

Name: \_\_\_\_\_ Period: \_\_\_\_\_ Due Date: \_\_\_\_\_  
 Lab Partners: \_\_\_\_\_

# CIRCUIT ANALYSIS

**Purpose:** To analyze subunits of complex circuits to see how the small branches may be analyzed as part of the analysis of the whole circuit. You will analyze a complex circuit: i) to verify the method used to calculate the equivalent resistance of a circuit and then use the equivalent resistance to calculate the battery current; ii) to practice using Kirchhoff's rules by using them to find the currents in the other branches of the complex circuit; and iii) to learn to recognize and translate between a drawn circuit and the actual wired circuit.

**Theory:** As a charge ( $q$ ) moves around a circuit, it gains and loses energy. In a simple circuit made of a battery and resistors, the moving charge gains energy from the chemical energy stored in the battery. The moving charge loses energy in the form of thermal energy as it travels through the resistors. The moving charge does not lose any energy (*and therefore does not change its voltage*) while traveling through the wires that connect the circuit elements. When a charge completes its trip around the circuit and returns to its starting point, it also returns to its original energy ( $\Delta E = 0$ ). Since the change in energy while traversing a closed loop on a circuit is  $\Delta E = 0 = q\Delta V$ , the sum of the voltage changes around any closed pathway on the circuit must also be zero ( $\Delta V = 0$  since  $\Delta E = 0$ ). This is the origin of Kirchhoff's voltage rule (*loop rule*):

***By any closed path (a closed loop), the sum of the voltage changes around a circuit is zero.***

Moreover, when current comes to a junction, called a branching node, some of the flowing charges will follow one path and the rest will follow another path. The total quantity of charge entering the junction each second must equal the total quantity of charge leaving the junction each second. If this were not true, charge would accumulate on the junction. Since like charges repel, this is unlikely and could not be sustained unless a separate energy source were available to constrain the charges to the node. This is the origin of Kirchhoff's current rule (*node rule*):

***At any point in a circuit the current entering the point equals the current leaving the point.  
 (While this is true at all points, branching nodes are the only important points for analyzing the circuit.)***

These two principles form the basis of the most powerful mathematical methods used in circuit analysis. Using them can be tricky and requires that we follow a carefully organized procedure in order to avoid several pitfalls.

You have already learned how to use these two rules to generate a system of independent equations involving the currents entering and leaving the nodes of the circuit and the voltage changes encountered by the current as it flows through the various resistors. You have learned to solve this system of equations to find the unknown currents. You have learned to use the matrix tools on your calculator to solve this system of equations in a very efficient manner. Now it is time to test out these methods and your mastery of them.

## Procedure: Part One: The Circuit

1. Before connecting anything. Measure the resistance of each of the resistors on the board with the Ohmmeter on the multimeter and record them in the table below. Be sure that the measured resistances agree with the band resistances (*within the indicated tolerance*) coded on the resistor.

