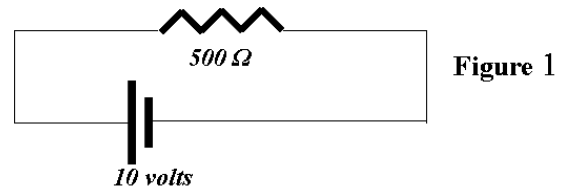# Ohm's Law
PHYS 296

Your name_____   **Lab section**_____ __
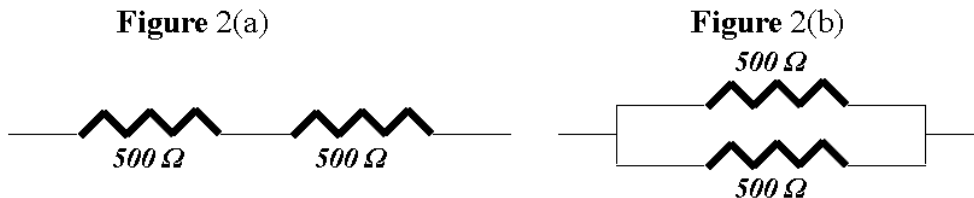
PRE-LAB QUIZZES

1.   What do we investigate in this lab?

2.   Calculate the current in the circuit shown in **Figure 1**.

Figure 1

3.   Calculate the equivalent resistance for the two combinations of resistors shown in **Figure 2**.

Figure 2(a)   **Figure** 2(b)

4.   The temperature coefficient of resistance for a conducting wire is *0.002 per Celsius degree*. The electric resistance of the wire is *200 Ω* at *25°C*. Calculate the resistance at *0°C*. Show derivation.

Ohm's Law
PHYS 296

Name_____   **Lab section**_____   __

Lab partner's name(s)_____   _____

Objective
In this lab, we study Ohm's law, measure the temperature dependence of electric resistivity of copper wire, and compare the *V-versus-I* relationships for the resistor, which obeys Ohm's law, and for the diode, which does not.

Background
The advent of electricity in the 19th century and of electronics in the 20th century is arguably the most important technological advance in history. The electrical and electronic components such as transistors, resistors, capacitors, diodes, etc. are now ubiquitous in our daily life. These components are the building blocks for numerous types of circuits with a vast array of functions. One of these magic products is this computer sitting on your lab bench.

In this lab, we will first study the most basic electrical component: the resistor. An ideal resistor obeys Ohm's Law discovered by Ohm:

$$V/I \text{ is a constant,} \tag{1}$$

where *I (unit: ampere (A) =coulomb per second)* is the current passing through the resistor and *V (unit: volt (V))* is the voltage across the resistor. The ratio *V/I* is the resistance of the resistor: *R (unit: ohm (Ω))*. Thus, Ohm's Law can be stated as:

$$R = V / I \quad \text{OR} \quad V = IR \tag{2}$$

Physicists found that all materials possess resistivity to various degrees (except in the superconducting state). Some materials exhibit very small resistivity while others block current almost completely. The resistance of an **ideal** resistor is a constant, independent of voltage and current. However, resistance does depend on temperature. Since temperature can be affected by current, the resistance of a **real** resistor *can* be dependent on current. And since the atomic structure of some materials can be affected by voltage, the resistance of a **real** resistor *can* be affected by voltage also. For many materials this dependence is weak over a large range of currents and voltages. At such a condition, they can be treated as **ideal** resistors.

In an electrical circuit, resistors can be connected in series (**Figure 3**) or in parallel (**Figure 4**). The equivalent resistance, R, for the combination of resistors in series is given by
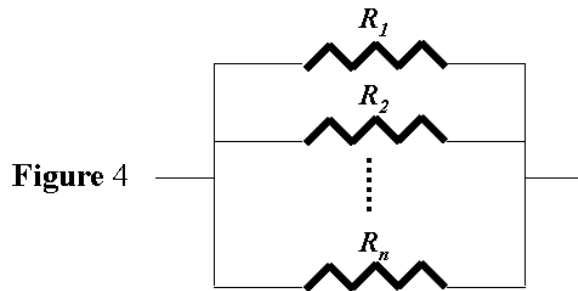
$$R = R_1 + R_2 + \cdots + R_n. \tag{3}$$

Figure 3

The equivalent resistance, R, for the combination of resistors in parallel is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}.$$ (4)

Figure 4

The table shown below displays the symbols for several electrical components including resistor, capacitor, inductor, and battery, most commonly found in electrical circuits.

