LAB 3
Ohm's Law

OBJECTIVES

1. Become familiar with the behavior of some common circuit elements.
2. Gain an understanding of Ohm's Law, and some of the factors that might affect the resistance of a circuit element. Is Ohm's Law universal, is it approximate, or are there elements that do not obey it even approximately?

EQUIPMENT

Power supply, 1 kΩ resistors, 22 Ω resistor, 6.3 V light bulb, diode, breadboard, wires, digital multimeters (two).

THEORY

As you know from last week's lab, electrical current tends to flow from points at high voltage, to points at lower voltage. (Which, of course, means that the actual *electrons*, being negatively charged, are moving from the low-voltage point to the high-voltage point. Damn you, Ben Franklin!)

In the early 1800s, George Ohm investigated *how much* current will flow along a given path from high to low voltage. He found that for many types of conducting materials, the current flowing through a circuit element such as a wire is directly proportional to the voltage difference ΔV between its ends. The proportionality constant between voltage and current allows you to then define a quantity known as the *Resistance* of a circuit element; the higher the resistance, the *less* current will flow through the element:

$$I = \frac{\Delta V}{R} \quad \textit{(Ohm's Law)}$$

Resistance is measured in the unit Ohms (Ω), named of course after the man himself. As you would expect from the form of Ohm's Law, 1 Volt / 1 Amp = 1 Ohm.

The resistance R depends on the size and shape of the element (long, skinny conductors have higher resistance than short, thick ones), and the material it is made of (copper, for example, has far lower resistance than graphite.) It often depends on parameters such as the temperature of the material. But if the material is *ohmic*, then the resistance does *not* depend directly on applied voltage; if you triple the voltage difference, while leaving all other important factors constant, the current will triple.

Thus, when a graph of current versus voltage (holding temperature and other confounding factors constant) forms a straight line, the slope of the line is 1/R. An element is *non-ohmic* if the graph of voltage versus current is *nonlinear*.

An example of a non-ohmic element is a diode. A diode is an electronic device that only allows current to flow in one direction once a certain *forward voltage* is established across it. If the voltage is too low, no current flows through the diode. If the voltage is reversed, no current flows through the diode. A light-emitting diode (LED) emits light as current passes through the diode in the forward direction.

In this lab, we will investigate the behavior of a resistor, a light bulb, and a diode by analyzing the graph of the current vs. voltage or I-V characteristic curve.

A useful approximation when building a circuit is to treat the connecting wires as having essentially zero resistance (since they are fairly thick, and made of an excellent conductor such as copper.) This means that two points connected by such a wire will be at the same voltage (because by Ohm's law, the voltage difference between the ends of the wire is $\Delta V = IR = 0$ regardless of how much current is flowing through the wire.

By contrast, an element with *infinite* resistance would not allow any current at all to flow through it, regardless of how high the voltage difference between its ends.

Circuit elements in today's lab that *cannot* be treated as zero-resistance include the resistors (which are made of graphite or some other low-conductivity material) and the lightbulb filaments (which are made of tungsten, a good conductor, but are extremely narrow.) The diodes are a special case; you'll decide for yourselves how to describe those.

PROCEDURE

Part 1: Do Carbon Resistors obey Ohm's Law?

Part 1A: 1 kΩ Resistor

a) Using the breadboard, build a simple circuit consisting of a 1 kΩ resistor connected to a power supply. In your circuit, include two digital multimeters to measure the voltage across and the current though the 1 kΩ resistor.

b) Set the voltage across the resistor to about 10 V. Immediately after you turn on this voltage, observe the current through the resistor for about 30 seconds. *Does the current through the resistor change during the 30 seconds? What does this tell you about the temperature of the resistor?*

c) If the resistor is noticeably hot, turn off the power and let it cool. Then adjust the power supply until the voltage across the resistor is about 1.0 V. Record both the voltage across and the current through the resistor.

d) Increase the voltage across the resistor to about 2.0 V and record the voltage and current. Continue to increase the voltage in 1.0 V increments until you reach 10.0 V.

