OHM'S LAW

OBJECTIVE: The object is to study the application of Ohm's law to circuit measurements and to investigate the factors upon which the resistance of a conductor depends.

THEORY: The basic idea of an electrical **CIRCUIT** is that the power supply "pushes" electrical charges around the circuit similar to the way a pump pushes water in a fountain. The resulting flow of charges is called the **CURRENT** ($I \equiv \Delta q/\Delta t$). The power supply supplies potential energy to each of the charges that flow through it. We can measure this energy per charge with a voltmeter where we define **VOLTAGE** as the electrical potential energy per charge ($V \equiv PE/q$). Note in particular that the power supply (sometimes called the voltage supply) does NOT supply the current, it only supplies the energy to move the current, just as the water pump does not supply the flowing water, only the pressure to make the water flow. Just as in the water in a water fountain, the current must be allowed to leave the power supply and then eventually return to the power supply. Hence an electrical circuit starts at the (positive terminal of the) power supply and must eventually end at the (negative terminal of the) power supply - hence the name circuit.

The individual circuit elements are connected in such a way that the current flows through them, usually giving up energy in the process. As the charges give up energy, the potential energy of the charges (and hence the voltage) will decrease as they traverse the circuit. **OHM'S LAW** states that for most common conductors the potential difference (ΔV) across the conductor is proportional to the current (I) that flows through the conductor: $\mathbf{V = I\,R}$. The **RESISTANCE** is then simply the constant of proportionality and is a measure of how hard it is to force the current through the conductor: the bigger the resistance, the more voltage is needed to force a certain amount of current; or alternately, the bigger the resistance, the less current will flow through the resistance for a certain voltage.
(NOTE: Although the formula should read $\Delta V = IR$, we often measure voltage like we measure height: from some common reference level we label as 0, and hence V and ΔV become the same.)

In this experiment we will use the law to calculate the resistance of certain conductors, after measuring the current and the potential difference. Since both the ammeter (for current measurements) and the voltmeter (for potential difference measurements) have some resistance, there will be certain errors in the measurements. Corrections would have to be made for this in very accurate work.

There are two basic ways of connecting components into a circuit: series and parallel. In **SERIES**, the same current must flow through each component. In **PARALLEL**, the current will divide and different amounts will flow through the different components. The current in a series circuit is the same throughout, so an ammeter is always connected in series. A voltmeter measures the potential difference between two points in a circuit, or across a particular part of a circuit, and this means that a voltmeter is always connected in parallel.

In using D.C. instruments, care must be taken to connect them up with the proper polarity. The terminal marked (+) should always be connected to the positive terminal of the power supply and the terminal marked (-) to the negative terminal. They need not be connected directly, but you should be able to trace back to the proper terminal. On many instruments only one terminal is marked, and it is understood that the other is the opposite polarity. On meters with more than one scale, the number on the terminal refers to the MAXIMUM value that can be measured on that scale.

METHOD: In Part One, the current in a resistor is varied by changing the applied voltage. The currents and the corresponding voltages are measured. A voltage-current curve is plotted and the slope of a straight line fitted to the points yields a value of a resistance which can be compared to the known value.

In Part Two, we use a length of wire as our resistor. The potential difference across various lengths of resistance wire are measured while the current is kept constant. A graph of resistance versus length (which should yield a straight line) will illustrate the dependence of resistance on length of conducting wire.

In Part Three, the resistance of several coils of wire of various sizes and materials are measured by the voltmeter-ammeter method. From this data, the variation of resistance with length, cross-sectional area and material is noted.

In Part Four, the resistance of coils connected in series and in parallel is measured to determine how series and parallel connections of resistors affect the total resistance.

In Part Five, the resistance of a light bulb is determined along with its electrical power consumption. Then similar light bulbs are connected in series and in parallel and the effect of the connections on effective resistance and power consumption is studied.

*CAUTION: The power supply output should be turned down between readings to minimize heating of the resistors. Heat causes the resistance to increase and this could decrease the accuracy of your results.

Part 1. Ohm's Law: V = IR

PROCEDURE:

1. Connect the apparatus as shown in Fig. 1, using the 10 ohm resistor for R. Although this resistor is stamped 10 Ω, it will not be exactly 10 ohms when measured. Resistors are guaranteed accurate only within a certain percent (10% in this case) which is usually indicated on the resistor in some way. The power supply (PS) has a control so that by rotating it the voltage across the resistor (and hence the current through the resistor) can be varied from zero to some maximum value.

2. Adjust the voltage control on the PS so that about 0.5 A runs through the resistor. Then take readings of voltage and current at about 0.1 A intervals as the current is decreased from 0.5 A to zero.