ELECTRICAL COMPONENTS IN CIRCUITS	
SYMBOL	NAME
	Resistor
	Capacitor
	Inductor
	Voltage
	Diode

You should use the following rules to measure current and voltage. (a) To measure CURRENT: an ammeter (which usually bears only small resistance) is always connected in series with the object to be measured. (b) To measure VOLTAGE – a voltmeter (which usually bears very large resistance) is always connected in parallel with the object to be measured. If you do not follow these rules, the readings will be incorrect and you may risk burning out the ammeter.

PART I   Ohm's Law

In part I of the lab, we demonstrate Ohm's law with a single resistor.

Figure 5
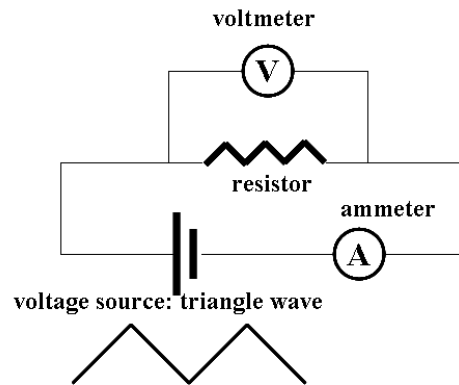
PROCEDURES

1.   Set up the circuit as shown in Figure 5 with any one of the three resistors. Connect the voltage sensor to input A and the current sensor to input B. Ask the TA to check the circuit to ensure correct connection.

2.   Open **Data Studio**, click on input *channel A* and choose voltage sensor for input *channel A*. Click on input *Channel B* and choose current sensor for input *channel B*. Select proper sensitivities for the current sensor (X100) and the voltage sensor (X1). Wrong selections will cause incorrect measurement. Open a graph display, select voltage (*channel A*) for the y-axis. Click on "time" on the x-axis, change the default setting of the x-axis from time to current. It now displays *V-versus-I*. Click on *signal generator* and select *Triangle wave* as the output. Set the amplitude at *1 V* and the frequency at *10 Hz*.

3.   Set the sampling rate of measurement at *1000 Hz*. In so doing, in each period of the *Triangle wave*, you collect 100 data points from the voltage sensor and from the current sensor.

4.   Click on "*start*" to record data. In only a few seconds you should accumulate enough data points. You may find the fit resistance is not correct, because the current sensor needs calibration. Ask your TA to calibrate the current sensor.

5.   Repeat the measurement for the other two resistors.

Data Analysis

1.   Choose an appropriate formula from the curve-fitting menu. Use it to fit the acquired *V-versus-I* curves in the *graph* window. Write down the fitting formulas for the three measurements:

Measurement 1:

Measurement 2:

Measurement 3:

PART II Resistors in Series
PROCEDURES
1.   In the circuit board, set up a circuit with the three resistors in series. Ask the TA to explain if you do not know how to connect them.   Ask the TA to check the circuit when you finish setup. Because the current is small, set the sensitivity of the current sensor to "X100".
2.   Following steps 2-4 in Part I.

Questions
1.   Fit the acquired *V*-versus-*I* curve. What is the resistance of the circuit?

2.   Calculate the equivalent resistance of the three resistors in series. Show derivation. Find the % error of the measured equivalent resistance compared to the calculated equivalent resistance.

PART III Resistors in Parallel
PROCEDURES
1.   Set up the circuit with the three resistors in parallel. Ask the TA to explain if you do not know how to set up.   Ask the TA to check the circuit when you finish setup.
2.   Following step 2 to step 4 in Part I.

Questions
1.   Fit the acquired *V*-versus-*I* curve. What is the resistance of the circuit?

