EXPERIMENT 3: OHM'S LAW

One of the fundamental laws of current electricity is Ohm's law, which gives the relation between potential difference and current in a circuit element. The goal is to find if there is a set relation between these two quantities, and if there is, what is the nature of that relationship?

ADVANCE STUDY ASSIGNMENT

1. If two quantities are related, one way to determine the mathematical nature of that relationship is to plot one quantity versus the other on a graph. If the relationship is linear, what is the shape of the graph produced? Give an example from Physics 217, basic mechanics.
2. If two quantities are related in some mathematical way which is not linear, the plot of one versus the other will not be a straight line. However, straight lines are easy to see and verify the exactness of a relation. (That is, it's easy to see if a curve is not a straight line. It is less easy to see if a curve is or is not parabolic, or cubic or some other function.) Suppose you have two quantities which are related by the square of one of them, as position is to time when there is a constant acceleration.
   a) What is the shape of the graph of position vs time when there is a constant acceleration? (Hint: if you need to, go back to chapter 2 or 4 to check some of the graphs there.)
   b) How would you change your graphing to get a straight line graph, which makes the relationship easier to verify?

BACKGROUND

We have not yet started the study of current electricity in lecture, but we will start that study here in lab. We have already the idea of potential, V, or potential difference, ΔV. This tells us the energy supplied per coulomb as a charge moves through a region where there is an electric field. We have discussed current already, though briefly, as $i = dq/dt$. In turning to current (as opposed to static) electricity, we are often interested in the current resulting in a conductor as a result of an applied potential difference.

A potential difference exists whenever there is an electric field, but often we think of a source of potential difference as a simple device, a battery. We think of a current in a conductor as caused by the potential difference supplied by the battery, which can do work (remember, V = J/C) on charges moving across the potential difference (or through the battery). In general, if we supply the same potential difference to two different conductors, we observe different currents, depending both on the type of conductor (for example, copper or aluminum) and the physical properties of the conductor (for example a long or a short wire, a thick or a thin wire).

One way of characterizing this difference is to define a new quantity, resistance, or R, which is a property of any conductor. We define resistance, R as follows

$$R \equiv V/i,$$

with the unit being ohms ($\Omega \equiv V/A$). This should be understood as the definition of resistance for any conductor (and any material is a conductor to some extent, although some may have resistances of millions of ohms or more, and normally are classed as an insulator).

For a special class of conductors (but not all) the current and voltage are linearly related, so that if, say, the voltage is doubled, then the current is also. Conductors which behave like this are called ohmic, and are said to obey Ohm's law. Metallic conductors are usually ohmic. Ohm's law is usually written

$$V = i\,R,$$

which looks like a repeat of the definition of R, but is conceptually different. In this case, R is considered a constant (independent of V or i, since if we double one, for an ohmic conductor, the other also doubles).

Devices used to measure electric quantities include voltmeters and ammeters (in lieu of ampmeters). Voltmeters are always connected in parallel with the devices they are to measure the potential difference of. Ammeters measure current, and are always connected in series with a resistor. CAUTION: AN AMMETER SHOULD NEVER BE CONNECTED TO A VOLTAGE SOURCE WITHOUT A RESISTOR OF SOME TYPE IN THE CIRCUIT. OTHERWISE, THE AMMETER MAY BE SERIOUSLY DAMAGED. WHEN CONNECTING VOLTMETERS AND AMMETERS TO A CIRCUIT, YOU MUST PAY ATTENTION TO POLARITY; THAT IS, THE POSITIVE END OF THE BATTERY OR POWER SUPPLY MUST BE ATTACHED TO THE POSITIVE END OF THE VOLTMETER OR AMMETER.

One example of a nonohmic device is a diode. Not only is V not proportional to i in this device, the current is not symmetrical, depending on the polarity (orientation of the positive and negative terminals of the battery in relation to the diode). We will attempt to see this asymmetry and nonlinearity in the last part of this experiment.

PROCEDURE A

1. Turn on the Pasco interface first, then turn on the computer. Then, double-click on Data Studio. Click on "Create an Experiment". Then scroll down and select Power Amplifier from the Experiment Setup window. Verify that DC voltage is selected (on the Signal Generator –SG- window). If DC voltage is not selected, use the arrows if necessary to select DC. Do not turn the Power Amplifier on yet, either the real one or the window on the monitor. Select Voltage Sensor (from Experiment Setup window). Drag the table icon onto the Voltage Sensor icon for Analog Channel B to record your readings of voltage (potential difference). Select Current Sensor (from Experiment Setup) to utilize Analog Channel C. Drag the table icon (from Displays window) onto the Current Sensor icon for Analog Channel C.
2. Plug in the Power Amplifier, Voltage Sensor, and Current Sensor, to Analog Channels A, B, and C, respectively. Do not turn on the Power Amplifier.
3. Set the resistance on a resistor box to 100 Ω, and connect the resistance box in series with the Power Amplifier and the current sensor, observing correct polarities by

connecting positive to positive, negative to negative. See sketch on white board in class. Note at this point that the Voltage Sensor is not yet connected.

