

OHM'S LAW

OBJECTIVES:

- PART A:
- 1) Become familiar with the use of ammeters and voltmeters to measure DC voltage and current.
 - 2) Learn to use wires and a "breadboard" to build circuits from a circuit diagram.
 - 3) Verify Ohm's Law for series and parallel circuits.
 - 4) Reduce a complicated resistance circuit to a simple one-resistor equivalent circuit.
 - 5) Observe Joule Heating.
- PART B:
- 1) Verify Kirchoff's Voltage and Current Laws.
 - 2) Apply Kirchoff's laws to analyze more complex circuit.
 - 3) Measure an unknown device and see if it is a constant resistor.

Preparation for Part A (First Lab)

Study Introduction.

Review sections on Making Graphs, and Key Things You Need to Know from introduction.

You may wish to review circuits in your Physics textbook.

Preparation for Part B (Second Lab)

Study Kirchoff's Laws.

Study Introduction.

As part of your introduction, work out the theoretical circuit analysis for Part 3; **see page 14 of this lab.**

Note: If you are color blind or suspect that you are, you may find the color codes on the resistors difficult. Please consult your lab instructor for advice or help.

INTRODUCTION

One fundamental law in the physics that describe how electrical circuits behave is Ohm's law. According to Ohm's law, the relationship of the voltage, current, and resistance in a circuit bears a simple linear relationship:

$$V = I R \quad (1)$$

Here,

- V (in volts) = voltage applied to the circuit,
- I (in amperes) = current flowing in the circuit,
- R (in ohms) = resistance of the circuit.

Equation (1) implies that, for a resistor with constant resistance, the current flowing through it is proportional to the voltage across it. If the voltage is held constant, then the current is inversely proportional to the resistance. If the voltage polarity is reversed (that is, if the current is negative instead of positive), the same current flows, but in the opposite direction. Ohm's Law can be used to define the resistance by:

$$R = V / I$$

If the circuit element is a fixed resistor, **R** is a constant for any **V** and **I**.

It is important to understand just what is meant by these quantities. The current (I) is a measure of how many electrons are flowing past a give point during a set amount of time. The current flow flows because of the electrical potential (V), sometimes referred to as the voltage applied to a circuit. In much the same way that a gravitational potential will cause mass to move, electrical potential will cause electrons to move. If you lift a book and release it from a height (high gravitational potential) it will fall downward (to a lower potential). The electrical potential works in a similar way. If we induce a large negative charge on one end of a wire and a large positive charge on the other, the electrons in the wire will flow because of the charge difference. The resistance of the circuit is just that; it is a measure of how difficult it is for the electrons to flow. This resistance is a property of the circuit itself, and just about any material has a resistance. Materials that have a low resistance are called conductors and materials that have a very high resistance are called insulators. Some materials have a moderate resistance and still allow some current to flow. These are the materials that we use to make resistors like the ones we will use today. In short, the electrical potential causes the current to flow and the resistance impedes that flow.

Two or more resistors can be connected together either in series or in parallel. Resistors in series means that the resistors are connected one after another (figure 1a). Resistors in parallel means resistors are connected side by side, parallel to one another (figure 1b).

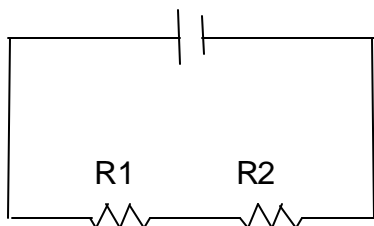


Figure 1a
(Series)

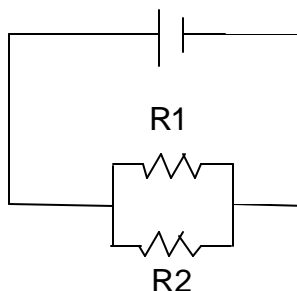


Figure 1b
(Parallel)

When two resistors (R_1 and R_2) are connected in series, the *equivalent* resistance R_s is given by $R_s = R_1 + R_2$. That is, the circuit in Figure 1a behaves (draws current from a given voltage), as if it contained a single resistor of resistance R_s .

