Ohm's Law and Resistivity (approx. 2 h) (8/6/15)

Introduction

In this lab you will investigate simple DC (direct or constant current) circuits using a DC power supply, a multimeter and wire resistors. You will measure voltage and resistance for different components in your circuits. (You will not use the multimeter to measure current in this lab.)

Equipment

- DC power supply with voltage and current displays (3A)
- rheostat (about 100 Ω)
- multimeter
- resistance demonstrator
- alligator-to- banana plug leads (3)

For class: Phillips screwdriver and spare fuses for multimeters

Theory

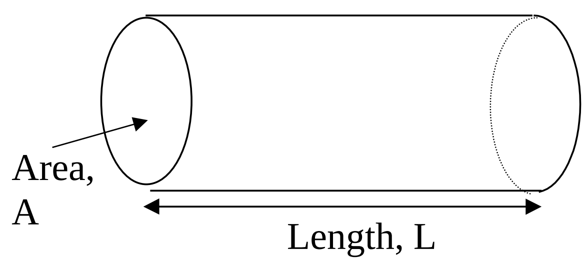
Ohm's Law: $V = IR$ (by definition, $R \equiv V/I$)

Resistance, R, is a measure of how difficult it is (i.e. how much voltage is needed) to force each unit of current (i.e. an ampere) to flow through a circuit element (e.g. a wire, a resistor, etc.). "Ohmic" devices have a linear relationship between voltage, V, and current, I.

Power: $P= IV$, which for an ohmic device yields: $P=IV= I^2R = V^2/R$.

Electrical energy is converted to thermal energy in a resistive load. The rate at which it is converted is P=IV. Power, P, in units of Watts (= Joules/second) is Current, I (=charge flow rate in units of Amperes=Coulombs/sec) times Energy change per Coulomb of charge, V (=Voltage=Joules/Coulomb). For an Ohmic device, the voltage drop across the resistance is V=IR, so we get the result $P=I^2R$. If you double the current through a given resistance, then you will quadruple the rate at which electrical energy is converted to thermal energy (i.e. heating).

Resistivity: $R = \rho \dfrac{L}{A}$.



Resistivity, ρ, is a characteristic of a given material which describes how hard it is to force current to go through that material. Good conductors have very low resistivity. Insulators have very high resistivity. Resistance (R) is a property of a particular wire, resistor, etc. For wire, resistance is determined by the resistivity of the material, the length of the material (*L*), and its cross sectional area (*A*), as given in the above equation.

Handbook Resistivities of Some Common Metals (20°C):

Material	Resistivity (Ω-m)		Material	Resistivity (Ω-m)
Copper	1.72×10^{-8}		"Nickel-Silver" (alloy)	29×10^{-8}
Silver	1.47×10^{-8}		Copper-Nickel (70/30)	37.4×10^{-8}
Tungsten	5.25×10^{-8}		Nickel	7.8×10^{-8}

SAFETY NOTE

Every time you need to manipulate the circuit, turn off the current and disconnect one lead from the power supply. Note that the current reading will become ZERO. Although the following circuits should be safe to touch, this is always a good safety precaution that will protect both you and the circuit elements!

Procedure

With no leads connected to the power supply:

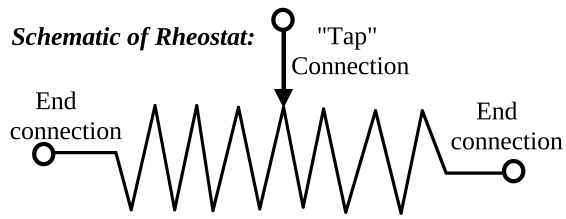
Set up the Power Supply so it is on the 2 Amp setting (there is a button to select 2A or 3A).

Press in AND HOLD the "CC Set" button. The current limit will be displayed. To protect your circuits from possible overheating, set the current limit to 1.00 amp by adjusting the Current knob.

Part A: Verifying Ohm's Law

A rheostat is a variable resistor made of a long wire wound in a cylindrical shape. There are connections for each end of the wire. The resistivity of the wire will be constant so long as there is negligible heating of the wire, so don’t leave the current on any longer than necessary. There is also a "tap" that can be moved back and forth along the rheostat. There is a third connection (or one at each end of the bar running above the wound wire) that connects to this "tap". This allows you to connect to the rheostat at any point along the wire. The symbol for a rheostat represents a resistor with a connection at each end and also a variable "tap" connection.

Schematic of Rheostat:



Use your multimeter on the ohmmeter (Ω) setting to make sure you understand how to measure resistances between each pair of connections on the rheostat.

