Name: Section: 202L- Date:

Experiment 4: Ohm’s Law

Objectives

- To learn the basics of good lab practice
- To learn how to estimate uncertainties
- To learn how to propagate uncertainties
- To determine if certain circuit elements obey Ohm’s Law

Equipment

- One (1) BK Precision 24/48 V 0.5/1.0 A Power Supply
- Two (2) Protek B940 Digital Multimeters (DMMs)
- One (1) 1.8 kΩ (or larger) resistor
- One (1) 6.3 V/250 mA lightbulb with socket
- One (1) 1N4004 Diode

Safety

Although you will be working with voltages below 50 V, it is always a good habit to practice electrical safety. Following these instructions will help keep you and the equipment safe:

- ***No food or drink is allowed.*** Water and electrical equipment do not play well together.
- ***Never “get between”a voltage source and ground.*** Do not touch metal parts unless you are **<u>certain</u>** that they do not have voltage on them. Currents as low as 10 mA are painful and currents of 20 mA and higher can do harm if they are allowed to travel through your body---especially across your chest.
- ***<u>Never</u> touch the positive and negative leads together to form a “short” circuit.*** Doing so may cause a spark which can destroy sensitive equipment or cause an electrical fire.
- ***<u>Always</u> turn off the power supply before connecting or disconnecting new circuit elements.*** Doing so will minimize the chance of causing sparks.

<u>Introduction</u>

In 1827, Georg Simon Ohm published his version of what we now call “Ohm’s Law:”

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

His determination is remarkable because very crude batteries (the “Voltaic Pile”) were only just invented by Alessandro Volta in 1800. These batteries did not maintain voltage very well. In 1822, Thomas Seebeck discovered that voltage is produced at the junction between two dissimilar metals (a modern “thermocouple”). Ohm’s later experiments utilized this source of voltage.

In addition, there were no current meters. In 1820, Hans Christian Oersted noticed that magnetism was generated by electric currents, so Ohm measured his currents by comparing the magnetic forces generated by the currents flowing through his copper wire resistors. Prior to this time, scientists such as Henry Cavendish measured currents by touching the ends of wires connected to the Lyden jars (primitive capacitors) that served as batteries and comparing the shock produced.

Luckily, you will have modern equipment to produce and measure the voltages and currents that will be sent through three devices: a modern resistor, a light bulb, and a diode.

<u>Theory</u>

If we re-arrange Ohm’s law, we can *define* the resistance of a material to be

$$R \stackrel{\text{def}}{=} \frac{V}{I} \tag{2}$$

If we measure the current, *I*, that flows through a material across which we put different voltages, *V*, notice that the slope of the *V* vs. *I* curve will be the resistance of the material. Therefore, in each of the three experiments to follow, you will be putting different voltages across the three devices, measuring the current that flows through the device, and plotting this curve. The slope of this curve will be the resistance of the device.

If the slope of the curve is constant (*i.e.* it's a straight line), we call the device **ohmic.** Otherwise we call the device **non-ohmic.**

Experimental Procedure

Characterizing the Devices

The first task for this experiment is to use the DMM to measure the resistance of each of your devices. Measure each device twice: first allowing current to flow in one direction, and then the other direction.

Constructing the Measurement Apparatus

To accurately measure the voltage "across" and the current through each of our components, we will be using two Digital Multimeters (DMMs) in addition to our adjustable power supply. **Ensure that the DMMs and the Power Supply are turned off (use the rocker switches on the back of the DMMs). Turn all knobs on the power supply fully CCW.** The slide switches on the power supply should be set to "A" and "independent." The following two figures show you how to assemble the equipment properly.