When two resistors (R_1 and R_2) are connected in parallel, the *equivalent* resistance R_p is given by:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{or} \quad R_p = \frac{R_1 R_2}{R_1 + R_2}$$

That is, the circuits of Figure 1b behaves as if it contained a single resistor whose resistance is R_p .

Using these two relationships, we can take a complex circuit (like the one on page 14) and redraw it as if it were a circuit with only a single resistor. The resistance of that circuit can be calculated by using the equations for equivalent resistance to create simpler circuits. You may wish to review this process in your Physics text book before you come to lab.

Energy is dissipated in a circuit with resistors. That is, energy is lost as current passes through the resistor. The energy per unit time (power) lost is given by:

$$P = I^2 R$$

Power has units of watts = Joules / second. So $[\text{amp}]^2 \text{ Ohm} = \text{watts}$. By Ohm's law, we can also write the power equation in other forms. For example:

$$P = IV = V^2 / R$$

KIRCHOFF'S LAWS

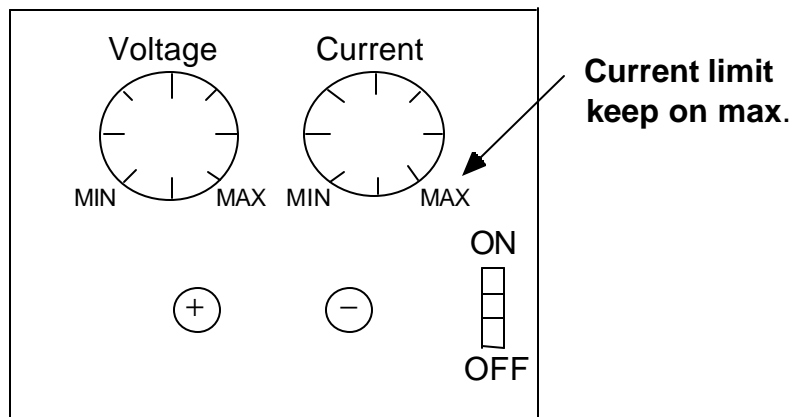
Gustav Kirchoff formulated two very useful general rules for analyzing circuits. The current law simply states that if current comes into a place where several wires meet, the sum of all the outgoing currents equals what went into the junction: "What comes in must go out." To apply the current law, assume a direction of current. If you guess the direction wrong, all that happens is some of the currents might need to be negative.

The voltage law says that if you measure the voltage changes as you go around a circuit loop, their algebraic sum must add up to zero: "If you go in a circle, you get back to where you came from." Again, you need to define voltage drops in a consistent direction going around the loop. The law can apply to any loop in a circuit. Applied to a circuit with a single voltage supply, the law simply means that the voltage drop across the circuit element(s) is just equal to the voltage supply. Why? If you take the direction so that the supply voltage represents an increase, the voltage change in the circuit will be a decrease of the same magnitude, so they add up to zero. Applied to a parallel arrangement of circuit elements, the voltage law states that the voltage drop across the two elements is the same. Why? Since there is no voltage supply in the loop formed by the parallel elements, one voltage drop as the negative of the other's rise as you go around the loop.

DIRECTIONS FOR THE USE OF APPARATUS: The DC Power Supply

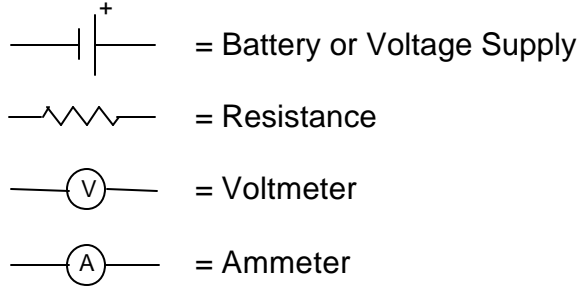
A DC power supply provides a variable voltage to a circuit. The black and red connectors are the negative (-) and the positive (+) output terminals respectively. The voltage knob controls the output voltage and the current knob controls the *limiting* current. In this lab, **set the current control at maximum (all the way to the right) at all times.**

NOTE: Before making any change in the circuit, always turn the voltage knob to minimum (all the way to the left) and turn off the power supply!



