

# Experiment 20

## Kirchhoff's Laws for Circuits

**Advanced Reading:**  
 University Physics Vol. II by OpenStax  
 Chapter 10

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

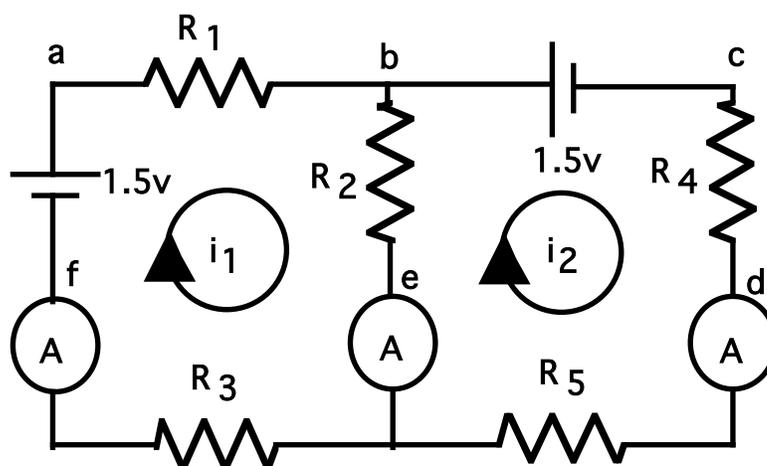


Figure 20-1

### 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 path shared by two loops has a combined current of the two loops, 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 current traverses the resistor 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:

$$\epsilon_1 - i_1 R_1 - (i_1 - i_2) R_2 - i_1 R_3 = 0$$

or:

$$\epsilon_1 - i_1 (R_1 + R_2 + R_3) + i_2 R_2 = 0$$

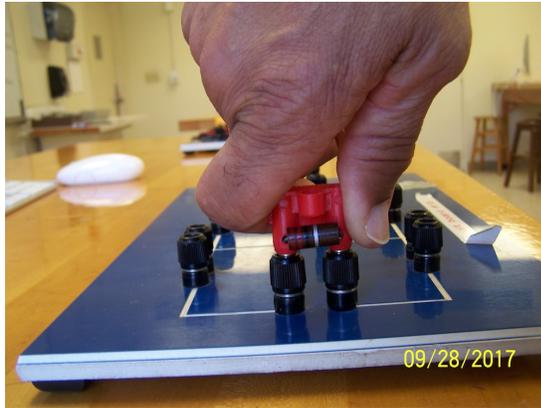
A similar equation can be written for the other loop and by solving the two equations simultaneously, the values for  $i_1$  and  $i_2$  can be obtained.

### Procedure:

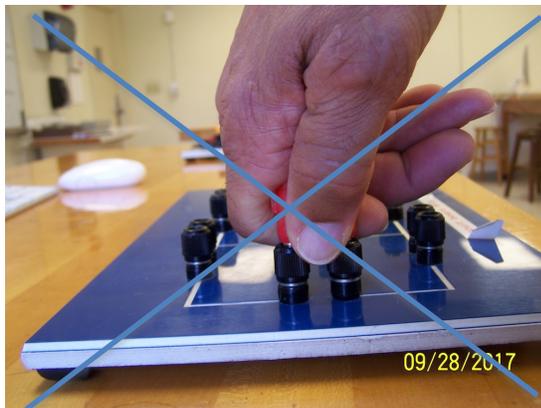
1. Using DMM measure and record the resistance of each of the seven resistors on the lab table with the ohmmeter. The two 10M Ohm resistors are for part two of lab.

2. 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  $10M$  ( $10 \times 10^6$ ) 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 ( $\epsilon$ ) 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. Using Kirchoff'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.**

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

- a) Calculate equivalent resistance of circuit without DMM
- b) Calculate the equivalent resistance of the 10 M ohm resistor circuit **assuming** that the **voltmeter (i.e., DMM) is a  $10 \times 10^6$  Ohm resistor.**

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

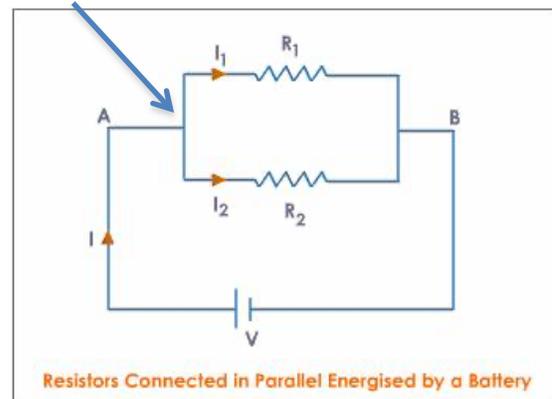
3) Assume you have a 10 V battery supplying current to a 10 ohm resistor. **Using Ohm's Law we calculate the current flowing is 1 Am.**

You **hook an ammeter** (with a resistance of one ohm) up **incorrectly** (i.e., in parallel) to the resistor. Draw this circuit. Is

- a) What is the new equivalent resistance of circuit current?
- b) What is the new current through the circuit?
- c) What would the ammeter read?

d) What would happen to your ammeter if it had a 2.5 Amp fuse?

4) Given the circuit below. The voltage is 5 volts and each resistor is 10 ohms. The current flowing through the circuit (when measured by an ideal ammeter) is 1 amp.



a) Show current through the circuit is 1 A.

Next, assume you put a **DMM (in ammeter mode) which has a resistance of one ohm** at point A. Recalculate the equivalent resistance of the circuit.

b) What is the current flowing through the circuit now. *This is the current reading the DMM will give as flowing into the junction indicated by the arrow.* Is it still 1 A?

Move the DMM to measure  $I_1$ .

c) The resistance through the top branch is now 11 ohms (resistor + ammeter). Calculate the new current.

You now move ammeter to measure the  $I_2$ . *There is no need to redo calculation since current will now be the same as calculated for  $I_1$  since both resistors are the same.*

d) Is the measured current into the (indicated) junction the same as the sum of the currents measured out of the junction?

**Data Table**  
**(a.k.a. “Not the results table”)**  
**Kirchhoff’s Laws**

**Data for current values**

Measured-(DMM) <i>Current ± δCurrent</i> (A)	Calculated (A)	% Difference
I <sub>1</sub>		
I <sub>2</sub>		
I <sub>3</sub>		

**Data table for measured potentials**

Loop1 Potentials $V \pm \delta V$ (V)	Loop2 Potentials $V \pm \delta V$ (V)	Loop3 Potentials $V \pm \delta V$ (V)
V <sub>fa</sub>	V <sub>bc</sub>	V <sub>fa</sub>
V <sub>ab</sub>	V <sub>cd</sub>	V <sub>ab</sub>
V <sub>be</sub>	V <sub>de</sub>	V <sub>bc</sub>
V <sub>ef</sub>	V <sub>eb</sub>	V <sub>cd</sub>
$\sum V_{loop} \pm \delta V_{loop}$	$\sum V_{loop} \pm \delta V_{loop}$	V <sub>de</sub>
xxxxxxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxxxxxxxxxxx	V <sub>ef</sub>
xxxxxxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxxxxxxxxxxx	$\sum V_{loop} \pm \delta V_{loop}$

**Show minimum sample calculations (one each) for:**

- 1) uncertainty in current, 2) uncertainty in voltage and 3) uncertainty in voltage sum.**