, and voltage in various configurations (Figures 4, 5, 6, and 7).

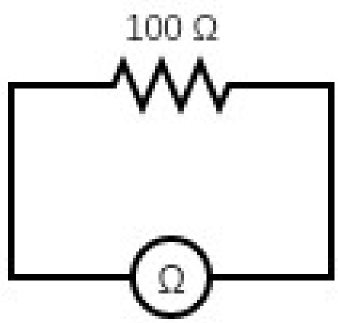

Figure 4

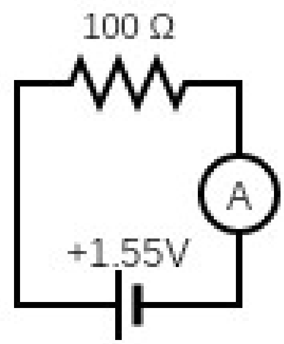

Figure 5

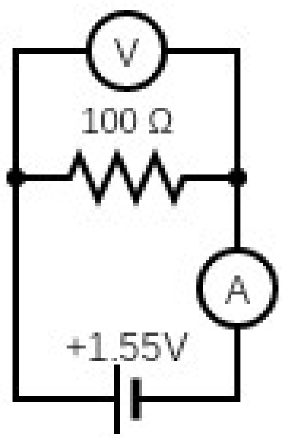

Figure 6

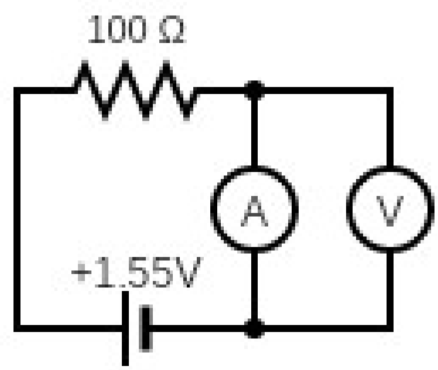

Figure 7

First, the DMM is used as an ohmmeter in the configuration of Figure 4 to measure the actual resistance of 100-Ohm resistor and is recorded in Data Table 2. All the values recorded in this investigation were put into Data Table 2. Next, the EMF of the battery is recorded using the configuration in Figure 1 in Investigation 1. Then, the current through the resistor is measured using the configuration in Figure 5. The configuration in Figure 5 is modified to measure the voltage difference across the resistor, resulting in the diagram in Figure 6, and the voltage is then recorded. Lastly, the voltmeter is unplugged and moved to measure the voltage difference across the ammeter like in Figure 7 and the burden voltage of the circuit is recorded.

Configuration	Value Measured	δ
Figure 4 (Actual resistance of 100-ohm resistor)	97.78 Ω	0.9778 Ω
Figure 1 (EMF of battery)	1.55 V	0.0155 V
Figure 5 (Current through resistor)	0.0141 A	$1.41*10^{-4}$ A
Figure 6 (Voltage across resistor)	1.398 V	0.01398 V
Figure 7 (Burden voltage of circuit)	0.0157 V	$1.57*10^{-4}$ V

Data Table 2 – Recorded values for each circuit configuration

The actual resistance of the 100-Ohm resistor was compared to the nominal resistance of 100 ohms and the nominal tolerance of ±10 Ω. The measured value of 97.78 Ω is within that nominal value.

Next, the voltage across the resistor and current through the resistor is used with Ohm's Law and compared with the actual resistance of the resistor measured in Figure 4 to verify the validity of Ohm's Law. The internal resistance of the battery is also calculated using the EMF of the battery, the voltage across the resistor, and the burden voltage of the circuit with the Loop Rule. Since the circuit is a closed loop, the Loop Rule says the sum of the voltages of all components of the circuit must be equal to zero, which is why it can be used in this case. These calculated values can be found in Data Table 3.

What is being calculated	Final Value	δ
Calculated Resistance (Using Ohm's Law)	99.53 Ω	0.0179 Ω
Internal Resistance of Battery (Using Loop Rule)	0.141 Ω	0.00141 Ω

Data Table 3 – Calculated values derived from Data Table 2

The error in Data Table 2 and the "Internal Resistance of Battery" was found from the 1% precision of the meter, while the "Calculated Resistance" error was found by comparing it to the "Actual resistance of 100-ohm resistor" in Data Table 2. This value for error is around 1.7%, which is slightly larger than the 1%. A possible source of error could be, like Investigation 1, that the battery was not sufficiently charged, although it would not have skewed the results much.

Investigation 3

In this investigation, networks of resistors were explored to verify the properties of resistors in series versus in parallel. This investigation required the DC power supply, two DMMs to act as the voltmeter and ammeter, and jumper cables. The setup of the investigation involves setting up the circuits as seen in Figures 8, 9, 10, and 11.

