

Experiment 20

Kirchhoff's Laws for Circuits

Spring 2021 version

Advanced Reading:

Openstax- University Physics-Vol 2
Chapter 10, section 10-3

Equipment:

1 Circuit board
2 D cell batteries with holders & leads
1 DMM with leads
1 10 Ω resistor
1 12 Ω resistor
1 15 Ω resistor
1 18 Ω resistor
1 22 Ω resistor

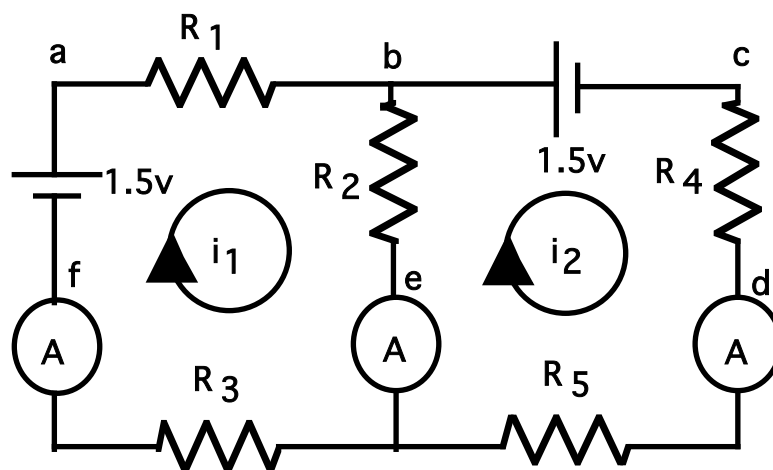


Figure 20-1

Objective:

The object of this experiment is to apply Kirchhoff's rules for circuits to a two loop circuit in order to determine the currents and voltage drops in each loop.

Theory:

The two basic laws of electricity that are most useful in analyzing circuits are Kirchhoff's laws for current and voltage. Kirchhoff's Current Law (KCL) states that at any junction of a circuit, the sum of all the currents entering the junction equals the sum of the currents leaving the junction. In other words, electric charge is conserved. Kirchhoff's Voltage Law (KVL) states that around any closed loop or path in a circuit, the algebraic sum of all the voltage drops must equal zero. In other words potential has to return to the original value.

There are three generally accepted ways to solve multiple loop circuit problems, the branch method, the nodal method, and the loop method. The loop method will be used in this experiment.

In this method a current loop is drawn for each closed loop of the circuit. To avoid confusion, it is good to arbitrarily have all the currents going clockwise. The currents in a loop always flow through a junction, so the KCL is satisfied. We need only to worry about satisfying the voltage requirements. To do this the following rules need to be followed:

(1) If a current traverses a resistor in the direction of the current (loop) flow, the change

in potential is $-iR$. If a 2nd current traverses the same resistor (e.g., R_2 in figure 20-1 above) in the opposite direction the change in potential is $+iR$.

(2) If a seat of emf (voltage source) is traversed in the direction of the emf (from - to + on the terminals), the change in potential is $+\epsilon$; if it is traversed in the opposite the emf (from + to -), the change in potential is $-\epsilon$.

For example, the equation for the loop one in figure 20-1 would be:

$$\epsilon - i_1 R_1 - i_1 R_2 + i_2 R_2 - i_1 R_3 = 0$$

or:

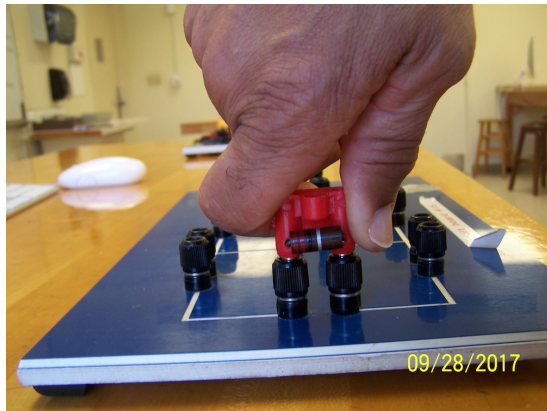
$$\epsilon - i_1 (R_1 + R_2 + R_3) + i_2 R_2 = 0$$

A similar equation can be written for the other loop and by solving the two equations simultaneously, the values for i_1 and i_2 can be obtained.

