

LAB 7 – KIRCHHOFF'S LAW (TPL2)

Objectives

- Compare the internal resistances of a “dead” battery to a “live” battery
- Calculate currents in a Kirchhoff's Law circuit
- Measure currents in a Kirchhoff's Law circuit

It would be very helpful to look at the [online help page for this lab](#).

Comment about the Multimeter. We will be using the multimeter to measure the voltages and currents in the resistors, as well as the resistance of the different resistors. Be VERY sure that you are on the right meter setting, and you have it connected the correct way – so we can protect the meters!

Basic connections/modes for the multimeter:

- Ammeter – should be “IN” the circuit (i.e., current has to flow through the meter – if the meter would not be there, the circuit would be open) – **best way to use it is to “break” the circuit and use the ammeter to patch the two open ends**
- Voltmeter – should be “ACROSS” an element (i.e., the current should be flowing in the circuit, the meter is not repairing a break – it is reaching across an element)
- Ohm-meter – just connect it across the leads of the resistor (no power supply needed – the resistor should be separate from any circuit ... with only the meter connected to it).

Part 1 – Internal Resistance of a power source

A battery has an internal chemical potential (known as the **emf** or electromotive force) that creates the current when you put 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 chemical plate to another), the current produced by the emf creates a voltage drop across the internal resistance, and thus there is very little voltage available to the outside circuit.

A multimeter can measure this emf since it has very little internal resistance inside the multimeter (thus, no “load”). 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:

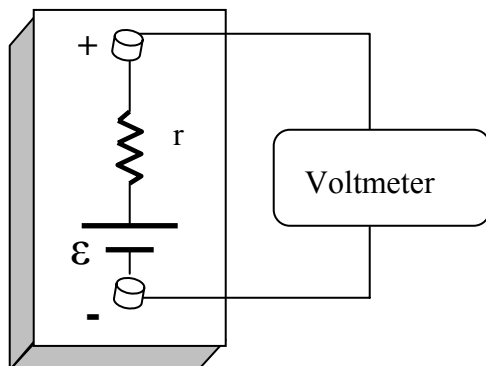


Figure 1A

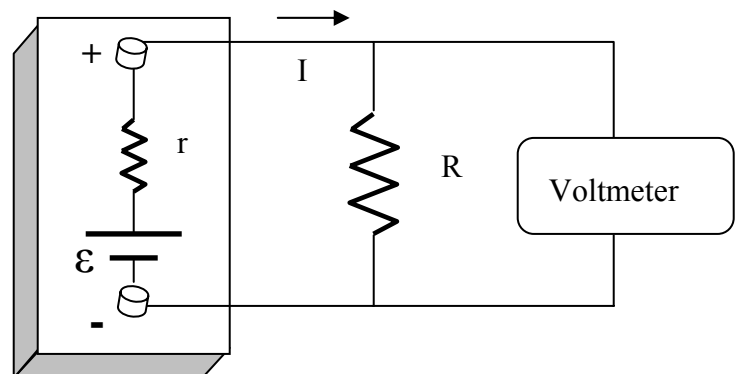
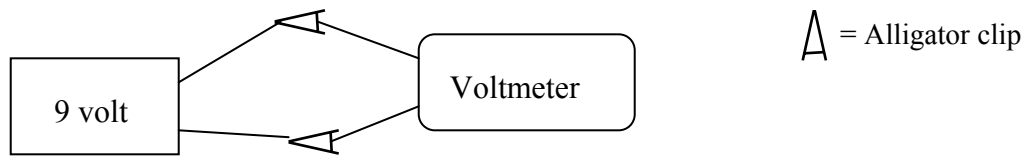


Figure 1B

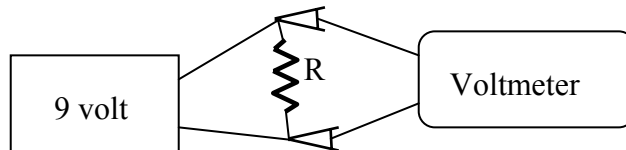
A) In Figure 1A, the battery is shown with the internal emf (ϵ) and the internal resistance (r). Measuring the voltage across the battery with the sensitive multimeters should give us a reading of the emf alone (that is, the multimeters do not need to draw current to make their reading). In Figure 1B 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 some current is produced which creates a voltage drop across the internal resistance – thus there is not much “available voltage” to the outside circuit (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!

1. Connect the 9-volt “dead” battery to the battery holder.

2. Circuit connections for Figure 1A (measuring ϵ). Set the voltmeter to the 20 volt DC setting. Connect the alligator clips to the leads of the 9-volt “connector” and measure the emf of the battery as illustrated below – record on the Data/Question sheets.



