

## *Ohm's Law*



*Produced by the Physics Staff at  
Collin County Community College*

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## Purpose

In this experiment, you will use Ohm's law to determine the resistance of several resistors. You will also investigate ohmic and non-ohmic resistances.

## Equipment

- Power amplifier
- Digital Multimeter
- D-cell battery
- Light bulb, 3 volt
- AC/DC Electronics circuit board
- Several resistors (10Ω to 1000Ω)
- Two banana-plug patch cords
- Two clip leads

## Introduction

Electric charge will flow through a conductor (such as copper wire) only when an electric field is maintained within the conductor by a difference of potential between its two ends. The rate of flow of charge (how much charge passes a point in a given time) is what we call electric current. For a given potential difference, more charge will flow per second through a good conductor than through a poor one.

The property of a conductor which determines the rate of charge flowing in it is called its *conductance*. The conductance of any object is simply the ratio of the rate of charge moving through it (current) to the potential difference (voltage) across it:

$$\text{Conductance} = \frac{\text{Current}}{\text{Potential Difference}} \quad \text{or} \quad G = \frac{I}{V}$$

It is often useful to characterize the ease with which electric charge flows in a conductor by the inverse of its conductance, a property called its *resistance*:

$$R = \frac{1}{G} = \frac{V}{I}$$

This relationship between the potential difference across a conductor and the resulting current in it is *the* fundamental relationship for electric circuits. It is written in any of three forms,  $R = V/I$ ,  $V = IR$ , or  $I = V/R$ , depending on which property is unknown or which is held constant.

The value of  $R$  for most conductors depends on the geometry of the piece and on its temperature. For a conductor of a given size and shape, and over a limited temperature range,  $R$  usually does not depend on either  $V$  or  $I$  — it is said to be constant. For these special conditions (when  $R$  is constant), the relationship  $V = IR$  is known as Ohm's law.

A circuit element which obeys Ohm's law (one for which  $R$  is constant) is said to be an *ohmic* element. Ohm's law does not apply generally in a given conductor over a large temperature range (e.g., from normal room temperature to the incandescent temperature of an electric heating element), nor in semi-conductors even at a fixed temperature. Ohm's law is thus not a fundamental law of physics like Newton's laws or Coulomb's law.

For most conductors used in circuits (e.g., wires and resistors), Ohm's law is valid over normal temperatures (say, the temperature range in which water is liquid). But the resistance

increases dramatically as the filament heats up in an incandescent light bulb or a heating element. If the effective applied potential difference is constant, such as the 120 volts of a normal household circuit, the filament has a much lower resistance (it carries a much larger current) when it is cold than it does after it heats up. That is why most light bulbs burn out when you first switch them on.

Furthermore, if the instantaneous applied potential difference changes rapidly, such as the 60-hertz frequency of a normal household circuit, the thermal inertia of the filament prevents it from changing temperature as rapidly as the voltage changes, so it remains at a nearly constant resistance. However, at low AC frequencies (e.g., around 1 hertz), the filament *does* have time to change temperature, so its resistance changes dramatically. The resulting change in current through the filament causes the light bulb's brightness to flicker between bright and dim.

To produce an electric current in a conductor, you must keep its ends at different electric potentials. One way of maintaining this potential difference is to connect the two ends to the terminals of a battery or power supply. If the conductor is ohmic, the current through it will be directly proportional to the potential difference applied to its ends.

$$I \propto V \qquad \text{Equation 3.1}$$

It is helpful to picture an electric current in a conductor as analogous to the flow of water (the water current) in a river or pipe. If the river or pipe is nearly horizontal, the current is small. But if one end is somewhat higher than the other, the current will be much greater. Therefore, the general observation is: the greater the difference in height, the greater the current.

A similar situation exists in electric circuits. Just as an increase in height difference (gravitational potential difference) between its ends causes a greater flow of water (water current) in a pipe, so an increase in electrical potential difference between its ends causes a greater flow of charge (electric current) in a wire.

The amount of charge that flows in a circuit depends not only on the potential difference between the ends but also on how much the metal of the wire resists the flow of the charge. The walls of a pipe resist the flow of water; similarly, the flow of charge in a conducting wire decreases because of collisions between the moving electrons and the (relatively) stationary atoms in the metal. The higher the resistance, the less the current for a given potential difference. You can thus define resistance to be inversely proportional to the current:

$$R \propto \frac{1}{I} \quad \text{or} \quad I \propto \frac{1}{R} \qquad \text{Equation 3.2}$$

When you combine equations 25.1 and 25.2, you get

$$I = \frac{V}{R} \quad \text{or} \quad V = IR \qquad \text{Equation 3.3}$$

where the potential difference across the circuit  $V$  is measured in units of volts (symbol V), the resistance of the conductor  $R$  is measured in ohms (symbol  $\Omega$ ), and the electric current in the conductor  $I$  is measured in units of amperes (symbol A).