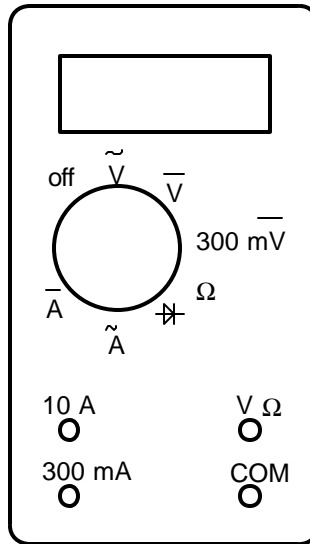
The DC Voltage Supply

Standard Symbols:



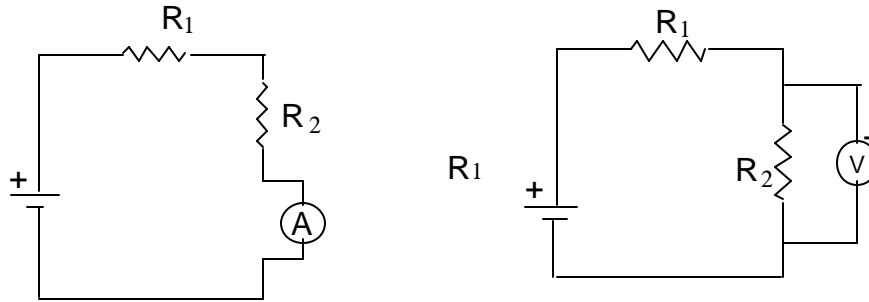
The Digital Multimeter

As the name suggests, a multimeter has multiple functionality. It can be used for several different purposes, two of which are as a voltage-measuring device (a voltmeter) or as a current measuring device (an ammeter).



The Digital Multimeter

To use the multimeter as a voltmeter, the dial selector must be set to one of the positions labeled with “V”. The probing cables should be connected to the two terminals labeled “VΩ” and “COM” respectively. It should be noted that there are two different types of “V” settings. One has a tilde (~) over it. This indicates that it is AC voltage. The two lines over the V (one solid and one dashed) indicate DC voltage. During the first two labs we will be interested in using the DC setting. It should be further noted that there is also a setting that reads “300 mV” (with DC again indicated by the two lines over the V). When it is on this setting, the multimeter reads in millivolts. **A voltmeter must be connected in parallel to the element of interest,** as shown on the right of the schematic picture below. Since a voltmeter measures a *potential difference* between two points, it is easy to connect. If we want to know how much the potential changed across a resistor, we can connect one end before the resistor and one end after the resistor. A voltmeter usually has a large internal resistance so that little current will flow through it, thus the current in the circuit will be approximately the same before and after the voltmeter is connected.