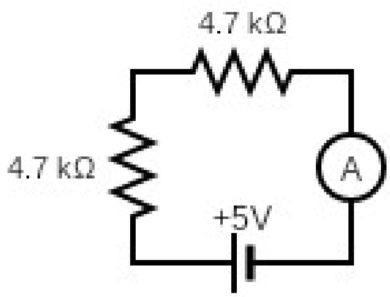

Figure 8

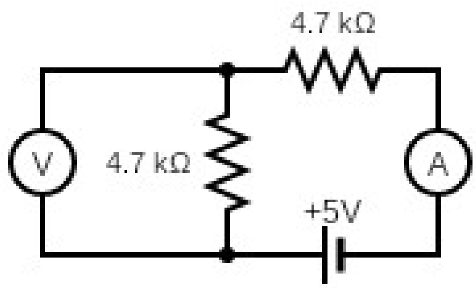

Figure 9

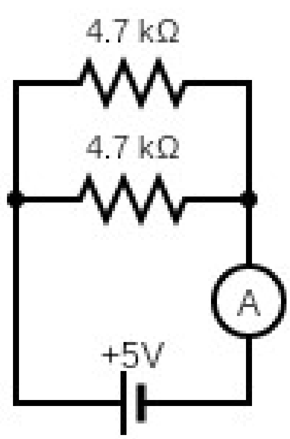

Figure 10

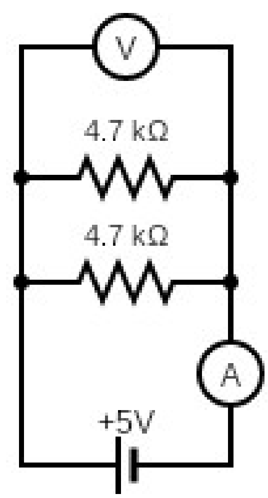

Figure 11

First, the DMM will be used as on ohmmeter to record the actual resistances of both the 470 -ohm resistor and 1000-ohm resistor using the configuration in Figure 4, Investigation 2. Next, the DC power supply is hooked up to a voltmeter just as in Figure 1 in Investigation 1 to find the EMF of the battery. This is done because the meter on the power supply is less precise than the voltmeter. Then, the two resistors are connected in series as in Figure 8 with an ammeter to measure the current which is recorded.

The voltages across every circuit element are then taken like in Figure 9 except repeated across every element excluding the power supply. All these values are recorded for the configuration. This process is then repeated for the resistors in the configuration in Figure 10, and then the voltages are measured the same way as in Figure 11. Specifically, for the resistors in parallel, the current over each resistor must be found. The raw data calculated is in the table below.

Resistor	Actual Resistance Recorded (Ω)	δ (Ω)
470 Ω	470.6	4.706
1000 Ω	989.4	9.894

Data Table 4 – Actual resistance of resistors

*Voltage for power supply was 4.9915 V with a 0.049915 V measurement error

Value Recorded	Resistors in Series (Figures 8 and 9)	Series δ	Resistors in Parallel (Figures 10 and 11)	Parallel δ
Current (A)	0.003399	$3.399*10^{-5}$	0.01558	$1.558*10^{-4}$
Voltage over 470Ω Resistor (V)	3.38	0.0338	4.991	0.04991
Voltage over 1000Ω Resistor (V)	1.61	0.0161	4.971	0.04971
Voltage over Current Meter (Burden Voltage) (V)	0.00026	$2.6*10^{-6}$	0.01238	$1.238*10^{-4}$
Current over 470Ω Resistor (A)			0.0106	$1.06*10^{-4}$
Current over 1000Ω Resistor (A)			0.00458	$4.58*10^{-5}$

Data Table 5 – Recorded values for series and parallel resistor networks

From this data, there is a lot of information that can be derived about the various circuits. Starting with the resistors in series, we can use the Loop Rule to sum all the voltages in the circuit and it should equal zero. Therefore, the sum of all the voltage drops in the system should equal the power supply voltage. The sum of all the voltage drops in the system is 4.991 V which, when compared to the 4.9915 V reading of the power supply, has an error of around 0.01% difference.

The power dissipated at every resistor can be found using Equation 4 where P is the power dissipated, V is the voltage across the resistor, and R is the actual resistance:

$$Equation\ 4: P = \frac{V^2}{R} = I^2 R$$

Either side of the equation is fine to substitute numbers into, but for this report, the voltage over resistance side was used. After plugging in the values, there is 0.0114 W dissipated over the 1000-ohm resistor and 0.00544 W dissipated over the 470-ohm resistor, with a 0.01732 error for both.