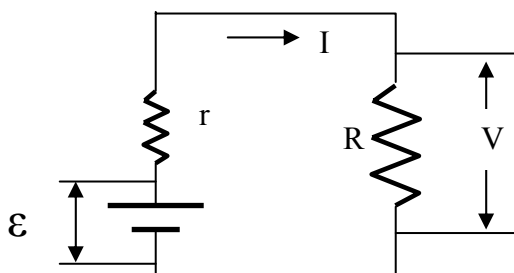
3. Circuit connections for Figure 1B (measuring V). Connect the 220 ohm resistor across the leads of the 9-volt connector (that is, use the alligator clips to connect the leads to each end of the resistor). Start on the 20 volt scale and measure the voltage of the battery as illustrated below (you might have to go down to the mV scale – remember to switch the wires to the appropriate plugs) and record it on the Data/Question sheets.



4. Measure the resistance of the resistor. Disconnect the 9-volt battery from the resistor. Switch the multimeter to read ohms and switch the banana plug wires to the appropriate ports. Connect the multimeter, via the alligator clips, to the resistor (without the battery in the circuit). Measure the resistance of the resistor 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.



$$\epsilon = I(r_{\text{int}} + R) = Ir_{\text{int}} + IR \quad I = \frac{V}{R} \quad V = IR$$

$$Ir_{\text{int}} = \epsilon - IR \quad r_{\text{int}} = \frac{\epsilon - IR}{I}$$

$$r_{\text{int}} = \frac{\epsilon - V}{I} = \text{_____ ohms}$$

Question Answer this on the Data/Question sheet:

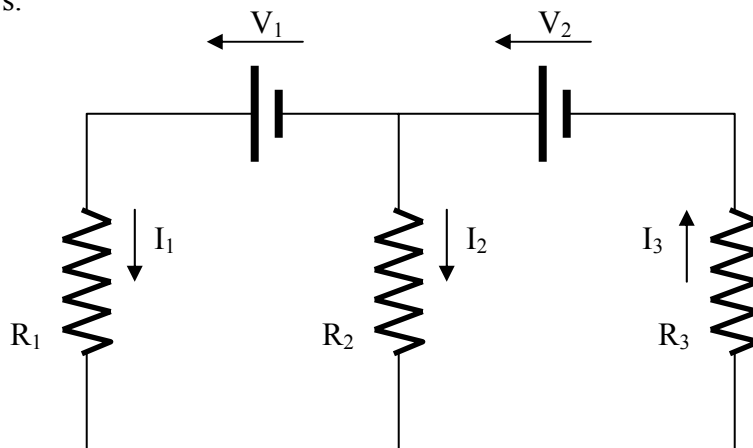
If your emf reading and your voltage reading were similar ($\epsilon \sim V$), you should find the internal resistance to be relatively small – if $\epsilon > V$, then you should find a higher internal resistance (a measure of how “dead” the battery is). Based on your numbers, on how “dead” do you think 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 – Kirchoff’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 Kirchoff’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 set of equations look 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 *lower plate* to the *upper plate* across the power supply, there is a voltage rise ($+V$).
- Traveling from the *upper plate* to the *lower plate* across the power supply, there is a voltage rise ($-V$).
- The currents coming into a junction must add up to the currents going out of a junction.

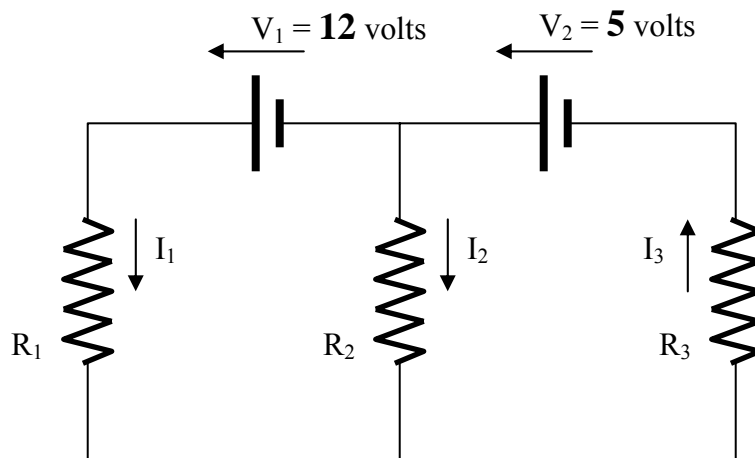
There are three equations above, and three unknowns (I_1, I_2, I_3). While they can be solved using the variables above, it is usually easier to solve them when the numerical values are inserted.