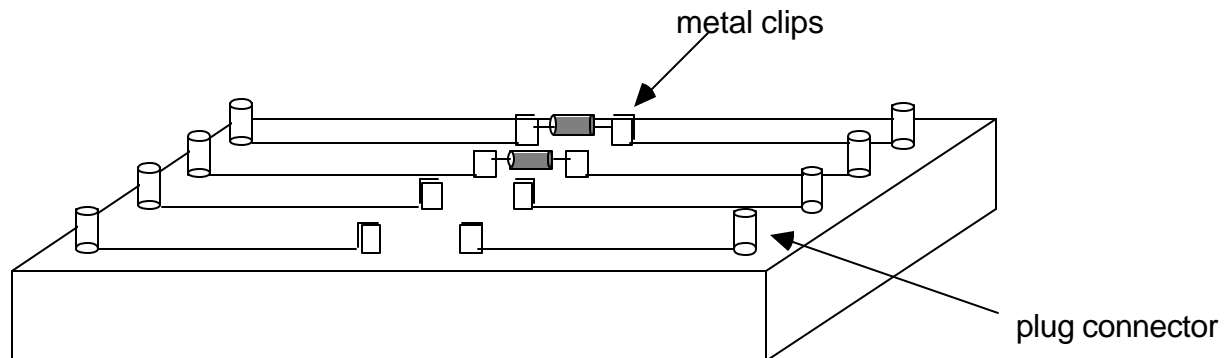


Circuit Schematic

To use the multimeter as an ammeter, the dial selector must be set to one of the positions labeled “A”. Just like the voltage settings, there is again a DC and an AC. The AC is the one with the tilde (~) over it. There are also now two different terminals you can plug the wire into. One of the cables will again be in the plug marked “COM” but the other cable can be either in the plug marked “10A” or the one marked “300mA”. If you have a large amount of current (anywhere close to 1A or higher) you **must** put it in the terminal marked “10A”. If you put it in the “300mA” you can damage the multimeter. If you are unsure if you have too much current to use the “300mA” plug, start with it in the “10A” port. If you don’t get any reading at all, chances are that you have a small current and can move the cable to the “300mA” port. **An ammeter must be connected in series to the circuit of interest.** This means that unlike measuring voltage, if we want to measure current, we actually must break the circuit and wire the ammeter in, almost as if it is another resistor. An ammeter usually has a very small internal resistance so that the current in the circuit will be approximately the same before and after the ammeter is connected.

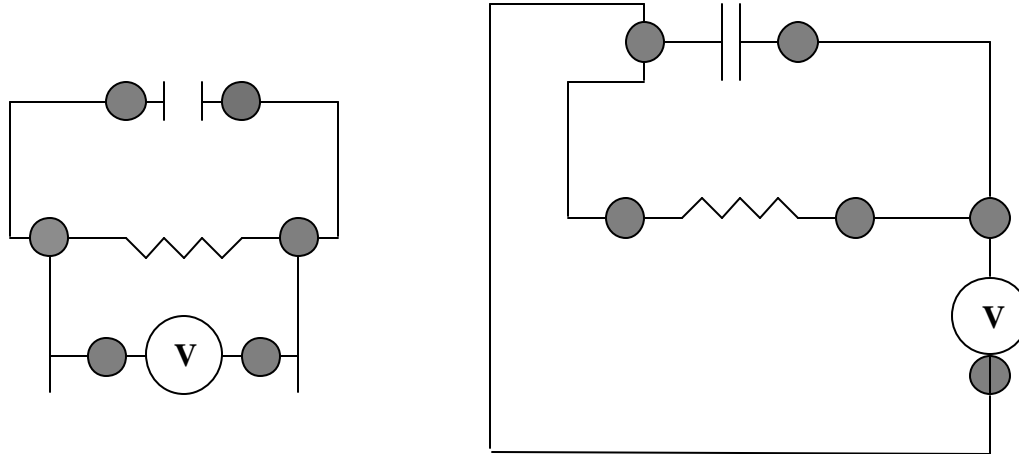
The Connection Box

The connection box is designed for quick construction of simple electronic circuits. Electronic elements (e.g., a resistor) can be easily attached to the metal clips in the middle of the box. For each metal clip, there is a corresponding plug connector (a black line connects them) which is electrically connected to the metal clip. Electronic circuits can be constructed by connecting the electronic elements and the power supply together using cables with banana plugs.



Wires

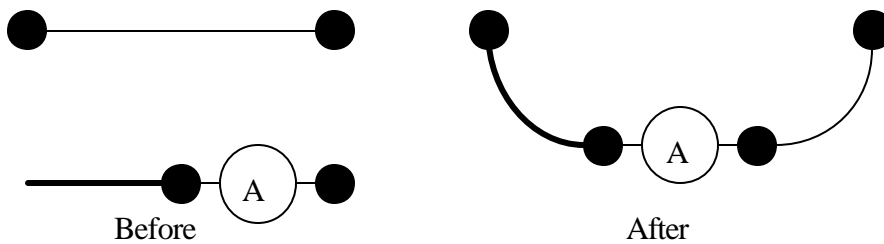
You will have to hook up wires to make the circuits described in the diagrams below. Each line without any circuit element should correspond to a wire in your circuit. A wire (or line in the diagram) represents a path where current can flow. **All points on the line have the same voltage.** Because of this, a circuit may be realized by several different arrangements of wire. The two circuits below are equivalent.