Equation 3.3 shows that the current in an ohmic resistor increases proportionally to the potential difference across the resistor. Therefore, a graph of potential difference versus current will be a straight line whose slope is the value of the resistance. However, if the resistance changes (i.e., is non ohmic), then Ohm's law does not apply and the graph will be a curve with changing slope.

# Procedure

## A. Known Fixed Resistor

In this part, the Power Amplifier will apply a voltage across a 10- $\Omega$  resistor mounted on the circuit board. The computer sensors will measure the potential difference across the resistor and the current through it. The *Data Studio* program will collect the data and display a graph of voltage vs. current. The slope of the plotted line is the value of the resistance.

1. Plug the Power Amplifier power cord into an electrical outlet and connect its input to Analog Channel A on the Interface unit.
2. Switch on the Interface unit and the Computer. Open Data Studio and select *Create Experiment*. Select the Power Amplifier sensor so its icon shows under Analog Channel A in the Experiment Setup window with a sine wave signal output, as shown in Fig. 3.1. Drag the Signal Generator window to one side.

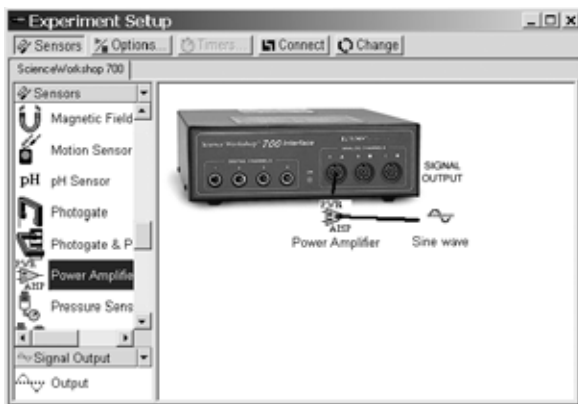


Figure 3.1

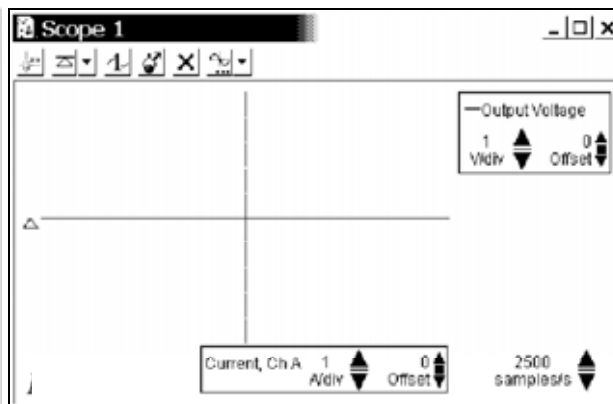
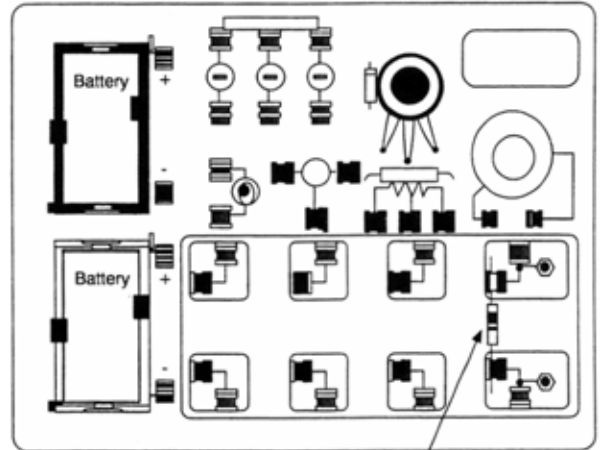


Figure 3.2

3. Double-click on the *Scope* display and select Output Voltage. Drag the Scope 1 display to one side. Drag the Current, Ch A icon in the Data list, to the abscissa of the Scope 1 display. The display changes from Output Voltage vs. Time to Output Voltage vs. Current, as shown in Fig. 3.2.
4. In the Signal Generator window, set the Amplitude to 2.970 V and the Frequency to 60 Hz. Select the Triangle Wave AC voltage waveform.
5. The scope will plot the voltage applied to the resistor on the ordinate (at a scale of 1.000 V/div) and the current through it on the horizontal axis (at a scale of 0.100 A/div).
6. Use color codes to select a 10- $\Omega$  resistor from those supplied to your team. Record its resistance value in Table 3.1. Insert it in the pair of component springs at the lower right corner of the circuit board, as shown in Figure 3.3 and connect banana-plug leads from the output of the Power Amplifier to the banana jacks at each end of the resistor on the circuit board.

Figure 3.3

7. Switch on the Power Amplifier. Click the *On* button in the Signal Generator window and press *Start*. Observe the Scope display of voltage vs. current. Adjust the vertical or horizontal scales, if necessary, (using the V/div and A/div up and down buttons) to get the entire range of voltage and current on the screen. After observing the plot for a few seconds, click the *Off* button.