**Table I**

Board Number = \_\_\_\_\_

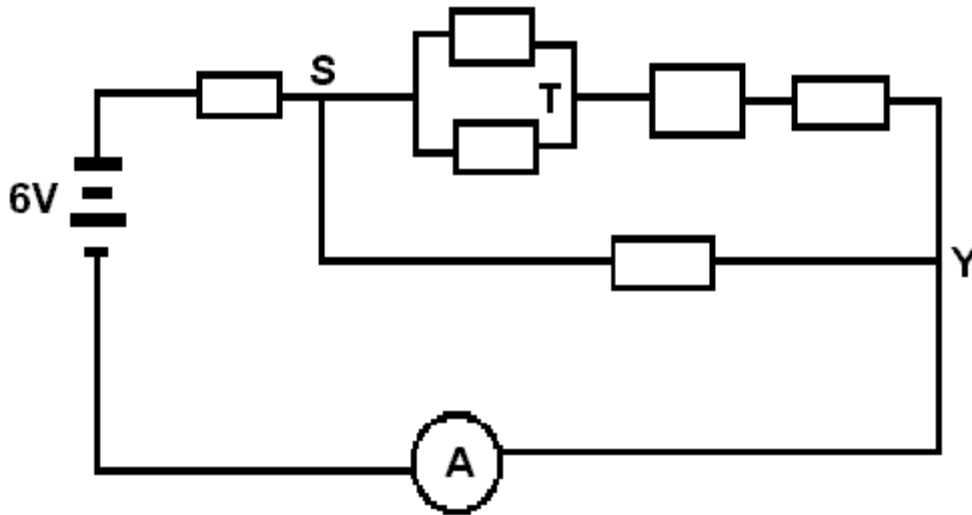
<u>Code</u>	<u>Band Color</u>	<u>Resistor</u>	<u>Measured Resistance</u>	<u>Resistance from Band Indicator</u>
0 : 10 <sup>0</sup>	Black			
1 : 10 <sup>1</sup>	Brown	F	_____ Ω	_____ Ω
2 : 10 <sup>2</sup>	Red			
3 : 10 <sup>3</sup>	Orange	E	_____ Ω	_____ Ω
4 : 10 <sup>4</sup>	Yellow			
5 : 10 <sup>5</sup>	Green	D	_____ Ω	_____ Ω
6 : 10 <sup>6</sup>	Blue			
7 : 10 <sup>7</sup>	Purple	C	_____ Ω	_____ Ω
8 : 10 <sup>8</sup>	Gray			
9 : 10 <sup>9</sup>	White	B	_____ Ω	_____ Ω
<u>Tolerance</u>				
2%	Red	A	_____ Ω	_____ Ω
5%	Gold			
10%	Silver			

2. Neatly draw the lines between the numbered connector posts (*without crossing any other lines*). Then connect the resistors on your board with wires following the plan indicated here. (*Note: the posts are not numbered on the board itself, but if you orient the board so the resistor labels appear in the same order from left-to-right as in the diagram below, then it should be obvious which numbers go with which posts.*)

- 1 to 4
- 1 to 6
- 3 to 8
- 5 to 8
- 7 to 10
- 9 to 11
- 1 to 12



3. You have now created this circuit (*without the battery or the ammeter, A*). Label each resistor in this diagram with the appropriate letter according to the wiring instructions given above. Indicate current direction in each branch of the circuit and the appropriate +/- signs on each circuit element. Include the post numbers, 1 – 12, on the correct ends of the resistors. (*Hint: to help you get started, it will be useful to know that the batter will be connected to the circuit with its positive terminal at post #2 and its negative terminal and post #11.*)



4. Before you hook up the battery, use the Ohmmeter function of the multimeter to measure the resistance between posts #2 and point #11. This should provide you with a measurement of the equivalent resistance of the entire circuit. (*Remember that the equivalent resistance is the resistance of the circuit from the point of view of the battery. To measure it all we have to do is put the ohmmeter in the position where the battery will be connected. Ignore the ammeter for now*) The measured equivalent resistance should be the same as your calculated equivalent resistance. If it is not, check you wiring and double-check you calculations. You cannot proceed until you have the correct calculated  $R_{eq}$  and confirmed it with a measurement of your predicted value for the equivalent resistance of this circuit. The instructor will tell you if you have the correct value, after you get the measured and calculated values to agree.

Board Number = \_\_\_\_\_

Calculated Equivalent Resistance of the entire circuit =  $R_{eq}$  = \_\_\_\_\_  $\Omega$

Measured Equivalent Resistance of the entire circuit =  $R_{eq}$  = \_\_\_\_\_  $\Omega$

**Your instructor knows the true resistance of the correctly assembled circuit. Before you continue, you must get the instructor’s approval and initials below.**

**The assigned circuit was correctly assembled, the equivalent resistance was correctly calculated, and the equivalent resistance of the circuit was correctly measured by this group.**

\_\_\_\_\_  
Instructor’s Initials

**5.** Intermittently connect the cell to the circuit just long enough to make the measurements.

- cell(+) to 2
- cell(-) to 11

You may leave one of the connections in place, and connect the other one for a few moments at a time. Do not leave both of them connected, however, as this drains and overheats the battery and can ruin your data with incorrect currents and voltages.

