LAB 8 – KIRCHHOFF'S LAW

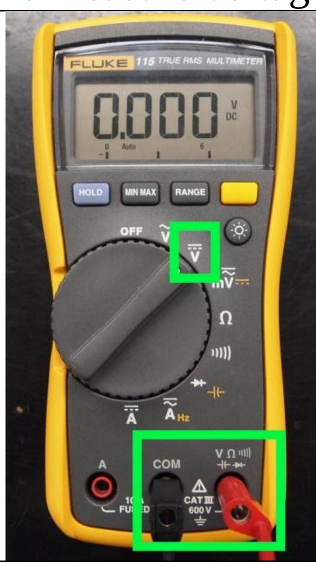
Goals:

- **Compare the internal resistance of a "dead" battery to a "live" battery**
- **Calculate currents in a circuit using Kirchhoff's Law**
- **Measure currents in a circuit using Kirchhoff's Law**

It would be very helpful to look at the online help page for this lab.

Multimeter. To measure different quantities, the multimeter must be set differently. Please follow the figures below for correct setting (wrong setting can damage the multimeter.) If you are not sure whether your connection is correct, ask your instructor to double check it.

Equipment:
In the RC circuit lab drawer, there is a plastic cup with several things in it. Not all of them are needed for this experiment, we just use a 220 ohms resistor and sever alligator clips. Please refer to the online help page to identify the resistor.

To measure voltage	To measure current	To measure resistance
		

Part 1 – Internal Resistance of a Battery

A battery has an internal chemical potential (known as the **emf** or electromotive force) that creates the current when you connect a resistance (a "load") across it. This emf does not change (for example, in a battery, the two chemicals that create the potential are unchanged as the battery discharges) – yet, over time and usage, the battery will "die" – it can't produce a current any longer.

The reason for this lies in the internal resistance of the battery. As the internal resistance rises (a chemical process that makes it harder for charges to move from one terminal to another), the current through it causes a greater internal voltage drop, and thus there is less voltage available to the outside circuit.

A multimeter can measure this emf because it has very HIGH internal resistance. But, if we try to measure the voltage produced by the "dying" battery with a load – we'll find a much smaller reading (and, the two readings can allow us to calculate the internal resistance).

Look at the circuits indicated below:

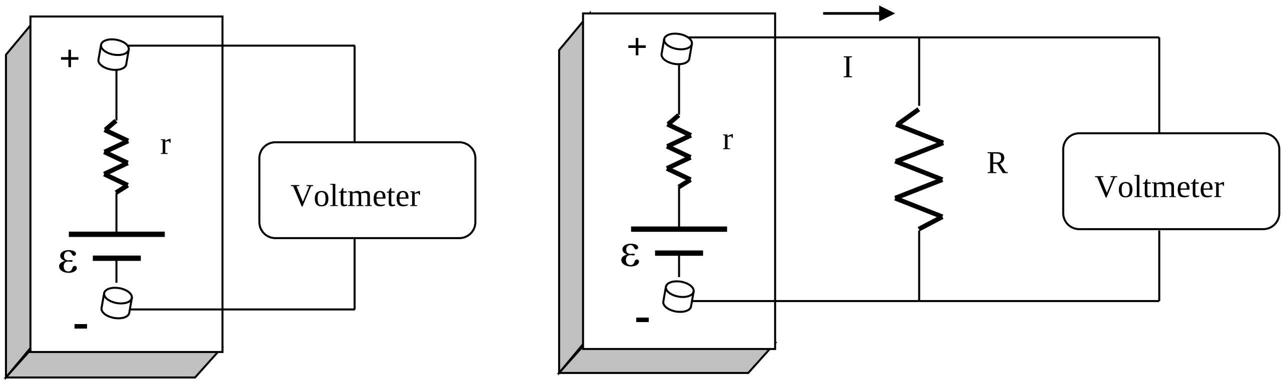
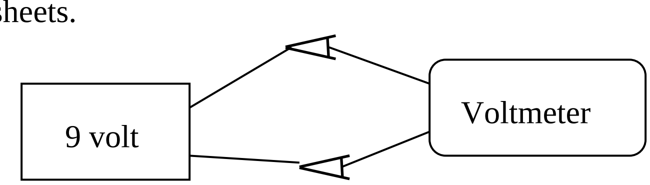