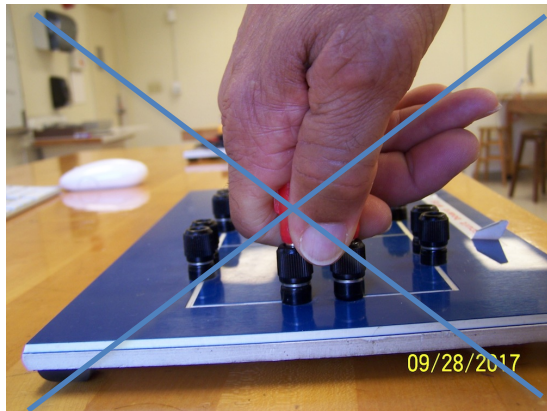
Procedure:

- Using DMM measure and record the resistance of each of the seven resistors on the lab table with the ohmmeter. The two 10M Ohm resistors are for part two of lab.
- Construct a circuit with the five resistors and the two batteries on the circuit board as shown in figure 20-1. Make sure the battery polarities are correct. **Please plug and unplug resistors as shown in the figure below. Failure to do so**

will damage resistors and make you stay in lab longer than necessary!



CORRECT WAY TO PLUG AND UNPLUG RESISTORS



INCORRECT WAY TO PLUG AND UNPLUG RESISTORS

3. Measure the voltage drops (i.e., resistor voltages) and emf's (i.e., battery voltages) around each loop using the DMM. Use data table to record these values. Do the loops obey Kirchoff's voltage law?

4. Place the DMM between R_3 and f on the circuit board. (See figure 20-1 for these locations.) Measure the current flow in the loop. See figure below for how to do so. Unplug DMM and plug the resistor back into the circuit.



After measuring the current flow, return the resistor to its original configuration.

5. Repeat for the other ammeter positions. Try to do these measurements as quickly as possible. If the batteries are nearly dead, then the potential difference across the battery could change rather quickly, causing the currents to be different. **Unplug batteries when you finish measuring the currents.**

Can you trust a measuring instrument all the time?

6. **Put the 5 resistors back in the bag.** Next, construct a series circuit using one battery, two 10M (10×10^6) ohm resistors and a jumper. **Measure the potential differences across the battery and each of the resistors of the circuit.** Record these values. Disassemble circuit when finished.

Do the potential differences (of the resistors from each circuit) add to the potential difference across the power supply? (See question 2 below).

7. Calculate the currents i_1 and i_2 **using the measured resistor values.** To do this, write the equation for each of the loops as given in the theory section. Move the emf term (ϵ) to the right-hand side of the equation. (WATCH YOUR \pm SIGNS! This is one of the most common causes of incorrect answers.) The coefficients for the equations are the values of the resistances. Solve for i_1 and i_2 . (If either current has a negative value, do not be alarmed.)

This means that the real current flow is opposite to the arbitrary current direction chosen.)

8. Compare the experimental values of i_1 and i_2 with the calculated values obtained in part 2. If they are not the same, check your calculations from part 2 and retest your circuit (or see warning above.)

Note concerning the calculations for the current. You do not have to show this calculation as a sample calculation. You simply need to neatly perform the calculation in your lab notebook and turn in with your lab data. See data sheet for which sample calculations to turn in.

Questions (Show all work):

1. Examine the results of **part 2** (step 6 in the context Kirchhoff's voltage law and the effect of DMM on the circuit).

a) Assume each resistor is 10M ohm. Calculate equivalent resistance of circuit (of this series circuit) without DMM

b) Calculate the equivalent resistance of the 10 M ohm resistor circuit **assuming** that the **voltmeter (i.e., DMM) is a 10×10^6 Ohm resistor**. Draw a circuit diagram.

c) How does the voltmeter affect the circuit? How would this affect KVL results? **The results above should be discussed in the RESULTS section of report.**

d) What do you think the sum of the voltages would be if you measured the voltage with a high impedance voltmeter with an **internal resistance of 1 giga ohms**? Explain your answer.

2. Using Kirchhoff's current and voltage laws explicitly (i.e., use sum of voltage around loops and sum of current in and out of one junction) **derive the current equations** to the circuit used in this experiment. You should have 3 equations & 3 unknowns.

Do not solve these equations See page 458 & 459 of text for help.

3. The uncertainties of the voltages were given to you in the data sheet.

a) Show how one of these are calculated using the lab website. Website will show you how they were calculated.

https://relativity.phy.olemiss.edu/~thomas/web/b/222_Miscellaneous%20folder/222_web_uncertainty_items/222_uncertainty_index.html

See **Kirchhoff's Laws uncertainty**.

b) Calculate the uncertainties for the voltage sum of each loop by adding in quadrature.

These (i.e., the calculated voltage uncertainties) should be inserted into your data table to determine correct number of significant figures.

4) Calculate the uncertainties of the 3 current you measured in lab. These (i.e., the calculated current uncertainties) should be included in your data sheet. Show all work.

Do not include uncertainty calculations as sample calculations since you are showing them in the post-lab questions.