With the battery connected in the circuit, use the multimeter set as a voltmeter (use 2V and 20V scales) to measure the potential (*voltage*) difference across each of the resistors and the cell. This measurement tells us how much energy is lost in each resistor and how much energy is gained going through the batter. If the meter reads a negative number, you should simply reverse the leads or ignore the negative sign. The voltages differences we want in this table should all be listed as positive numbers, even though we know that voltage was lost in the resistors and gained in the battery.

**Table II**

**Board Number = \_\_\_\_\_**

Circuit Element	Voltage difference Across each circuit Element (volts)	
Resistor F	_____	V
Resistor E	_____	V
Resistor D	_____	V
Resistor C	_____	V
Resistor B	_____	V
Resistor A	_____	V
Battery (Cell)	_____	V

**6.** Disconnect the lead from the positive terminal of the battery. Leave it disconnected until the instructor checks the rest of your work from this last section. With help from your instructor, switch the multimeter to the 200mA DC ammeter setting. Place it **into** the circuit in the position shown in the circuit diagram; between the negative terminal of the battery and the "Y" junction. Connect the mA lead to the negative terminal of the cell and the COM to position #2. You are now ready to measure the current in the battery line. Close the circuit briefly to make the current reading. This reading gives you the battery current (*also known as the cell current*).

Cell Current = \_\_\_\_\_ mA (milli-amperes) OR Cell Current = \_\_\_\_\_ A (amperes)

**You are finished with this circuit. Disassemble the circuit. Return the battery and the wire leads to their proper locations. Turn the multimeter to its OFF position.**

**Part Two: The Equivalent Resistance**

**Board Number = \_\_\_\_\_**

**7.** Connect wires to selected resistors to create the following resistor combinations. Use the Ohmmeter setting to read the equivalent resistance of each combination of resistors. Then check your answer by combining the resistors mathematically to find their equivalent resistance. The two results must agree.

	Measured Resistance ( $\Omega$ )	Calculated Equivalent Resistance ( $\Omega$ )	Sketch of Circuit Fragment
A in series with B	_____ $\Omega$	_____ $\Omega$	
A, B and C in series	_____ $\Omega$	_____ $\Omega$	
A parallel to B	_____ $\Omega$	_____ $\Omega$	
A, B and C parallel to each other	_____ $\Omega$	_____ $\Omega$	
A in series with (B parallel to C)	_____ $\Omega$	_____ $\Omega$	
(A in series with B) parallel to (C in series with D)	_____ $\Omega$	_____ $\Omega$	
(A parallel to B) in series with (C parallel to D)	_____ $\Omega$	_____ $\Omega$	

# Analysis:

## Part One: The Circuit

Board Number = \_\_\_\_\_

1. Use Ohm's Law ( $V = IR$ ), the resistances in **Table I**, and the voltages of **Table II** to calculate the current passing through each resistor. Convert it to milli-amperes (mA).

Resistor	Current (mA)	Explain how to find the current through the Cell from the information available on the left side of this table.
F	_____	_____ _____ _____ _____ _____ What is it? $I_{cell} =$ _____ mA
E	_____	
D	_____	
C	_____	
B	_____	
A	_____	

Use your voltage data to **verify Kirchhoff's voltage rule** for the circuit loops defined as follows (*theoretically these sums should be zero, but you should expect to get small non-zero results because of measurement uncertainties*):

- I. 2=F=1—4=E=3—8=C=7—10=B=9—cell—2      Sum of voltages = \_\_\_\_\_ V  
 (Note: 1 denotes a post number, =A= denotes a resistor, and — denotes a wire)
- II. 12=A=11—9=B=10—7=C=8—5=D=6—12      Sum of voltages = \_\_\_\_\_ V
- III. 4=E=3—5=D=6—4      Sum of voltages = \_\_\_\_\_ V
- IV. 2=F=1—12=A=11—cell—2      Sum of voltages = \_\_\_\_\_ V