Record the total (i.e. end-to-end) resistance of the rheostat as measured by your multimeter.

Relationship between current and voltage.

Turn the voltage of the power supply down to ZERO.

Keep the power supply connected across the total (i.e. end-to-end) resistance of the rheostat.

Starting with **zero volts** and **zero current** as your first data point, make a record of voltage (V) and current (I) displayed by the power supply as you turn up the voltage. You should record about 8 data points as you turn the voltage up from ZERO to the MAXUMUM (about 15 volts on the 2 Amp setting.)

For each data point calculate and record the resistive load (R) by using Ohm's Law (i.e. R=V/I).

MAKE A GRAPH of voltage (V) in volts versus current (I) in amperes (amps). Use a curve fitting procedure (with EXCEL for example) to fit a straight line graph to your data.

Part B: Investigating the Rheostat.

REMOVE ONE LEAD FROM THE POWER SUPPLY SO THE CURRENT READING IS ZERO. Leave the power supply on its highest voltage setting.

Move the center tap of the rheostat so that it is about 20% of the length from one end.

Measure and record the resistance between the end and the tap using the ohmmeter (Ω) setting of your multimeter. Remember, you only get a true value of the resistance when all other circuit elements are disconnected.

Connect one power supply lead to one end of the rheostat and the other to the center tap (still at 20% of the length away).

Reconnect both leads to the power supply and record the voltage and current from the power supply display, then promptly DISCONNECT THE POWER.

Calculate and record the resistance using Ohm's law and compare to the multimeter reading.

REPEAT for 4 additional positions of the rheostat tap (about, say 40%, 60%, 80% and 100%). DISCONNECT THE POWER SUPPLY EACH TIME YOU MOVE THE RHEOSTAT TAP!

Questions (Parts A and B)

1. Look at your graph from Part A. What evidence, if any, does it show that the rheostat is an *ohmic* device?

   What does the slope of your straight-line graph represent?

   How does the value of resistance as determined by your graph compare to the value measured using your multimeter?

2. Considering the uncertainty in the last digit displayed by the power supply, what is the minimum uncertainty in your current measurements?

   What percentage uncertainty does this result in for your lowest current measurement in Part A?

   What percentage uncertainty does this result in for your highest current measurement in Part A?

3. In part B, are the discrepancies between the values you measured with the ohmmeter and the values you calculated *random* (some high, some low), or *systematic* (consistently high or low)?

   Discuss possible causes for these discrepancies.

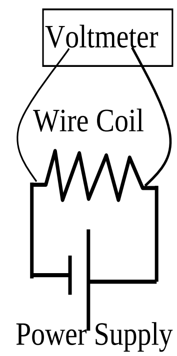
Part C: Resistivity

The resistivity demonstrator consists of five coils of wire. Each is labeled by material composition (Cu=Copper, NiAg=Nickel-Silver alloy, or CuNi=Copper-Nickel alloy). The wires are clad in copper-colored insulation. There are leads that allow you to connect to the ends of the wires. Each coil is labeled with a length in meters and a "gauge" or diameter (either in inches or millimeters). *Before taking any measurements on the resistivity demonstrator*, read the information provided for each coil and jot down here your predicted order from highest resistance to lowest resistance coil: 1._______ 2._______ 3._______ 4._______ 5._______ Proceed!

Remove the rheostat from the circuit and set it aside. Verify that the current-limit setting on your power supply is precisely at 1.00 amps. TURN THE POWER SUPPLY OFF!

Connect the + and – terminals of your power supply across the #1 copper coil on your resistance demonstrator by connecting to the ends of the blue insulated lead wires where they are soldered to the terminals.

Set your multimeter to measure DC voltage, then connect it across the wire coil at the same locations as you connected the power supply, as shown in the schematic drawing. With no current the voltage should read zero. (If it does not read zero, record the millivolt offset from zero.)



Schematic Drawing

Once the circuit is made and checked, be prepared to record the voltage and current as soon as you turn the power supply on.

Turn the power supply on and record the voltage drop across the coil using the multimeter (not the power supply). Record the current from the power supply display, since it is the same as the current through the coil. Write down these numbers as soon as you turn the power on, then disconnect the power supply. (You may notice the voltage changing if you wait too long.) Calculate the resistance of the wire coil using your measured values of voltage drop and current.

DISCONNECT THE POWER SUPPLY SO THE CURRENT IS ZERO.