The dots represent places where wires are plugged into connectors.

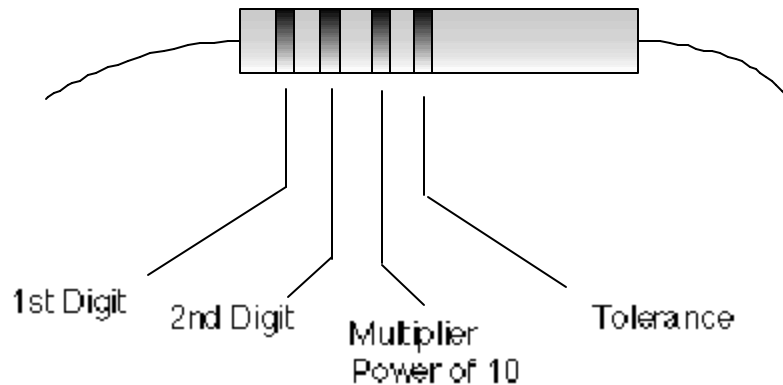
Suggestions for Building Circuits

- 1) Build the basic circuit without any meters. Where two lines meet, you need two wires.
- 2) Get a single wire of a different color and attach it to one of the inputs of your ammeter. Identify where in the circuit the current you want to measure flows. Unplug the wire(s) carrying the current at one end. Plug the wire dangling from the ammeter into the connection from which you just removed the wire. Now plug the wire(s) you just unplugged into the empty ammeter connection. You have forced all the current carried by the wire(s) to go through the ammeter.
- 3) Attach 2 wires to the voltmeter inputs and then attach these leads across the points whose voltage you wish to measure.



RESISTOR COLOR CODES

Most resistors are coded with color bands around one end of the resistor body. These color bands tell the value of the resistance. Starting from the end, the first band represents the first digit of the resistance value and the second band the second digit. The third band represents the power of ten multiplying the first two digits. The fourth band represents the tolerance. If the fourth band is absent, it means the tolerance is 20%. The following is a color code chart, from which one can tell the resistance of a resistor:



<u>Color</u>	<u>1st Digit</u>	<u>2nd Digit</u>	<u>Power of 10</u>	<u>Multiplier</u>	<u>Tolerance</u>
Black	0	0	0	1	-
Brown	1	1	1	10	-
Red	2	2	2	100	-
Orange	3	3	3	1,000	-
Yellow	4	4	4	10,000	-
Green	5	5	5	100,000	-
Blue	6	6	6	1,000,000	-
Violet	7	7	7	10,000,000	-
Gray	8	8	8	100,000,000	-
White	9	9	9	1,000,000,000	-
Gold	-	-			5%
Silver	-	-			10%
None	-	-			20%

Example:

yellow violet orange gold $R = (47 \pm 2) \times 10^3 \Omega$ or $(47 \pm 2) \text{ k}\Omega$

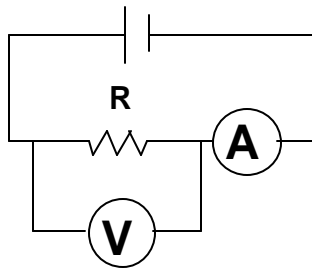
Part A

Partners: _____

Name: _____
 Section: _____

- the units on ALL quantities must be specified, i.e. Ω = Ohms, V = Volts, A= Amps
- $K = 10^3$ $m = \text{milli} = 10^{-3} = 1/K$
- Set the current control knob to the maximum at all times.

