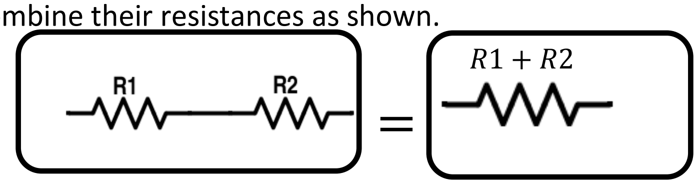
PHY 242

Lab 4: Series and Parallel Resistors

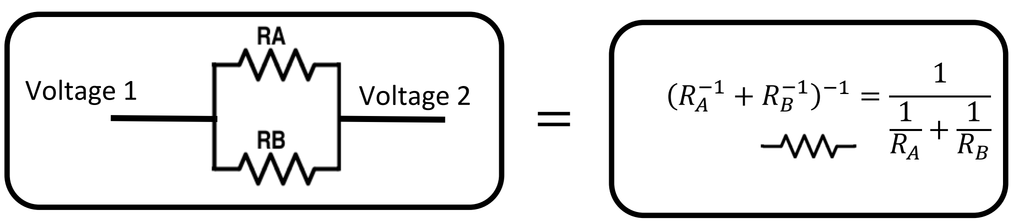
Introduction

We know from lecture that when resistors are connected into a circuit, the way that they are connected significantly changes the behavior of the entire circuit. For example

Series: When two (or more) resistors must have the **same current,** we say that they are **"in series"** and we can combine their resistances as shown.



Parallel: When two (or more) resistors must have the **same voltage difference,** we say that they are "**in parallel"** and can combine their resistances as shown.



Frequently the parallel resistance formula is written

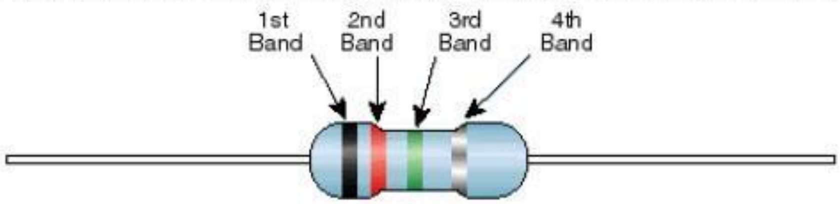
$$R_{parallel} = \frac{R_A * R_B}{R_A + R_B}.$$

Resistor Color codes: Most resistors are designed to be tiny parts of electrical devices. And it is important for people who are working with these small components to know what the resistance is approximately without needing extra equipment. The standard way this information is written is using color bands.

The first two bands combine to make a number from 1 to 99, the third band is a multiplier ($\times 10^{color}\ \Omega$) and the fourth band shows the *tolerance* of the resistor, or in the language we have been using the *Percent Uncertainty,* $\frac{\delta R}{R} * 100\% = 10\%,\ 5\%,\ or\ 2\%.$

For the resistor pictured below the resistance is understood as Black =0, Red = 2, Green=5, Silver=10%. So $02\times10^{5}\ \Omega \pm 10\% = 2\times10^{5}\Omega \pm 10\%$.

Standard EIA Color Code Table **4 Band**: ±2%, ±5%, and ±10%



Color	1st Band (1st figure)	2nd Band (2nd figure)	3rd Band (multiplier)	4th Band (tolerance)
Black	0	0	10^{0}	
Brown	1	1	10^{1}	
Red	2	2	10^{2}	±2%
Orange	3	3	10^{3}	
Yellow	4	4	10^{4}	
Green	5	5	10^{5}	
Blue	6	6	10^{6}	
Violet	7	7	10^{7}	
Gray	8	8	10^{8}	
White	9	9	10^{9}	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%

Chart Provided By XICON

Five and six band resistors exist, but we will only focus on reading four band resistors.

Purpose

The goal of Lab 4 is to compare direct measurements of the effective resistance of a collection of resistors to the values predicted by the series and parrallel formulas.

Equipment

1 DC power supply- Set the current limit on the power supply to .01 A and the voltage to .4 V

1 ammeter/Galvanometer- A Galvanometer is a sensative Ammeter for measuring small currents. We will primarily be using the 500 μA scale.