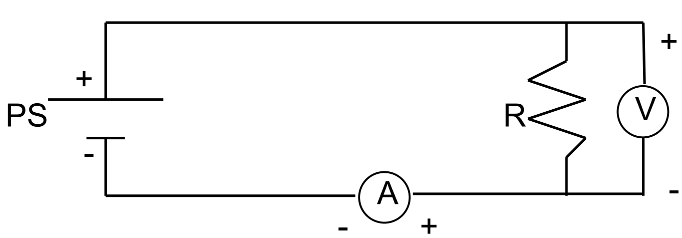

FIGURE 1

REPORT:

1. Plot a graph of voltage (ordinate or vertical axis) and current (abscissa or horizontal axis), and compute the slope of the best straight line through the points. Use a point on the line near the top and one near the bottom to calculate the slope.
2. Compute the percent difference between the slope and the nominal value of 10 Ω for the resistor. Is it less than 10%?

Part 2. Resistance vs Length

PROCEDURE:

1. Connect the slide wire to the power supply as shown in Fig. 2. Adjust the power supply voltage so that a current of 0.5 Amps or less flows through the circuit.

2. Record the voltages and currents for lengths, ℓ, of the wire of 20, 40, 60, 80, and 100 cm. Simply press the end of one of the voltmeter leads to the wire to make contact for a voltage reading. Press at different points along the wire to change the length.

3. Calculate the resistances of the various lengths of wire (using $V=IR$). Note whether the incremental change in resistance is nearly constant.

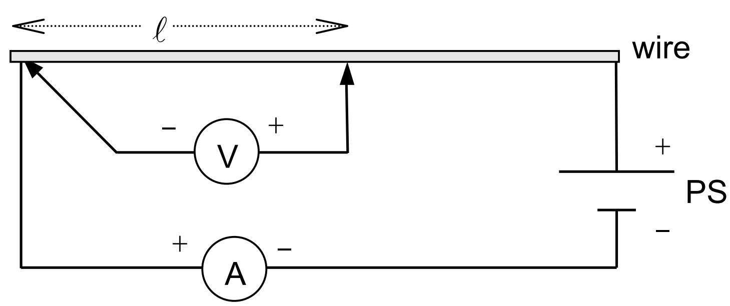

FIGURE 2

REPORT:

1. Plot a graph of resistance against length. As best as you can, fit a straight line to the points.

2. Describe or express in some way the relation between the resistance of a conductor and its length as illustrated by your graph.

Part 3. Resistance: $R = \rho\ell/A$

PROCEDURE:

1. The board in this part has five coils of wires, four made from copper and one made from a nickel alloy. The terminals on the board are labeled according to the diameter, material and length of wire connected between the pairs of terminals. The conducting properties of a material are described by its resistivity, ρ.

[NOTE: The 28 gauge wire has a diameter of 0.032 cm. The 22 gauge wire has a diameter of 0.064 cm, twice that of the 28 gauge wire. The resistivity of copper is $\rho = 1.72\times10^{-6}$ Ω-cm. That of the nickel alloy is different.]

Connect the apparatus as shown in Fig. 3.

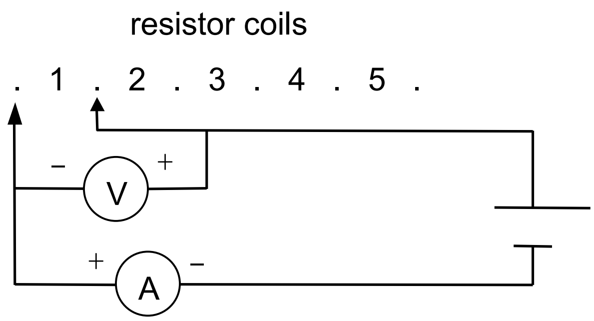

FIGURE 3

2. Measure the current and voltage across coil #1. Calculate the resistance for this coil of wire using Ohm's law.

3. Repeat this procedure for the coils #2, 3, 4, and 5. Be sure to write down the specifications of the wires connected between each pair of terminals.

REPORT:

We would expect that the resistance of a conductor of constant cross-sectional area *A* and length ℓ is given by the equation $R = \rho\ell/A$, where ρ is the resistivity of the material of which the conductor is made.

1. Do the four copper coils support this relation? In particular, do the resistances of the copper coils support the dependence of the resistance on ℓ and A? (Note that if the length of a wire doubles, the resistance should double. Note that if the diameter of a wire doubles, the area quadruples, and the resistance should reduce by a factor of four.)
2. Does your measured resistance of the alloy coil imply that its resistivity is larger or smaller than that of pure copper? Why?
3. Compute the resistivity of the alloy in Ω-cm. The resistivity of the alloy can range from approximately 8×10^{-6} Ω-cm all the way to 10^{-4} Ω-cm depending on the type alloy. Is the value you calculated reasonable?

Part 4. Resistors Connected in Series and Parallel

<u>PROCEDURE:</u>

1. Connect two adjacent coils in series. In doing this, make sure the current MUST flow through one resistor and the same current MUST flow through the second resistor. Have your instructor confirm that your resistors are in fact connected in series. Measure the effective resistance of the pair of the resistors using the same method as in Part 3. Now connect three of the coils in series. Measure their effective resistance. What do you conclude about the effective resistance of several resistors connected in series? Can you see how to derive this expression from either **V = I*R** or from **R =** $\rho \ell$**/A** ?