1. Connect the circuit as shown below and measure the resistance of the resistor. Compare your result with the value of the resistor given by its color code. (Because the ammeter has an internal resistance of 6Ω , **you must use resistors that have a resistance of at least 1000W**)



Resistor color code: _____

Resistance from color code: $R = \text{_____} \pm \text{_____} \Omega$

Measured voltage: $V = \text{_____} \pm \text{_____} \text{ Volts}$

Measured current: $I = \text{_____} \pm \text{_____} \text{ mA}$

Resistance from Ohm's law: $R=V/I = \text{_____} \pm \text{_____} \Omega$

$$\frac{\delta R}{R} = \frac{\delta V}{V} + \frac{\delta I}{I}$$

Compare the resistance from color codes and the measured resistance, comment:

2. Graphical test of Ohm's law for a constant resistor. (Same circuit as in step 1.)
 Begin with a very small voltage and gradually increase the voltage. For several voltage settings throughout the range, record both the voltage readings from the voltmeter and the current reading from the ammeter in the table below. *You should review section 10 of the introduction before doing this.*

VOLTAGE V (volts)	CURRENT I (mA)

Plot V (vertical axis) vs. I (horizontal axis) and measure the slope of the line.

Q: Should your data contain the point V=0 V, I=0 A? Why or why not?

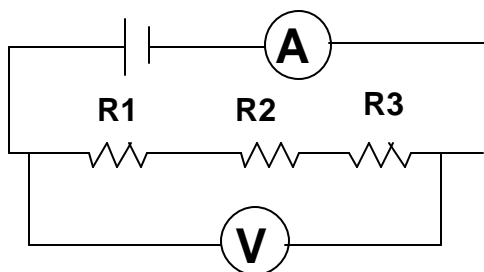
Q: Is the voltage across a resistor a linear function of the current passing through the resistor?
How do you know this?

Slope = R = _____
(show calculation)

Q: Does the slope agree with your measured value of the resistance from Ohm's Law?

Q: Why should they be the same?

3. *Three resistors connected in series.* Connect the circuit as shown below. (Use three not very different resistors):



Resistance R_1, R_2, R_3 from color codes:

$R_1 =$ _____ \pm _____

$R_2 =$ _____ \pm _____

$R_3 =$ _____ \pm _____

Theoretical effective resistance: $R_S = R_1 + R_2 + R_3 =$ _____ \pm _____

($\delta R_S = \delta R_1 + \delta R_2 + \delta R_3$)

Results from measurements:

Voltage: V = _____ \pm _____

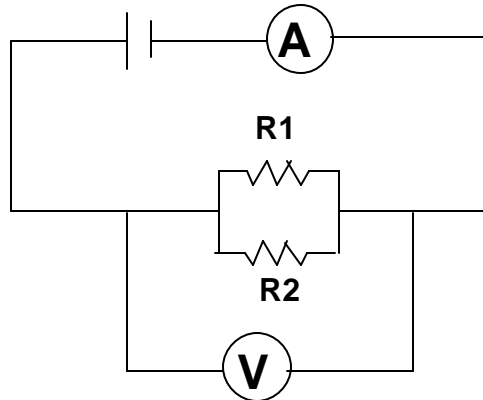
Current: I = _____ \pm _____

Effective resistance: $R = V/I =$ _____ \pm _____

$$\frac{\delta R}{R} = \frac{\delta V}{V} + \frac{\delta I}{I}$$

Compare and discuss your theoretical and measured effective resistance:

4. *Two resistors connected in parallel.* Connect the circuit as shown below. (Use two nearly equal resistors.)