Connect the power supply and voltmeter across the next coil of wire, as before, and repeat the above procedure for all five coils.

DISCONNECT THE POWER SUPPLY SO THE CURRENT IS ZERO.

From resistance (R) and knowing the length (L) and cross sectional area (A= πr^2) you can calculate the resistivity, ρ, of each wire coil. NOTE THAT THE WIRE DIAMETER (not radius!) IS GIVEN IN INCHES (not meters). Calculate and record the resistivity in units of Ω-m for each coil. For the copper coils compare to the handbook value given for pure copper at 20°C.

Part D: Effect of Heating on Resistivity and Resistance.

Passing current through a wire results in some electrical energy being dissipate as heat. The rate at which energy is dissipated has units of power (energy per second). For ohmic devices this is given by the equations: P= IV = I^2R = V^2/R. With your current limited to a constant 1.00 A, your heating power will be linearly proportional to (and numerically equal to) both V and R.

For each coil, record the voltage drop across it ***immediately*** after the power supply is connected to it, then leave the current on for 2 minutes and again record voltage drop across it. Disconnect power, calculate and record the resistances before and after heating, and the percent change in resistance (and therefore resistivity) due to heating. Note whether it is an increase or decrease by using + or - .

Questions (Part C and D)

1. Compare the resistance for copper wires of the SAME radius but DIFFERENT lengths. CALCULATE the ratio of lengths and compare to the ratio of resistances.

2. Compare the resistances for copper wires the SAME length but DIFFERENT radii. CALCULATE the ratio of cross-sectional areas and compare to the ratio of resistances.

3. Are the above results consistent with the theoretical relationship between resistance and resistivity?
   Were your predictions for the order of coil resistances correct? If not, try to understand why.

4. What is the discrepancy between the average of your experimentally determined values for the resistivity of copper and the handbook value for pure copper given on the first page?

   Are your values for resistivity consistent with the coils being pure copper at 20°C?

5. The Ni-Ag wire does not have a handbook value. WITHIN THE EXPERIMENTAL UNCERTAINTY can you say whether its resistivity differs from that of the copper coils? Which is the better conductor (if you can say)?

   Do your results indicate that the addition of silver to pure nickel lowers its resistivity?

6. The temperature dependence of resistivity of copper near room temperature is given approximately by:
   $\rho = \rho_o[1 + \alpha(T - T_o)]$, where ρ_o is the resistivity at temperature T_o and α=0.00393 $°C^{-1}$ for copper. Using this relationship, estimate how much each coil was heated (in degrees Celsius) during two minutes. Record your values in the table. (Hint: Use $\rho/\rho_o = R/R_0$ and solve for $\Delta T = T - T_o$) Which coil had the least estimated temperature increase, the coil with the lowest resistance (and therefore least energy dissipated as heat), or the one with the least % increase in resistance?

7. Which copper wire coil showed the most change in resistance when the power supply stayed on for two minutes?

   Explain why this wire would be expected to have the greatest change in resistance.

8. Do you think a piece of wire made of, say pure platinum, could be used to measure temperature simply by measuring its resistance? Explain why or why not.

READ AND FOLLOW INSTRUCTIONS!

Part A: Verifying Ohm's Law

Total Resistance of Rheostat (from multimeter) = ____________________________

Voltage V	Current, I	R from Ohms Law	% Difference from multimeter

Part B: Investigating the Rheostat.

Approx position	Voltage	Current	R from Ohms Law	R from multimeter	% Difference

SAMPLE CALCULATIONS:

Part C: Resistivity WRITE UNITS DOWN!

Record Coil Characteristics:

Coil #	Material	Length, L, meters	Diameter, Inches	Radius, R, meters	Cross Sectional Area, A, m^2
1					
2					
3					
4					
5					

Calculations for Area:

READ AND FOLLOW INSTRUCTIONS!

Part C: Resistivity WRITE UNITS DOWN (Continued)

Coil # & Material	Voltage across coil	Current Through coil	Calculated Resistance, R=V/I	Calculated Resistivity $\rho_{Exp.}$	Handbook Resistivity, ρ_{HB}	% Diff.

Part D: Effect of Heating on Resistivity and Resistance.

Coil #/ Material	Current (A) (constant)	V_{Coil} (t=0)	Resistance (t=0)	V_{Coil} (2 min.)	Resistance (2 min.)	% change (Resistance)	Heating ΔT(°C)
#1 Cu	1.00 A						
#2 Cu	1.00 A						
#3 Cu	1.00 A						
#4 Cu	1.00 A						