4. BE CAREFUL NOT TO SHORT CIRCUIT (CONNECT TOGETHER) THE TWO WIRES CONNECTED TO THE POWER AMPLIFIER. DOING SO WILL BLOW A FUSE, OR DAMAGE THE EQUIPMENT. For this reason the Power Amplifier should be left turned off when not in actual use. ALSO BE SURE THE RESISTANCE BOX IS NEVER TURNED TO O WHEN DOING ANY PART OF THE EXPERIMENT. THE CURRENT SENSOR MUST ALWAYS HAVE A NON-ZERO RESISTANCE IN SERIES WITH IT WHEN IT IS CONNECTED TO ANY POWER SUPPLY. OTHERWISE, IT MAY BURN UP.
5. Connect the Voltage Sensor to either end of the resistance box, using stacked banana plugs or alligator clips, and observing polarity, plugging the positive of the Voltage Sensor into the side of the resistance box connected to the positive side of the Power Amplifier.
6. On the Experiment Window, click on Options (on the top of the Experiment Setup window) and make sure only the box next to "Keep data values only when commanded is checked. Do not change anything else, and click OK.
7. Be sure the resistance box is set at 100 Ω and be sure the Power Amplifier is set on "DC Voltage" (from SG window in Data Studio). Set the voltage on the Power Amplifier to the first value shown in Data Table A, either by clicking the arrows, or by highlighting the existing voltage and typing in the desired voltage, followed by Enter on the keyboard.
8. Turn on the Power Amplifier, by clicking ON on the Experiment Window, and turning on the actual, physical switch on the back of the amplifier.
9. Click Start on the Experiment Window, then click Keep to record data on table. Notice there are voltage and current entries in line one of the two data tables on the monitor. Adjust the voltage to values from -5.0 V to +7.5 V, in steps of 0.5 V, clicking Keep each time.
10. Enter the data from the two Data Studio data tables onto Data Table A, either by hand to the printed table attached to these directions, or by copying and pasting onto an Excel Data Table A preliminary table, which your instructor will provide or direct you to. (The pasted data may have two entries at the top which we do not want. Copy the data from the preliminary table to the actual Excel table.)

PROCEDURE B

11. Turn off the Power Amplifier on the Experiment Window (to avoid the possibility of a short circuit while changing wires) and replace the resistance box with the unknown resistor supplied. The connection to the unknown resistor is probably best made with banana plug/alligator wires, and using alligator clips on the ends of the Voltage Sensor. Repeat procedures 7 through 10, using the unknown resistor and filling in Data Table B.

PROCEDURE C

12. Again, turn off the Power Amplifier, reconnect the resistance box, set the voltage for 2.0 V, and fill in Data Table C, this time changing the resistance setting of the resistance box while not changing the applied voltage. Repeat Procedures 7 through 10, running through the resistance values in Data Table C. Fill in Data Table C.

PROCEDURE D

13. Now place the diode supplied in the circuit, in place of the resistance box in the sketch on page 2 of this handout, with the negative of the Power Amplifier connected to the dark end of the diode, and with the Voltage Sensor wires connected across the diode, as they were before across the resistance box. As you adjust the Power Amplifier voltage through the voltages given in the data table (-2.0 V to + 2.0 V, in 0.25 volt steps) record the readings in Data Table D.

PROCEDURE E (These procedures are all calculations, and do not need to be done during the lab period.)

14. On one piece of paper, plot V vs i for the 100 ohm resistor and the unknown resistor. You may either do this by hand or by using the Excel program. Calculate the slope for each graph. Pay attention to the units. (If you use Excel there will be no units. Then you must supply the units.)
15. On another piece of paper, plot V vs i for Data Tables C and D. Calculate the slope for each graph. Pay attention to the units.
16. Calculate the percent difference between the experimental value of the resistance box in Procedure A and the value given by the dials on the box.
17. Calculate a percent difference between the applied voltage read from the Power Amplifier control window and the slope of the graph for Procedure C.
18. For the diode, calculate two different resistances for the two different areas of the graph with notably different slopes.
19. Write all the slopes you calculate, with units, on the corresponding graph. You may use the Excel program to calculate slopes, except for the diode, which you should show the calculation for.

QUESTIONS

1. For the diode, we speak of forward bias and reverse bias. The former allows a current to flow, and the other does not. Which portion of the graph represents forward bias?
2. According to your graph, at what forward bias voltage does the diode become conducting?
3. Divide the four different current carrying devices (3 resistors and one diode) into ohmic and non-ohmic devices, according to their graphs, and give your reasoning.

Data Table A

	R = 100
V	I

Data Table B

	Rx
V	I

Data Table C

	Vs = 2.0v	
R	1/R	I
10		
20		
30		
40		
50		
60		
70		
80		
90		
100		