The experimental resistances can be calculated for the series as well by using Ohm's Law again. The experimental resistance of the 1000-ohm resistor is 994.91 Ω with a 0.5% difference when compared to the actual resistance reading. The experimental resistance reading of the 470-ohm resistor is 473.48 Ω with a 0.61% difference when compared to the actual resistance reading. This can also be done with the total resistance of both resistors, where the experimental sum is 1468.4 Ω with a difference of 0.58% when compared to the actual resistor sum, 1460 Ω. This can be done because the individual resistances can be added together when they are in a series using the Equation below that is an extension of the Loop Rule.

$$Equation\ 5, Resistance\ in\ Series:\ R_{eq} = R_1 + R_2 + \cdots + R_n$$

If the burden voltage was not accounted for, the voltage drop sum would be thrown off, but it would not be changed by much because of how small the burden voltage is. However, it is large enough to be significant.

Moving on to the resistors in parallel, we can calculate the total resistance again by using Ohm's Law once more. After plugging in the total current and total voltage, a total calculated resistance value is found to be 320.317 Ω with a 0.014 error value. The resistances of each resistor individually are calculated as well using Ohm's Law, resulting in the calculated resistance of the 470-ohm resistor being 468.96 Ω and the 1000-ohm resistor being 1089.76 Ω.

For resistors in parallel, the sum of the reciprocals of all the resistors in parallel equals the reciprocal of the total. The values calculated previously using Ohm's Law can be summed using this rule listed below:

$$Equation\ 6, Resistance\ in\ Parallel: \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

After plugging in the values, the R_{eq} value for the resistors is 327.869 Ω which has a 2.36% difference in comparison to the 320.317 Ω value calculated before.

The power through each resistor can be calculated using Equation 4 again, which results in the 470-ohm resistor dissipating 0.114 W and the 1000-ohm resistor dissipating 0.240 W, with both having an error of 0.0173.

The sum of the currents across both resistors can be summed using the Junction Rule and should equal the total current of the system. The summation of currents equals 0.0152 A which has a 2.44% difference from the recorded current in Data Table 5.

Conclusion

The goals of the experiment were to further understand DC circuits and how EMFs and resistors act in parallel and in series. The lab was also done to verify Ohm's Law and the Loop and Junction Rules. In Investigation 1, the EMFs in the form of batteries were placed in series and in parallel to examine the differences. In Investigation 2, a resistor and battery were used to verify Ohm's Law and the Loop Rule. In Investigation 3, two resistors and a DC power bank were used to examine the properties of resistors in series and in parallel and verify the Junction Rule.

Overall, the values calculated and recorded were somewhat off from the expected, meaning there must have been some random or systemic errors in play. One such systematic error discussed earlier in the report is the batteries not being fully charged when they are used which would result in differing values for each battery. Another possibility could be the jumper wires not being connected fully. A poor connection would throw off the results of the voltages and the currents, as there would not be as much area for the current to flow through as possible.

The procedure could be improved by using new batteries every time and requiring students to make sure the connection between the jumper cables is good.

Questions

1. A 6 *V* battery is connected in series with a 1.5 *V* flashlight cell. What possible terminal voltages are available?

The possible terminal voltages could be 7.5 V since they are connected in series and they would be summed to find the terminal voltage. It could also result in a 4.5 V terminal voltage, since the if the 6 V battery is placed in the opposite direction of the flashlight cell, then the voltages would be subtracted.

2. You are given two equal resistors. Will the total resistance be larger when they are in series or parallel? What will the new resistance be in each case?

The total resistance would be greater when they are in series since they would be additive. If the resistance of the resistors equals R, then the resistance in series would be 2R and the resistance in parallel would be R/2.

3. Does a 1.5 V battery have an internal resistance? If the maximum current the battery can supply is 200 mA, what is the value of its internal resistance?

The battery would probably have an internal resistance. Using Ohm's Law, the resistance would be:

$$R = \frac{V}{I} = \frac{1.5V}{0.2\ A} = \mathbf{7.5}\ \Omega$$

4. What is the resistance of a 1.5 kW/110 V electric teapot?

Using Equation 4 from Investigation 2, the resistance can be derived from the power and voltage:

$$R = \frac{V^2}{P} = \frac{(110V)^2}{1500\ W} = \mathbf{8.07}\ \Omega$$

5. Determine the resistance between points A and B in Figs. 17.8a and 17.8b, where the dotted lines indicate that the visible circuit pattern is repeated infinitely to the right.

In Figure a, the resistors are in parallel, so Equation 6 can be used to derive the total resistance:

$$Fig. a\text{:}\ R_{eq} = \frac{1}{r} + \frac{1}{r} + \cdots + \frac{1}{r_n} = \lim_{n \to \infty} \frac{n}{r} = \infty$$

Therefore, if the pattern in figure a was continued infinitely, the current would not have any easiest way to travel from point A to B, meaning that it will go through an infinite number of resistors with a sum of infinite resistance.

Figure B is different, however, for the shortest route for the current in the circuit just requires it to travel through two resistors in series, meaning the resistance in figure b is:

$$Fig. b\text{:}\ R_{eq} = 2R$$

Acknowledgments

I would like to thank my groupmates for assisting in the collection of data and in the calculations. I would also like to thank Ben Sung for guiding us through the lab.