2.   Calculate the equivalent resistance of the three resistors in parallel. Show derivation. Find the *% error* of the measured equivalent resistance compared to the calculated equivalent resistance.

3.   Assume that the applied voltage across this circuit is *220 V*, what would be the current in the circuit?   Show your derivation.

PART IV Diode

In part V of the lab, we demonstrate that a diode does not obey Ohm's Law.

Figure 8
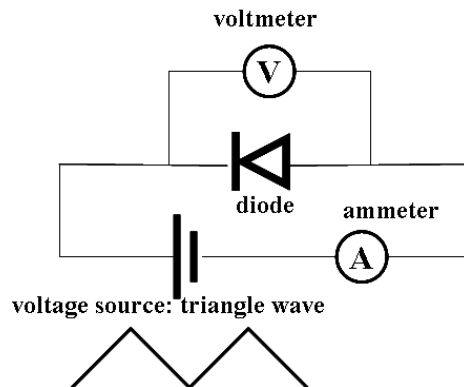
PROCEDURES
1.   Set up the circuit as shown in Figure 8. Ask the TA to check the circuit to ensure correct connection.
2.   In this experiment, select *Triangle wave* as the output, and set the amplitude at *1 V* and the frequency at *10 Hz*.
3.   Set the sampling rate of both the voltage sensor and the current sensor at *1000 Hz* or faster.
4.   Now open graph display *I-versus-V*. Click on "start" to record the data. Just a few seconds of measurement should suffice. Print out the measured *I-versus-V* curve.

Questions
1.   Does the diode obey Ohm's Law? Explain how you draw the conclusion based on the measured *I-versus-V* curve.

2.   When the voltage is negative, what is the value of the current through the diode?

PART V   Temperature Dependence of the Resistivity

In Part IV, we investigate the temperature dependence of the electrical resistivity of copper wire. For metal, the electric current is carried by the conduction electrons. Coherent transport of the conduction electrons in an applied electric field can be disrupted by random motion of atoms or other electrons, for instance by random atomic vibration about the equilibrium lattice position. These random motions increase as the temperature (T *(unit: °C)*) increases. As a result, the resistance of the metal increases with temperature, as approximately described by:

$$R(T) = R_0(1+\alpha T).$$ (2)

$R(T)$ is the resistance at temperature of T, R_0 is the resistance at 0 °C, and α is a constant called *the temperature coefficient of resistance*.

PROCEDURES
1.   Ask the TA to fill the supplied tin can with hot water. Place the can cover with the copper wire spool over the can. Consider the copper wire as a resistor and connect it to the circuit through the red-black pair of "*banana connector*", as you have done in Part I. In addition, insert the temperature sensor into the center hole of the spool and connect it to input *Channel C*.
2.   Open **Data Studio**, select input *channel A* as the voltage sensor to measure the voltage across the copper wire, select input *Channel B* as the current sensor to measure the current through it. Click on input *Channel C* and choose temperature sensor for input *channel C* (top one of the list of temperature sensors) to measure the temperature inside the can. Set the sample rate at *1 Hz* for all of them.
3.   Open the calculator window and enter the following equation: *R(ohm) = V/I*. After accepting the equation, set *V* and *I* respectively to measure *Channel A* and *Channel B*.
4.   Open a Graph display to display the resistance (defined by the calculator in step 3) as the y-axis. Click on "time" on the x-axis, and change the default setting of the x-axis from time to temperature.
5.   Open the *signal generator* window. Use DC output of 1 V and, and as usual, select the *auto* mode. Select "Gain X100" for I and "Gain X1" for V.
6.   Start recording data. Stop after collecting data over *25 minutes*. Fit the *resistance-versus-temperature* curve, but use only the appropriate portion of the curve. Do not include in the fit with the data points from the first *5 minutes because the system is not stable*. Print out the graph.

Questions
1.   From the fitting equation of the *resistance-versus-temperature* curve, obtain R_0.

2.   Obtain the value of α from the slope and the intercept of the curve fitting. The corresponding textbook value for copper is $\alpha = 4.65 \times 10^{-3}$ *(°C)$^{-1}$*. Calculate the percent error between the measured value and the textbook value.