3. Using your current data to **verify Kirchhoff's current rule** at these circuit nodes (*theoretically the two sums at each node should be exactly equal to each other but you should expect small differences because of measurement uncertainties*):

- I. S      Current In = \_\_\_\_\_ mA      Current Out = \_\_\_\_\_ mA
- II. T      Current In = \_\_\_\_\_ mA      Current Out = \_\_\_\_\_ mA
- III. Y      Current In = \_\_\_\_\_ mA      Current Out = \_\_\_\_\_ mA

4. Use  $V_{cell}$  and  $I_{cell}$  to calculate  $R_{circuit}$ , the apparent, or equivalent, resistance of the entire circuit taken as a whole.

$$R_{circuit} = V_{cell} / I_{cell} = \text{_____} / \text{_____} \text{ ohms} = \text{_____} \text{ ohms.}$$

Is  $R_{circuit}$  approximately equal to the  $R_{eq}$  measured in step 4 on Page 3? [Y/N] \_\_\_\_\_; %Diff = \_\_\_\_\_%  
 (Use the measured  $R_{eq}$  from step #4 on page 3 as your reference value when comparing it to  $R_{circuit}$  above.)

**Review Questions: Power, Energy, and Heat**

Board Number = \_\_\_\_\_

Assume the circuit is already assembled and connected to the battery. (*Show your work for each question.*)

5. What is the power delivered to resistor **A**?

$$P_A = \text{_____ W}$$

6. How many positive charges pass through resistor **C** each second?

$$I_C = \text{_____ mA} = \text{_____ A} = \text{_____ } q^+/s$$

7. What would be changed within the circuit if you reversed the battery connections?

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8. How many Joules of heat energy are dissipated by resistor **F** each minute? (*It equals the energy delivered to the resistor each minute.*)

$$\text{Energy dissipated in resistor F each minute} = \Delta E_F = P_F \times \text{time} = \text{_____ W} \times \text{_____ s} = \text{_____ J}$$

9. If you put resistor **D** (*assumed to be appropriately water-proofed*) into an insulated cup containing 550 grams of cold water, how long would it take to raise the temperature of the water by 1°C? (*Remember:  $Q = mc\Delta T$* )

$$\begin{aligned} \text{Time}_D \text{ (for resistor D to heat 550 gm of water } 1^\circ\text{C)} &= \text{_____ s} = \text{_____ min} = \text{_____ hours} \\ &= \text{_____ Days} = \text{_____ years} \end{aligned}$$

10. Suppose that resistor **B** is made of graphite in the shape of a cylinder or rod. The length of the carbon rod is 8.00 mm. What diameter is required reproduce the resistance of your resistor **B**? (*Look up the resistivity of graphite.*)  
(Measured Resistance of resistor B from Page 1 =  $R_B = \text{_____ } \Omega = \rho L / A$ )

$$\text{Diameter}_{\text{graphite rod}} = \text{_____ m}$$

- 11.** You have completed an experimental analysis of the circuit introduced at the beginning of this lab. It is now time to complete the theoretical analysis by performing a complete Kirchhoff analysis. Pretend that all you know are the voltage of the battery, the resistances of the resistors, and the connections within the circuit. Use Kirchhoff's two rules to compute all the currents in the circuit. A blank circuit is included here for your convenience. Label it fully and then derive the five currents that exist within this circuit. Append as many additional pages as necessary to show the complete work-up for this analysis. You may use matrix methods once you derive all the necessary equations and write them in the correct final form.

After you finish calculating the five currents, calculate the percent difference between the theoretical currents found in this section and the currents you reported in the table near the top of page 6. Use the theoretical values found in this section as the reference values in your percent difference calculations.