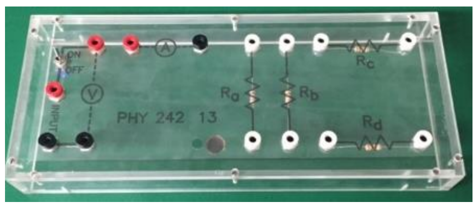
Use this button to turn on the meter.

The three plugs along the side change the maximum amount of current that can be measured (changing the units on the scale)

1 oscilloscope

1 resistor board

Multiple wires



1 Digital MultiMeter (DMM)

Procedure:Part 1

1) Record the resitance and uncertainty of all four resistors on the board based on their color code.

2) Set the power supply to $.4\ V$. If you need to decrease the voltage, feel free to go as low as you need, but do not go over $.5\ V$.

3) Set up a simple circuit (Prelab question 4) to measure the “voltage across” and “current through” one of the resistors using your equipment. Use Ohm’s law to check the resistance you determined in the previous step. **Use formulas in excel to make this efficient.**

4) Finally, measure the resistance of each resistor using the DMM. Use the Ω setting and apply the two DMM wires to the two sides of the resistor. It is important to note that

you must disconnect the resistor from the circuit for the DMM to give an accurate reading.

5) To calculate the uncertainties δR_{ohm} modify the excel sheet as you need. Most groups will probably need to calculate ΔV_{max}, I_{min}, ect…

6) Think carefully about any *systematic* errors that might have been introduced into our two methods, Ohm and DMM, of measuring the resistance.

7) Taking all of part 1 into consideration, dermine the resistance of each of the resistors to the best of your ability. ($R_a =$ _______ $\pm$ _______Ω, $R_b = \cdots$)

Part 2: In Series

8) Connect two of the resistors in series (this requires 1 wire). Use the simple circuit from step 3 to measure the voltage and current across this **pair** of resistors.

9) At this point we have three methods to calculate the resistance of R_a and R_b in series. We can use Ohm's Law, $R_{ohm} = \frac{\Delta V_{across\ both}}{I_{through\ both}}$, OR we can use the series formula $R_{series} = R_1 + R_2$. OR we can hook up the DMM with the resistors inbetween. Since these three methods should agree, use all methods to see if they do.

10) As usual, we can not make a useful comparison between calculations without uncertainty. Rather than following the standard rules for uncertainty used so far, we would like to take advantage of calculus to calculate the uncertainty:
    a. If we have a formula for R_{ohm} in terms of the other measured quantities we should properly write that using functional notation as $R_{ohm}(V, I)$. This is just like $f(x)$ except in our case the function f represents the resistance of a wire, and instead of a generic x we have two specific things that the wires resistance depends on.
    b. If we want to know how much R_{ohm} will change if we change V by a little amount, we can calculate the $partial\ derivative$ of our function and multiply by that small change:

$$\delta_{from\ V} R_{ohm} = \frac{\partial}{\partial V}[R_{ohm}(V, I)] * \delta V.$$

> Just a bit on notation: in your calculus class you probably saw the derivative of y written as $\frac{dy}{dx}$. Here we write that as $\frac{d}{dx}[y]$ to make it more clear that the derivative $\frac{d}{dx}$ is acting on the function y.

c. $\frac{\partial}{\partial V}[R_{ohm}(V,I)]$ is just like a normal derivative, but the script deltas, ∂, promise us that none of the symbols in the formula depend on each other. So when take the V derivative we can treat everything other than "V" as a constant.

d. To find how much R_{ohm} can change if both V and I are uncertain we simply perform the previous step for each variable and add together their absolute values

$$\delta R_{ohm} = \left|\frac{\partial}{\partial V}[R_{ohm}(V,I)] * \delta V\right| + \left|\frac{\partial}{\partial I}[R_{ohm}(V,I)] * \delta I\right|.$$

e. For our case we can evaluate the partial derivatives to get

$$\delta R_{ohm} = \left|\frac{1}{I} * \delta V\right| + \left|-\frac{V}{I^2} * \delta I\right|$$

or

$$\delta R_{ohm} = R_{ohm}\left(\frac{\delta V}{V} + \frac{\delta I}{I}\right).$$