Figure 1A Figure 1B

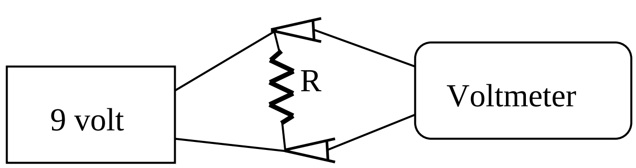
In Figure 1A, the battery is shown with the internal emf (ε) and the internal resistance (r). Measuring the voltage across the battery with the sensitive multimeters should give us a reading of the emf alone (that is, the multimeters do not need to draw current to make their reading). In Figure 1B above, the battery now has a load resistor (R) across it, and then the multimeter in parallel. This voltage reading should show a much smaller value, since the current through the circuit creates a voltage drop across the internal resistance – thus there is less "available voltage" to be measured across the load resistance R. If we can't measure the full amount of voltage across the battery, we say that it is "dying/dead". Technically, there is still the emf inside; we just can't access it with a load circuit!

Procedures

1. Connect a 9-volt "dead" battery to the battery holder.
2. Circuit connections for Figure 1A (measuring ε). Set up your multimeter as a **voltmeter**, and measure the emf of the battery as illustrated below, the reading should be between 3 to 8.5 volts. – record on the Data/Question sheets.



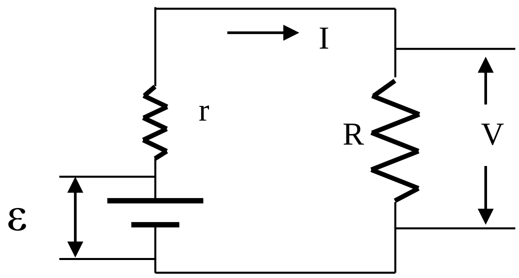
3. Circuit connections for Figure 1B (measuring V). Connect the 220 ohm resistor across the leads of the 9-volt connector, and measure the voltage across the resistor as illustrated below and record it on the Data/Question sheets.



4. Measure the resistance of the resistor R. The specified resistance of the resistor R is 220 ohm, but the true resistance can be slightly different due to manufacturing quality control standards. Use your multimeter as an **ohmmeter** to find out the true resistance, and record it on the Data/Question sheets.

5. Calculate the current in the loaded circuit. Using the previous two measurements, calculate the current in the circuit (in amps) on the Data/Question sheets.

6. Calculate the internal resistance. Consider the circuit diagram and the calculations below – use the final calculation to determine the internal resistance of the battery.



$$\varepsilon = I(r_{\text{int}} + R) = Ir_{\text{int}} + IR \qquad I = V/R \qquad V = IR$$

$$Ir_{\text{int}} = \varepsilon - IR \qquad r_{\text{int}} = \frac{\varepsilon - IR}{I}$$