Record all of your data in a table.

e) Reverse the polarity of the voltage across the resistor by switching the leads from the power supply (change + to – and – to +). Check on the current for two or three different values of the voltage and compare with your previous results. *Does the polarity of the voltage across the resistor make any difference in the current through the resistor?*

f) *Use Excel to make a plot of current vs. voltage. Is the resistor ohmic or non-ohmic? How do you know?*

g) Use Excel to fit the data to a straight line. From the slope of your line, calculate the resistance *R*.

h) Your multimeter has an "ohmmeter" setting. Use this setting to measure the resistance of your resistor. *How well (in terms of a percent difference) does this measurement match the one you obtained in part (g)? How well do they both match the resistor's rated 1 kΩ value?*

Part 1B: 22 Ω Resistor

a) Using the breadboard, build a simple circuit consisting of a 22 Ω resistor connected to the power supply. Once your circuit is complete, attach two digital multimeters to measure the voltage across and the current through the 22 Ω resistor.

b) Set the voltage across the resistor to about 10 V. Immediately after you turn on this voltage, observe the current through the resistor for about 30 seconds. *Does the current through the resistor change during the 30 seconds? What does this tell you about the temperature of the resistor?*

SPOILER ALERT: This resistor may get much hotter than the previous one. BE CAREFUL NOT TO BURN YOURSELF!

c) If the resistor is noticeably hot, turn off the power and let it cool. Then adjust the power supply until the voltage across the resistor is about 0.5 V. Record both the voltage across and the current through the resistor.

d) Increase the voltage across the resistor to about 1.0 V and record the voltage and current. Continue to increase the voltage in 0.5 V increments until you reach 5.0 V. *Record all of your data into a table.*

e) Immediately after finishing your 5-V measurement, lower the voltage of the resistor back down to 0.5 V. *Does the current through the resistor agree with the value that you got previously? Why or why not?*

f) *Use Excel to make a plot of current vs. voltage. Is the resistor ohmic or non-ohmic? How do you know?*

Part 2: Does a light bulb filament obey Ohm's Law?

Throughout this section, keep the power supply set at 6 volts or less – a higher voltage will destroy the bulb.

a) Build a simple circuit consisting of a 6.3 V light bulb connected to a power supply. In your circuit, include two digital multimeters to measure the voltage across and the current though the light bulb.

b) *Does the tungsten filament of the light bulb filament seem to follow Ohm's Law? Collect and explain convincing evidence one way or the other.*

c) *If the filament follows Ohm's Law, what do you measure to be its resistance? (As before, please use at least two different methods to measure this resistance. How well do they match?) If the filament does not seem to follow Ohm's Law, can you give a physical explanation as to why not?*

Part 3: Does a Light-Emitting Diode obey Ohm's Law?

a) Using the breadboard, build a simple circuit consisting of a 1 kΩ resistor **and** an LED connected *in series* with a power supply. In your circuit, include two digital multimeters to measure the voltage across and the current though **the LED**.

b) Adjust the power supply until the voltage across the LED is about 1.75 V. *Is there any current flowing through the LED?*

c) Reverse the polarity of the voltage across the LED by switching the leads from the power supply (change + to – and – to +). *Does the polarity of the voltage across the LED make any difference in the current through the LED?*

d) Adjust the polarity of the voltage across the LED so current flows through the LED.

e) Adjust the voltage across the LED to 0.5 V and record the current through the LED. Increase the voltage to 1.0 V and then 1.5 V and record the current through the LED.

f) Record the current through and the voltage across the LED for about 10-20 values between 1.5 V and 2.0 V. Record all of your data into a table. *What is the turn-on voltage of the LED?*

g) Use EXCEL to plot current vs. voltage for the LED. *Is the LED ohmic or non-ohmic? How do you know?*