10  $\Omega$  Resistor (Brown, Black, Black)

8. Click the *Smart Tool* button in the SCOPE display (at the left end of the tool menu) to change the cursor into a crosshair. When you move the crosshair into the display area, the values of its  $x$  (current) and  $y$  (voltage) coordinates are shown in the first quadrant of the dotted lines.
9. Select a point near the end of the plotted line on the Scope display, record the coordinates of the point (voltage and current), and use their values to calculate the slope of the plotted line (assume the line intersects the origin of the plot). Record the voltage, current, and slope in Table 3.1. Calculate and record the percent difference between your calculated resistance (slope of the voltage/current plot) and the color code resistance. Switch off the Power Amplifier.
10. Decrease the scale of the abscissa to 0.010 A/div, then replace the 10- $\Omega$  resistor with a 100- $\Omega$  resistor and repeat steps 6–9.

### B. Unknown Variable Resistor

For this part you will use the filament of a flashlight bulb as the resistor, you will change the amplitude and frequency of the applied AC voltage, and you will also change some of the settings on the Scope display.

1. Click the *Signal Generator* window to make it active. Change the Amplitude value to 2.500 V and the Frequency value to 0.30 Hz.

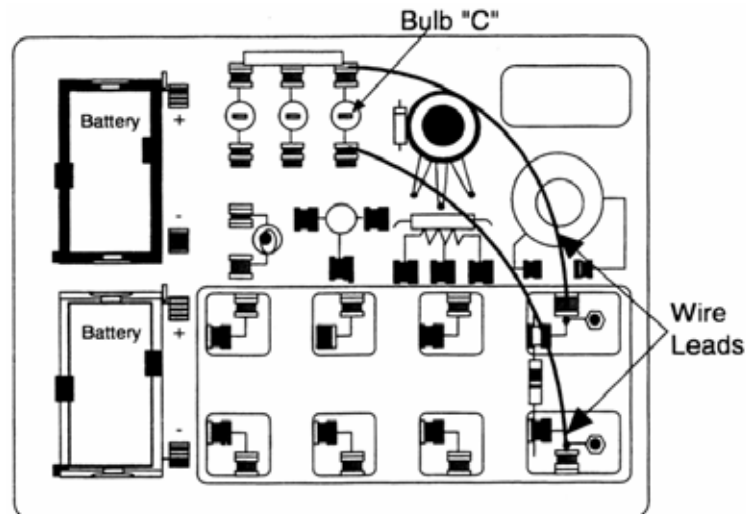


Figure 3.4

2. Remove the resistor from the component springs on the circuit board. Use clip leads to connect to the component springs for the socket labeled 3 VOLT BULB “C”, as in Figure 3.4.
3. Switch on the Power Amplifier. Click the *On* button in the Signal Generator window and press *Start*. Observe the Scope display of voltage vs. current. Adjust the vertical and horizontal scales, if necessary, using the volts per division buttons. You will notice that the plot is no longer a straight line. Press *Stop*, click the *Off* button and switch off the Power Amplifier.
4. Close the Scope display window, open a Graph display, and select *output voltage (V)*. Drag the Current, Ch A icon in the Data list to the abscissa of the Graph display. The Graph should now show voltage vs. current.
5. Switch on the Power Amplifier. Click the *On* button in the Signal Generator window and press *Start*. Adjust the vertical and horizontal scales so that the plot fills the entire Graph display. Press *Stop*, click the *Off* button and switch off the Power Amplifier.
6. Highlight a small number of points near the end point of the graph. Select linear fit, and record the given slope in Table 3.2. Now highlight a small number of points near the origin of the graph. Select linear fit, and record the given slope in Table 3.2. Calculate and record the percent difference between the resistance at 2.5 V (slope at the end point) and the resistance at 0 V (slope at the origin).
7. Repeat steps 5-6 for frequencies of 0.75 Hz, 1.50 Hz, and 3.00 Hz.

### **C. Determining $R$ from Measurements of $V$ and $I$**

1. Choose a new resistor of any value (different from the two you have already used) that is less than  $100\ \Omega$ . Use the color code chart to determine the resistor’s value and record it in Table 3.3.
2. Install a *D* battery in the circuit board’s battery holder and install the chosen resistor between any set of component springs.
3. Connect the multimeter leads across the resistor and set the multimeter to the 2.0 VDC range. Use clip leads to connect the battery to the resistor leads. Read and record the voltage across the resistor, then disconnect one of the battery leads to open the circuit.
4. Set the multimeter to the 200mA range, noting the different meter connections needed for measuring current. Connect the multimeter in series between the battery and the resistor, observing the correct polarity. Close the circuit, read and record the current in the resistor, then open the circuit.
5. Remove that resistor and install another (less than  $100\ \Omega$ ) in its place. Record its color-code resistance value. Repeat steps 3 and 4 to measure and record the voltage across the resistor and the current in it. Continue this process until you have measured and recorded  $V$  and  $I$  for all the resistors your team has been given, including the  $10\ \Omega$  and  $100\ \Omega$  resistors.
6. For each resistor, calculate and record the voltage/current ratio. To compare the calculated values of each resistance (voltage/current) with the value you read from the color code, determine the percent difference between them.