$$r_{\text{int}} = \frac{\varepsilon - V}{I} = \_\_\_\_\_\_\_ \ ohms$$

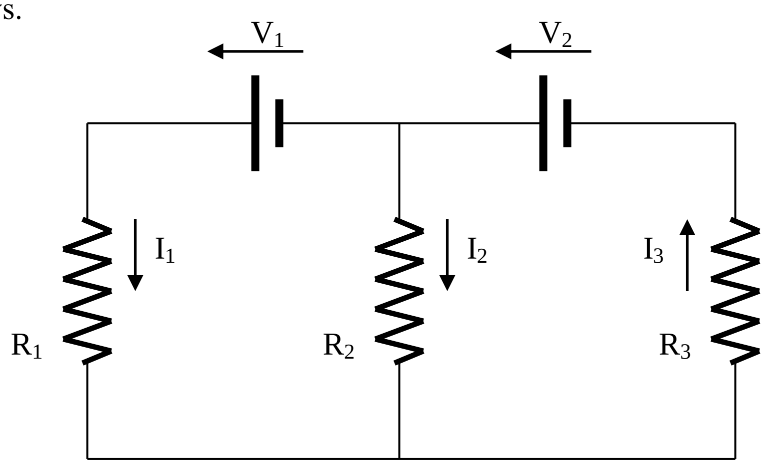
Question Answer this on the Data/Question sheet:
If your emf reading and your voltage reading were similar (ε~V), you should find the internal resistance to be relatively small. If ε>V, then you should find a higher internal resistance (a measure of how "dead" the battery is). Based on your numbers, how "dead" do you think your battery is? Explain.

B) Take the "dead" battery out of the holder and connect the "live" battery in to it.

Repeat steps 2,3,5, and 6 from A). Record your data on the DATA/QUESTION Sheet

Part 2 – Kirchhoff's Loop Rules - Introduction

Consider the following circuit showing two power supplies and three resistors. We will assume that the internal resistance of the power supplies will be negligible. There are current and voltage rules known as Kirchhoff's Laws.



Based on the above circuit, we could construct several voltage loops – we'll choose the left loop and the right loop. To this, we will add a current rule. The combined equation set looks like this:

$$I_3 = I_1 + I_2$$

$$V_1 = I_1R_1 - I_2R_2$$

$$V_2 = I_2R_2 + I_3R_3$$

Note: the following conventions were followed:

- Traveling in the **same** direction as the current through a resistor, there is a voltage drop (IR).
- Traveling in the **opposite** direction as the current through a resistor, there is a voltage rise (-IR).
- Traveling from the negative terminal to the positive across the power supply, there is a voltage rise (+V).
- Traveling from the positive terminal to the negative across the power supply, there is a voltage drop (-V).
- The currents coming into a junction must add up to the currents going out of a junction.

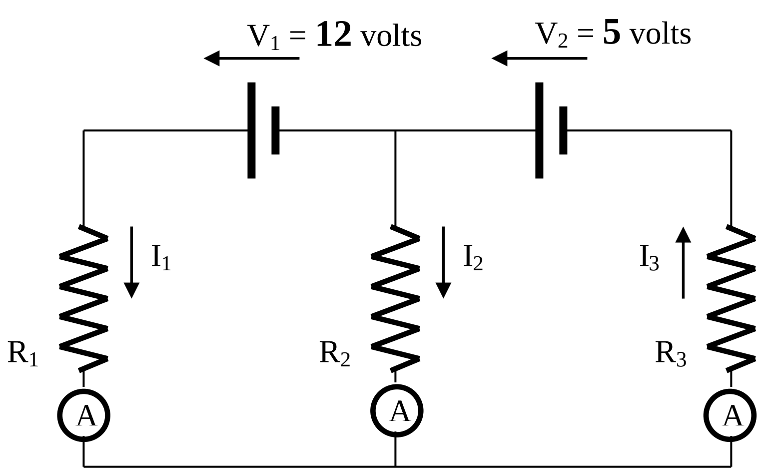
There are three equations above, and three unknowns (I_1, I_2, I_3). While they can be solved using the variables above, it is usually easier to solve them when the numerical values are inserted.

1. Measure resistances._ Use the multimeter to measure resistance (ohms). Measure each of the three resistors (R_1, R_2, and R_3) at the end of the resistor box and record the values on the Data/Question sheets:

2. Measure voltages of the power supplies. We will use two power supplies, one 5 volt and one 12 volt.

Part 3 – Kirchhoff's Circuit A

1. Setting up circuit A. Using the two power supplies and the resistor box, set up the following circuit. **Notice that the directions of V_1 and V_2 are very important**. Please ask your instructor to double check your wire connection before you plug in the power supply.