Resistance of R_1 , R_2 from color code:

$$R_1 = \text{_____} \pm \text{_____}$$

$$R_2 = \text{_____} \pm \text{_____}$$

Theoretical effective resistance: $R_p = \frac{R_1 R_2}{R_1 + R_2} = \text{_____} \pm \text{_____}$

$$\left(\frac{dR_p}{R_p^2} \right) = \left(\frac{dR_1}{R_1^2} \right) + \left(\frac{dR_2}{R_2^2} \right)$$

Results from measurements:

Voltage: $V = \text{_____} \pm \text{_____}$

Current: $I = \text{_____} \pm \text{_____}$

Resistance: $R = V/I = \text{_____} \pm \text{_____}$

$$\frac{\delta R}{R} = \frac{\delta V}{V} + \frac{\delta I}{I}$$

Compare and discuss your theoretical and measured effective resistance:

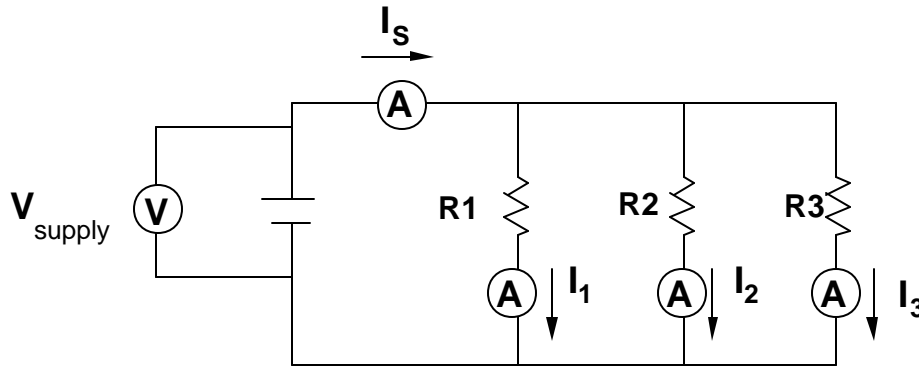
5. Apply 5 volts across an approximately 50Ω resistor. Does the resistor get warm? How many watts of power are produced as heat here? ($P = IV = I^2 R = V^2 / R$)

Part B

Partners: _____

Name: _____
 Section: _____

1. Verifying Kirchoff's Current Law: *Three resistors in parallel.*
 (Because the ammeter has an internal resistance of 6Ω , **you want to use resistors that each have a much greater resistance, at least $1000\ \Omega$.**)
 Connect the circuit as shown below and measure the currents I_1 , I_2 , I_3 , I_S , and V_{supply} .
 Verify experimentally $I_S = I_1 + I_2 + I_3$.



Resistance of R_1 , R_2 , R_3 from color code:

$R_1 = \text{_____} \pm \text{_____} \Omega$
 $R_2 = \text{_____} \pm \text{_____} \Omega$
 $R_3 = \text{_____} \pm \text{_____} \Omega$

Results from measurements:

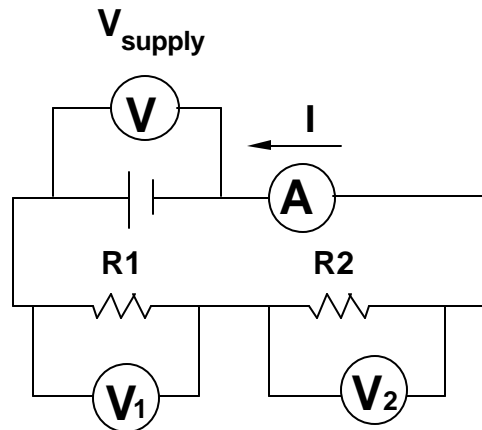
$I_1 = \text{_____} \pm \text{_____} \text{ mA}$ $I_S = \text{_____} \pm \text{_____} \text{ mA}$
 $I_2 = \text{_____} \pm \text{_____} \text{ mA}$ $V_{\text{supply}} = \text{_____} \pm \text{_____} \text{ V}$
 $I_3 = \text{_____} \pm \text{_____} \text{ mA}$
 Calculate: $I_1 + I_2 + I_3 = \text{_____} \pm \text{_____} \text{ mA}$

Compare $(I_1 + I_2 + I_3)$ with I_S and comment:

Calculate the theoretical values of I_1 , I_2 and I_3 , using V_{supply} and the resistance from the color codes. (Give the theoretical expression for each current.) Compare them with the experimental values and comment. *Hint: $dI/I = dV/V + dR/R$, but the uncertainty in V is negligible compared to the uncertainty in R .*

2. Verifying Kirchoff's Voltage Law: *Two resistors in series*

Connect the circuit as shown below. Measure the voltage drop across each resistor V_1 and V_2 , and across the source V_{supply} . Measure the current I .