2. Connect two adjacent coils in parallel. In doing this, make sure the current coming from the supply can divide with some flowing through one coil and the rest flowing through the other coil. Again have your instructor confirm that your two resistors are in fact connected in parallel. Measure the effective resistance of the pair. Do this again for a second pair of coils. What do you conclude about the effective resistance of several resistors connected in parallel? Can you derive this expression from either **V = I*R** or from **R =** $\rho \ell$**/A** ?

<u>REPORT:</u>

1. Make a diagram of your wiring showing the series connection and then the parallel connection.
2. State your conclusions of how the effective resistance of a series connection is related to the individual resistors involved based on your observations. Do the same for the parallel case as well.
3. Show your derivation of the effective resistance of several resistors connected in series. Do the same for the parallel case.
4. How well do your experimental results compare with the theoretical results?

Part 5. Voltage, Current and Power

<u>PROCEDURE:</u>

WARNING: Do NOT go above 5 volts across any one light bulb. If you do, you may burn the bulb out!

1.a) Using your voltmeter and your ammeter, determine the resistance of **one** light bulb using voltages of 1 V, 2 V, 3V, 4 V, and 5 V.

b)Does the resistance remain constant as you increase the voltage (as it did in Part One for the resistor)? In the case of a light bulb, the filament is designed to get very hot ($\approx$ 3000 K) so that it glows. [We will study this phenomenon later.] From the results of your resistance determinations, what can you conclude about Temperature and Resistance?

c) Recall that **POWER** $\equiv$ **Energy/time**, and that, from the definition of Voltage, Energy = Charge * Voltage. Thus Power = Charge/time * Voltage, or **P = IV**. What is the power requirement to make one light bulb bright?

d) For future reference, record the current and power when five volts was placed across the bulb; and try to remember the brightness.

2. Now connect two lightbulbs in **SERIES**. (In other words, make all the current flow through both lightbulbs - do not give the current a choice).

a) Now set the voltage of the PS to 5 volts and note both the current and the brightness of both bulbs. Are the bulbs the same brightness as when you placed five volts across each separately? Is the same current going through each bulb as when you had 5 volts across them separately? Is the current indicated by the ammeter the same as the current flowing through lightbulb #1, #2, both, or neither?

b) What do you have to do to the voltage to make both light bulbs bright? What happens to the current when you do this?

c) What power is being used by the two lightbulbs when they are both bright? Is this twice the power to make one bulb bright? Should it be?

d) What happens when you unscrew ONE of the two lightbulbs? Why does this happen? Does it matter which bulb you unscrew?

e) Now hook up all three lightbulbs in series. Predict what voltage you will need to make all three bulbs bright. Predict the power required. Now see if your predictions are correct.

f) What happens when you unscrew ONE of the three lightbulbs? Why?

g) Is your house wired so that all your appliances and lightbulbs are connected in series?

3. Unhook the lightbulbs and re-hook two of them in **PARALLEL**. (In other words, make the current divide with some flowing through lightbulb #1 and some flowing through lightbulb #2.)

a) Now set the voltage of the PS to 5 volts, measure the current, and note how bright each lightbulb is. Are they the same brightness as when you placed five volts across each separately? Is the same current going though each as when you had 5 volts across them separately? Is the current indicated by the ammeter the same as the current flowing through lightbulb #1, #2, both, or neither?

b) What power is required to make both light bulbs bright? Is this consistent with the power to make one bulb bright?

c) What happens when you unscrew ONE of the two lightbulbs? Why does this happen?

d) Now add the third lightbulb in parallel. Predict what voltage you will need to make all three bright. Predict what power will be required to make all three bright. See if your predictions are correct.

e) Predict what will happen when you unscrew one of the three lightbulbs. Test your prediction.

f) Is your house wired so that all your appliances and lightbulbs are connected in parallel?

4. Now connect the three lightbulbs together in a way that is **neither purely parallel nor purely series.**

a) Predict which of the three lightbulbs will be brightest. Test your prediction.

b) Predict what will happen when you unscrew each of the three lightbulbs. Test your predictions

c) Is there a fourth way of connecting all three lightbulbs together? If so, do it and make predictions like you did for a and b above, and then test those predictions.

REPORT:

1. Answer the questions asked in the procedure part above.

2. By placing more resistance in the circuit in a series fashion, does the overall (effective) resistance increase, decrease, or stay the same. Is this consistent with the results of part 2 which indicated that $R \propto \ell$?

3. By placing more resistance in the circuit in a parallel fashion, does the overall (effective) resistance increase, decrease, or stay the same. Is this consistent with the results of part 3 which indicated that $R \propto (1/\text{Area})$?

4. As always, identify the sources of experimental uncertainty in this experiment, and consider how these uncertainties affect your results.