1. Measuring resistances. Switch the multimeter to read 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. Measuring voltages of the power supplies. There are two power supplies at your station. The internal circuitry won't allow us to use the 5 V and the 12 V connectors from the same power supply in the same circuit, so we will use one from each power supply. Switch the multimeter to the 20 Volt DC scale, and connect the plugs in the appropriate ports. 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 them on the Data/Question sheets.

Part 3 – Kirchoff'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 – the red (high) side of the top power supply (V_2) should be connected to one of the leads of the R_1 resistor – the black (low) side of the top power supply (V_1) should be connected to the similar lead on the R_2 resistor, and so forth. Use two short wires to connect the lower leads of R_1 and R_2 and to connect R_2 and R_3 to complete the circuit. The [online help page for this lab](#) shows a diagram of this setup.



2. Measuring currents. Set the multimeter to read 20 mA, and use the appropriate ports. Measure the three currents (I_1 , I_2 , I_3) by breaking the circuit at the lower ends of the three resistors and “repairing the circuit with the multimeter. The descriptions of how to do this are as follows:

- For I_1 : disconnect from R_1 the short wire that goes to R_2 {but leave it connected to R_2 } – connect the multimeter between the two open parts {the end of R_1 and the lead to R_2 }. The wire from R_2 to the **COM** of the multimeter.
- For I_3 , disconnect from R_3 the short wire that goes to R_2 {but leave it connected to R_2 } – connect the multimeter between the two open parts {the end of R_3 and the lead to R_2 }. The wire from R_3 to the **COM** of the multimeter.
- For I_2 : this is a little trickier – there are two wires coming together at the lower part of R_2 – disconnect that combination (but leave the two wires connected to themselves) – connect the multimeter between the two open parts {the end of R_2 and the combined leads from R_2 and R_3 }. The wire from R_2 to the **COM** of the multimeter.

It is important to keep track of the direction of the currents – so to be consistent, use the RED lead closest to the resistor and the black lead for the other connection. If you get a positive value, then the current direction is from top to bottom through the resistor in the images – a negative value means the other direction. [These “directions” will be indicated by the signs of the currents in the later calculations.] Record your currents (with signs) below:

Circuit A - Measurements:

$$I_1 = \underline{\hspace{2cm}} \text{ mA} \quad I_2 = \underline{\hspace{2cm}} \text{ mA} \quad I_3 = \underline{\hspace{2cm}} \text{ mA}$$

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:

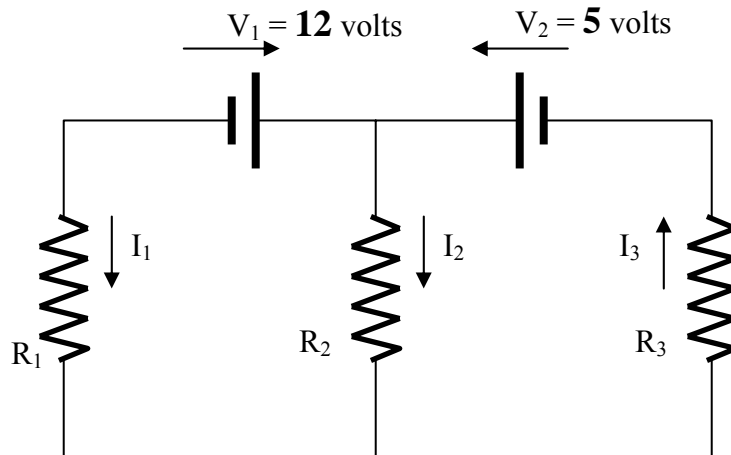
Circuit A - Calculations:

$$I_1 = \underline{\hspace{2cm}} \text{ mA} \quad I_2 = \underline{\hspace{2cm}} \text{ mA} \quad I_3 = \underline{\hspace{2cm}} \text{ mA}$$

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 might need to either re-measure or re-calculate.]

Part 4 – Kirchoff’s Circuit B

1. Setting up circuit B. Switch the leads on your top power supply (where they connect to the resistor box) so that you create the following circuit:



Notice that the current directions (vectors) are left the same in the diagram {even though the final current directions might be different} ... in this case, we can use the same equations as Part 2, just make sure you switch the sign of the V_1 voltage. If the current values switch sign as well as magnitude in our measurements or calculations, it just means the actual currents are flowing differently than depicted above (but the measurements will still match the calculations as long as we keep track of the new directions).

2. Measuring currents. Using the same method as before (and the same RED/BLACK direction for the multimeter), measure the currents (with signs) in the new circuit and record below:

Circuit B - Measurements:

$I_1 =$ _____ mA $I_2 =$ _____ mA $I_3 =$ _____ mA

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:

$I_1 =$ _____ mA $I_2 =$ _____ mA $I_3 =$ _____ mA

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 might need to either re-measure or re-calculate.]