Resistance of R_1 , R_2 from color code:

$$R_1 = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}}$$

$$R_2 = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}}$$

Results from measurements:

$$V_1 = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}}$$

$$V_2 = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}}$$

$$V_{\text{supply}} = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}}$$

$$I = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}}$$

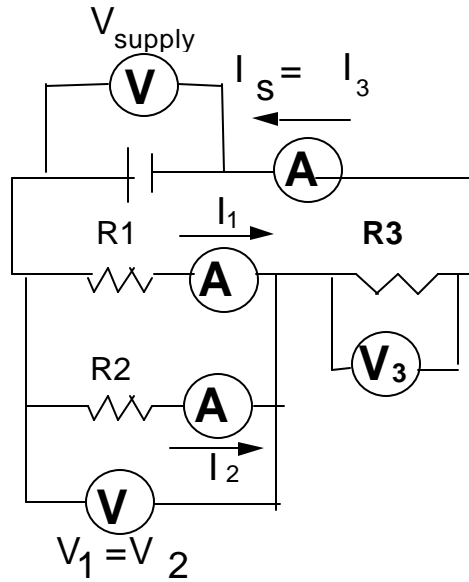
$$\text{Calculate: } V_1 + V_2 = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}}$$

Compare $V_1 + V_2$ with V_{Supply} and comment:

Calculate the theoretical values of V_1 and V_2 , using I and the resistance values from the color code. (Give the theoretical expression for each voltage.) Compare them with the experimental values and comment. *Hint: $dV/V = dI/I + dR/R$, but dI/I is very small compared to dR/R .*

3. Combining Kirchoff's Laws: Two resistors (R_1 , R_2) in parallel and one resistor (R_3) in series. (No uncertainty calculations are requested in this part.)

Connect the circuit as shown below.



Resistance of R_1 , R_2 , R_3 from color code:

$$R_1 = \text{_____} \pm \text{_____}$$

$$R_2 = \text{_____} \pm \text{_____}$$

$$R_3 = \text{_____} \pm \text{_____}$$

Results from measurements:

$$V_{\text{supply}} = \text{_____} \pm \text{_____}$$

$$V_1 = \text{_____} \pm \text{_____}$$

$$V_2 = \text{_____} \pm \text{_____}$$

$$V_3 = \text{_____} \pm \text{_____}$$

$$I_1 = \text{_____} \pm \text{_____}$$

$$I_2 = \text{_____} \pm \text{_____}$$

$$I_3 = \text{_____} \pm \text{_____}$$

Compare V_1 and V_2 , and comment:

$$V_1 + V_3 = \text{_____} \pm \text{_____}$$

Compare this sum to V_{supply} and comment:

$$I_1 + I_2 = \text{_____} \pm \text{_____}$$

Compare this sum to I_3 and comment:

It is possible to calculate everything about this circuit starting only with V_S , R_1 , R_2 , and R_3 . These calculations can be completely algebraically. This means that you do not need to plug in any numbers at first, you can just use Ohm's Law and Kirchoff's rules to calculate theoretical expressions for I_1 , I_2 , I_3 , V_1 , V_2 , V_3 . This can and should be done before lab, so that when you reach this part, you need only plug in your values for R_1 , R_2 , R_3 from the color codes and the supply voltage V_{supply} . Compare your results with the measured ones and comment. Do your calculations to 3 significant figures, as if the values for R_i were exact. You may wish to refer to your Physics textbook for help on this part. (Hint: Calculate the total equivalent resistance R_T first.)

4. You will be given an unknown device. Determine if it obeys Ohm's Law for a constant resistance. Determine this any way that seems reasonable and thorough. (*Hint: If it does obey Ohm's law, the resistance will be constant, regardless of the current or voltage.*)