2. Measuring currents. Set the multimeter as an ammeter to measure current, and use the appropriate ports. Remember, the ammeter must be connected in a way so that the current to be measured flows **through** it.

It is extremely important to keep track of the direction of the currents. If you have a positive reading in the ammeter, it means the current enters the ammeter from the “A” terminal, and exits from the “COM” terminal; a negative reading means a current in the opposite direction.

To measure all 3 currents in a consistent way, connect the “A” terminal of the ammeter right after a resistor as shown in the figure above. If you get a positive value, then the current direction is exactly as shown in the figure above. Ask your instructor to double check the connection if you are not sure about it.

Record your currents (with signs) below:

Circuit A - Measurements:

$\mathbf{I_1}$ = __________ A $\mathbf{I_2}$ = __________ A $\mathbf{I_3}$ = __________ A

3. Calculating currents. Use the circuit equations given in Part 2, and insert the appropriate values for your resistances and voltages (keeping track of the signs of the voltages). Solve the three equations and three unknowns to find your current values and record them below:

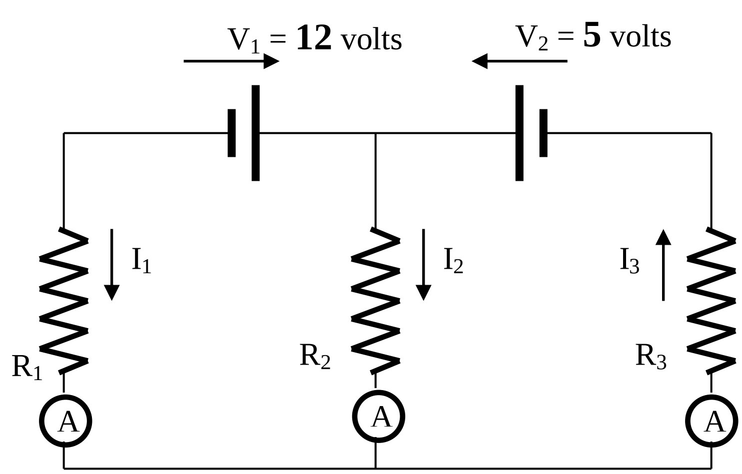
Circuit A - Calculations:

$\mathbf{I_1}$ = __________ A $\mathbf{I_2}$ = __________ A $\mathbf{I_3}$ = __________ A

Question Answer this on the Data/Question sheet:
How well did your calculated current values match up with your measured current values? How well did your signs/directions match? [If there are large differences, you need to either re-measure or re-calculate.]

Part 4 – Kirchhoff’s Circuit B

1. Setting up circuit B. Switch the direction of the 12 volt power supply as shown below. After this change, we would expect change in the direction of some currents as well. But we don’t know which current will change at this point. Let’s just **assume they are still in the same direction** as in the previous part, so that other than switching the sign of V_1, there is no change to the equations we already developed. Then we can use the same calculation and measurement to find out the correct direction.



2. Measuring currents. Follow the same procedures to measure the 3 currents.

Circuit B - Measurements:

I_1 = ___________ A **I_2** = ___________ A **I_3** = ___________ A

3. Calculating currents. Use the circuit equations given in Part 2, (and the negative V_1 voltage), solve the three equations and three unknowns to find your current values and record them below:

Circuit B - Calculations:

I_1 = ___________ A **I_2** = ___________ A **I_3** = ___________ A

Question Answer this on the Data/Question sheet:
How well did your calculated current values match up with your measured current values? How well did your signs/directions match? [If there are strong differences, you need to either re-measure or re-calculate.]