Which is exactly what we have been doing when following Uncertainty rule 6. This is where uncertainty rule 6 came from.

f. To find the uncertainty in any calculated value X that depends on values y_i we can use

$$\delta X(y_1, y_2, \ldots) = \sum_{all\ y_i} \left|\frac{\partial}{\partial y_i}[X] * \delta y_i\right|$$

11) Use step 10 to calculate δR_{ohm}. Similarly follow the logic of step 10 to calculate δR_{series}. Note: the calculation of δR_{series} is different from δR_{ohm} because R_{series} is a different function of different variables, $R_{series}(R_a, R_b) = R_a + R_b$.

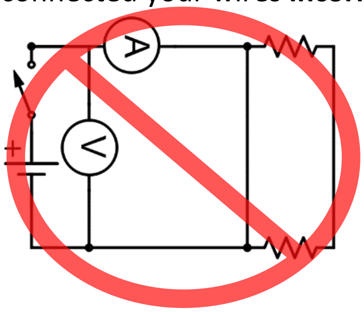
Part 3: In Parallel

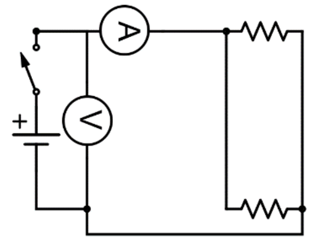
12) Turn off the power supply before hooking up your simple circuit to the R_c, R_d pair.

13) Connect R_c and R_d in parallel with each other (this requires 2 wires).

14) Before turning the power back on, we want to check for shorts in the circuit which could damage our equipment.

a. Phyiscally place your hand on the wire coming from the positive on the power supply. Follow this wire through the circuit trying to get to the negative on the power supply without going through a resistor. If this is possible you have connected your wires **incorrectly** and you need to rewire.





Correct!

15) Measure the effective resistance of the resistors three ways again: Ohm's Law, the formula for parallel resistors $R_{\|} = \frac{R_c R_d}{R_c + R_d}$ and the DMM. Again follow step 10 to determine your uncertainties. Since these three methods should agree, see if they do.

Part 4: Mixture of series and parallel

16) Using all four resistors, create a circuit of your choosing which is not all Series and not all Parallel but some mixture of the two. If possible, make it interesting or at least different from other groups.

17) Create a **schematic drawing** of the circuit you have constructed. You can do this in Word using "Insert->Shapes," but http://www.digikey.com/schemeit/ is a much faster program built for exactly this task. Under "Schematic symbols" you can find resistors are under "Passives," the voltmeter and ammeter are under "Test Equipment," and the power source is under "sources." Adding a photo of your circuit is an excellent idea, but does NOT qualify as a schematic drawing.

18) Using the techniques of Parts 1, 2, and 3
    a. Measure the effective resistance of this new circuit based on the current and voltage measured.
    b. Measure the efffective resistance using a DMM.
    c. The group needs to construct a formula to determine the effective resistance of the circuit you have constructed in terms of the series and parallal connections between resistors included. Call this equation/value $R_{effective}$.

19) The focus of your report is Part 4. You will need to explain how you determined the resistance of each of your resistors from step 7), but you do not need to discus parts 2 or 3 at all. Remember that the report should be two pages or less and follow the guidelines in "Rubric and Example for Lab Reports 2017" on Canvas.

20) Create a small scatterplot to display your data for Part 4 only to show that 18c accurately predicts the effective resistance of your circuit.

21) Explain how your group determined the equation for $R_{effective}$. Then use the final scatter plot to show that your equation is correct.

22) Explain how $\delta R_{effective}$ is calculated by evaluating the formula:

$$\delta X(y_1, y_2, \dots) = \sum_{all\ y_i} \left| \frac{\partial}{\partial y_i}[X] * \delta y_i \right|$$

23) What was the single **largest source of uncertainty** in your experiment? Is it systematic or random? How is this (or should this) be incorporated in your scatterplot?

24) Clean up your station and return all equipment that you took out of equipment drawers or off of wire racks.