DATA/QUESTION SHEET FOR LAB 7 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:

$$\text{Emf} = \epsilon = \text{_____} \text{ volts}$$

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

$$\text{Voltage with load resistor} = V = \text{_____} \text{ volts}$$

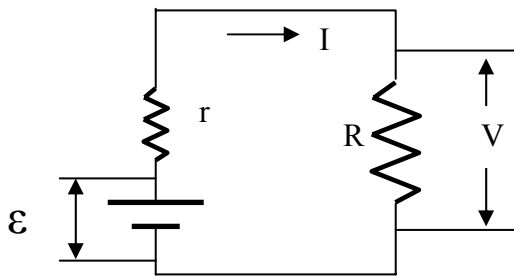
4. Measure the resistance of the resistor. Measure the resistance of the resistor and record it below:

$$\text{Resistance of the load resistor} = R = \text{_____} \text{ ohms}$$

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

$$\text{Current in the loaded circuit} = I = V/R = \text{_____} \text{ amps}$$

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.



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

$$Ir_{\text{int}} = \epsilon - IR \quad r_{\text{int}} = \frac{\epsilon - IR}{I}$$

$$r_{\text{int}} = \frac{\epsilon - V}{I} = \text{_____} \text{ ohms}$$

B) “Live” Battery

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

$$\text{Emf} = \epsilon = \text{_____} \text{ volts}$$

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

$$\text{Voltage with load resistor} = V = \text{_____} \text{ volts}$$

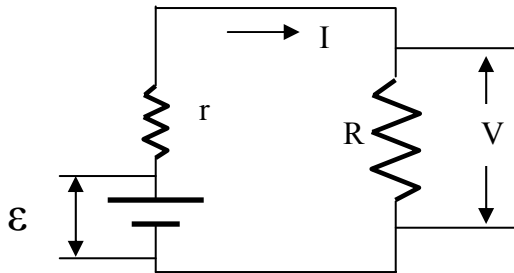
4. Resistance of the resistor. Record below the resistance of the resistor from A 4):

$$\text{Resistance of the load resistor} = R = \text{_____} \text{ ohms}$$

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 = $I = V/R =$ _____ 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.



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

$$Ir_{\text{int}} = \epsilon - IR \quad r_{\text{int}} = \frac{\epsilon - IR}{I}$$

$$r_{\text{int}} = \frac{\epsilon - V}{I} = \text{_____ ohms}$$

Question Answer this question below:
 If your emf reading and your voltage reading were similar ($\epsilon \sim V$), you should find the internal resistance to be relatively small – if $\epsilon > V$, then you should find a higher internal resistance (a measure of how “dead” the battery is). Based on your numbers, on how “dead” do you think your battery is – explain?

Part 2 – Kirchoff’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:

$R_1 =$ _____ ohms $R_2 =$ _____ ohms $R_3 =$ _____ 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:

Top power supply (V_1) : “5 volts” = _____ volts “12 volts” = _____ volts

Bottom power supply (V_2) : “5 volts” = _____ volts “12 volts” = _____ volts

Part 3 – Kirchoff's Circuit A

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

Circuit A - Measurements:

$$I_1 = \underline{\hspace{2cm}} \text{ mA} \quad I_2 = \underline{\hspace{2cm}} \text{ mA} \quad I_3 = \underline{\hspace{2cm}} \text{ mA}$$

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:

Space for loop calculations:

Circuit A - Calculations:

$$I_1 = \underline{\hspace{2cm}} \text{ mA} \quad I_2 = \underline{\hspace{2cm}} \text{ mA} \quad I_3 = \underline{\hspace{2cm}} \text{ mA}$$

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 might need to either re-measure or re-calculate.]

Part 4 – Kirchoff's Circuit B

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

Circuit B - Measurements:

$I_1 = \underline{\hspace{2cm}}$ mA $I_2 = \underline{\hspace{2cm}}$ mA $I_3 = \underline{\hspace{2cm}}$ mA

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 find your current values and record them below:

Space for loop calculations:

Circuit B - Calculations:

$I_1 = \underline{\hspace{2cm}}$ mA $I_2 = \underline{\hspace{2cm}}$ mA $I_3 = \underline{\hspace{2cm}}$ mA

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 might need to either re-measure or re-calculate.]

Questions/Suggestions -> James Nolta - Nolta@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 anWorkshop Physics curricula. You are free to use (and modify) this laboratory manual only for non-commercial educational uses.