DATA/QUESTION SHEET FOR LAB 8 KIRCHHOFF'S LAWS

Part 1 – Internal Resistance of a power source

A) "Dead" Battery

1. Circuit connections for Figure 1A (measuring ε). Measure the emf of the battery and record it below:

   Emf = ε = __________ volts

2. Circuit connections for Figure 1B (measuring V). Measure the voltage of the battery and record it below:

   Voltage across the load resistor R, **V** = __________ volts

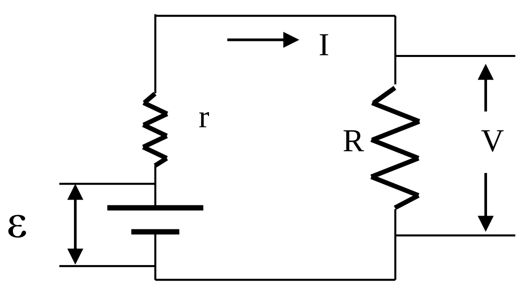
4. Measure the resistance of the resistor. Measure the resistance of the resistor and record it below:

   True resistance of the load resistor **R** = __________ ohms

5. Calculate the current in the loaded circuit. Using the previous two measurements, calculate the current in the circuit (in amps) :

   Current in the loaded circuit **I** = __________ amps

6. Calculate the internal resistance. Consider the circuit diagram and the calculations below – use the final calculation to determine the internal resistance of the battery.



$$\varepsilon = I(r_{int} + R) = Ir_{int} + IR \qquad I = V/R \qquad V = IR$$

$$Ir_{int} = \varepsilon - IR \qquad r_{int} = \frac{\varepsilon - IR}{I}$$

$$r_{int} = \frac{\varepsilon - V}{I} = \_\_\_\_\_\_\_ \ ohms$$

B) "Live" Battery

2. Circuit connections for Figure 1A (measuring ε). Measure the emf of the battery and record it below:

   Emf = ε = __________ volts

3. Circuit connections for Figure 1B (measuring V). Measure the voltage of the battery and record it below:

   Voltage across the load resistor R, **V** = __________ volts

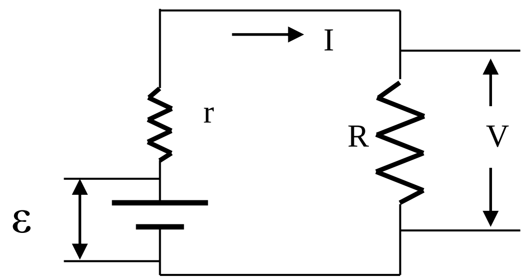
4. Resistance of the resistor. Record below the resistance of the resistor from A) 4 above:

Resistance of the load resistor **R** = __________ ohms

5. Calculate the current in the loaded circuit. Using the previous two measurements, calculate the current in the circuit (in amps) :

Current in the loaded circuit **I** = __________ amps

6. Calculate the internal resistance. Consider the circuit diagram and the calculations below – use the final calculation to determine the internal resistance of the battery.



$$\varepsilon = I(r_{\text{int}} + R) = Ir_{\text{int}} + IR \qquad I = V/R \qquad V = IR$$

$$Ir_{\text{int}} = \varepsilon - IR \qquad r_{\text{int}} = \frac{\varepsilon - IR}{I}$$

$$r_{\text{int}} = \frac{\varepsilon - V}{I} = \_\_\_\_\_\_ \; ohms$$

Question Answer this question below:
If your emf reading and your voltage reading were similar (ε~V), you should find the internal resistance to be relatively small. If ε>V, then you should find a higher internal resistance (a measure of how "dead" the battery is). Based on your numbers, how "dead" do you think your battery is? Explain.

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Part 2 – Kirchhoff's Loop rules - Introduction

1. Measuring resistances. Measure each of the three resistors (R_1, R_2, and R_3) at the end of the resistor box and record the values below:

$\mathbf{R_1}$ = __________ ohms $\mathbf{R_2}$ = __________ ohms $\mathbf{R_3}$ = __________ ohms

2. Measuring voltages of the power supplies. Turn the power supplies on, and using the designation of the top power supply as V_1 and the bottom one as V_2 – measure the voltages across the 5 volt outputs and the 12 volt outputs and record below:

power supply $\mathbf{V_1}$: "12 volts" = _________ volts

power supply $\mathbf{V_2}$: "5 volts" = ________ volts

Part 3 – Kirchhoff's Circuit A

2. Measuring currents. Record your currents (with signs) below:

Circuit A - Measurements:

$\mathbf{I_1}$ = ___________ A $\mathbf{I_2}$ = ___________ A $\mathbf{I_3}$ = ___________ A

3. Calculating currents. Use the circuit equations given in Part 2, and insert the appropriate values for your resistances and voltages (keeping track of the signs of the voltages). Solve the three equations and three unknowns to calculate the theoretical current values and record them below:

Space for calculations:

Circuit A - Calculations:

$\mathbf{I_1}$ = ___________ A $\mathbf{I_2}$ = ___________ A $\mathbf{I_3}$ = ___________ A

Question Answer this question below:
How well did your calculated current values match up with your measured current values? How well did your signs/directions match? [If there are large differences, you need to either re-measure or re-calculate. Do not leave the laboratory until you have this agreement]

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Part 4 – Kirchhoff's Circuit B

2. Measuring currents. Record your currents (with signs) below:

Circuit B - Measurements:

$\mathbf{I_1}$ = ___________ A $\mathbf{I_2}$ = ___________ A $\mathbf{I_3}$ = ___________ A

3. Calculating currents. Use the circuit equations given in Part 2, and insert the appropriate values for your resistances and voltages. Solve the three equations and three unknowns to calculate the theoretical current values and record them below:

Space for calculations:

Circuit B - Calculations:

$\mathbf{I_1}$ = __________ A $\mathbf{I_2}$ = __________ A $\mathbf{I_3}$ = __________ A

Question Answer this question below:
How well did your calculated current values match up with your measured current values? How well did your signs/directions match? [If there are strong differences, you need to either re-measure or re-calculate until you have a relatively close agreement. Do not leave the laboratory until you have this agreement.]

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Return equipment to instructor and to the drawer from where you have removed it. Please insure a good experience for the next lab group by cleaning up your lab station.

How do I write up this lab? … What is required for this lab report?

Consult the Rubric for this experiment and the "Lab Report Instructions" document (found on the Lab Schedule page).

Questions/Suggestions -> Dr. Changgong Zhou czhou@ltu.edu

Portions of this laboratory manual have been adapted from materials originally developed by Priscilla Laws, David Sokoloff and Ronald Thornton for the Tools for Scientific Thinking, RealTime Physics and Workshop Physics curricula. You are free to use (and modify) this laboratory manual only for non-commercial educational uses.

Lawrence Technological University
Department of Physics

University Physics 2 Lab
PHY2431

Rubric - Lab 8 Kirchhoff's Law - 80 points

Cover Page	Student Name	1
5 Points	Course-Section-Station	1
	Lab Title / Instructor's Name	1
	Date / Lab partner names	1
	HONOR CODE PLEDGE	1

Introduction	Content/Grammar/Spelling	10
10 Points		

Part 1 & 2	Measurements / Questions (D/Q)	5
5 Points		

Part 3 – Kirchhoff's Circuit A	Calculations (D/Q)	15
30 Points	Questions (D/Q)	5

Part 4 – Kirchhoff's Circuit B	Calculations (D/Q)	15
10 Points	Questions (D/Q)	5

Analysis	Spelling/Grammar	5
20 Points	Analyze the results of this experiment, and include a description of how well your measurements and calculations illustrated the ideas of Kirchhoff's Laws. Use some of your questions/answers on the Data Question (D/Q) sheets as a guide. (See "Lab Report Instructions" file for format details.)	15

Also: points will be taken off for the following as appropriate:

Report turned in late (5 points per school day)
Any units missing (if not printed on data table) (1 pt each)
Report not typed/stapled (5 pts)
Decimal point and sig fig errors (1 pt each)
Presentation (i.e. torn edges on papers (5 pts)
Instructor's signature/stamp missing – 5 points
Data/Question sheets missing – 20 points

Revised – 03/30/2012