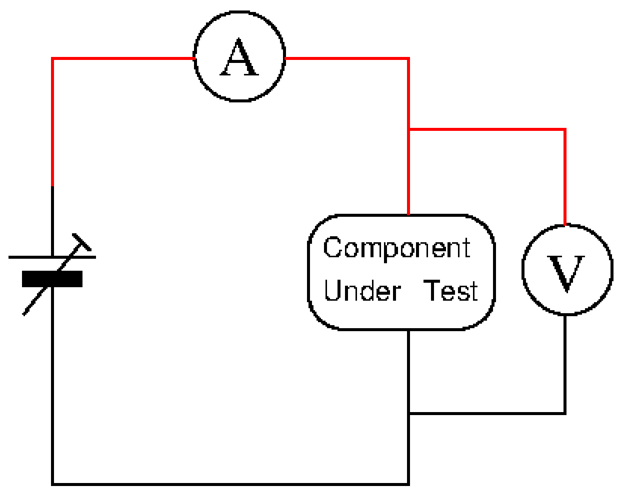

Figure 1: Test Circuit Schematic

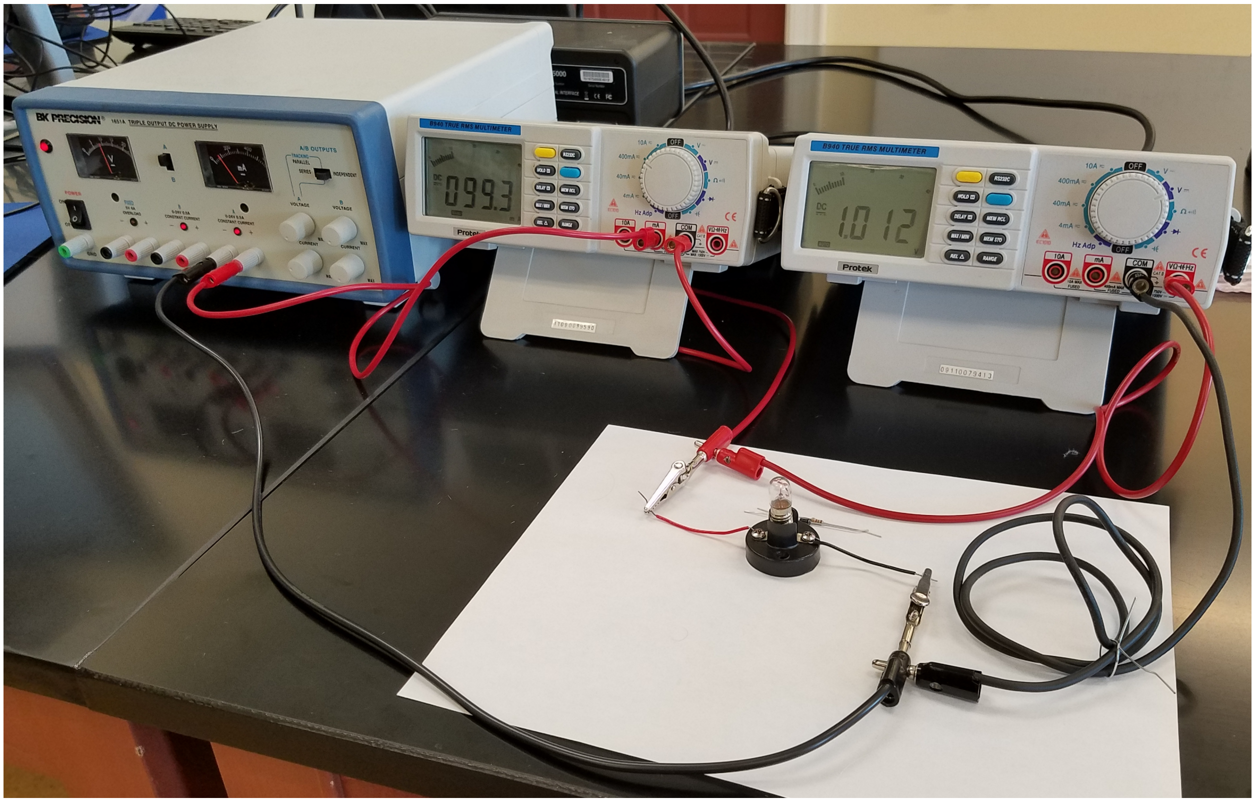

Figure 2: Test Circuit Setup (with Light Bulb)

In Figure 2, the left DMM is measuring current. Be sure that the knob is turned to the "400 mA" setting. The right DMM is measuring voltage. Be sure that the knob is turned to the "V=" setting. Do not turn on the DMMs or Power Supply yet.

Setting Up the Capstone Data Analysis Software

As you read off the voltage and current, you can enter it into the Capstone program and have it graph your data for you:

1. Start the Capstone Program and select "Table & Graph."
2. Click "<Select Measurement>" at the top of the left-hand column.
3. Select "Create New" → "User-Entered Data"
4. Type "Voltage" for the Data and "V" for the Units.
5. Repeat steps 2 and 3 for the right-hand column.
6. Type "Current" for the Data and "A" for the Units.
7. Click on the word "Set" at the top of each column and rename the voltage data to "ResistorV" and the current data to "ResistorA"
8. On the graph, select the voltage measurement for the vertical axis and the current measurement for the horizontal axis.
9. When you type in your voltage and current data, remember that it **must** be in ***volts*** and ***amps*** or the slope will not have the correct units.
10. When you are ready to enter a new data set, click on "ResistorV" and select "Create New User-Entered Data Set." Do the same for "Resistor A." Rename these columns appropriately. Each data set you create will be saved and can be found in the "Data Summary Tab" on the left-hand panel (under the "pencil" sub-tab).

Data Acquisition

Now that everything is set up, you can take data:

I. **<u>Resistor</u>**

A. Connect the resistor into the measurement circuit.

B. Turn on the power supply and DMMs.

C. You should be able to safely set the DMM measuring current to “40 mA.” **Pay attention to the DMM. If it beeps, you must reduce the voltage immediately to protect the DMM.**

D. Rotate the Current knob for the “A” channel fully clockwise. The red LED should go out.

E. Slowly increase the voltage for channel “A” and record voltages and currents every volt.

F. **Rotate the “A” channel voltage and current knobs fully CCW.**

II. **<u>Light Bulb</u>**

A. Replace the resistor with the light bulb.

B. **<u>Set the DMM measuring current to “400 mA.”</u>**

C. **Setting the Current Limit:** The Light Bulb can only handle 250 mA of current. The Power Supply can be set to limit the maximum current to this value:

1. With the Current knob for channel “A” fully CCW, rotate the voltage knob fully clockwise.

2. ***Slowly*** rotate the current knob until the DMM measuring current reads 250 mA. The maximum current is now set. Do not change this knob for the rest of the experiment.

D. Rotate the voltage knob back to zero and take voltage and current data every 0.5 V.

E. **Rotate the “A” channel voltage and current knobs fully CCW.**

III. **<u>Diode</u>**

A. The Diode has a polarity. Look carefully at the diode and locate the white band on one side. Connect this side to the **negative (black)** side of the power supply.

B. **Setting the Current Limit:** This time we must protect the DMM from excessive current.

1. With the current knob for channel “A” fully CCW, rotate the voltage knob fully clockwise.

2. ***Slowly*** rotate the current knob until the DMM measuring current reads 390 mA. The maximum current is now set. Do not change this knob for the rest of the experiment.

C. Rotate the voltage knob back to zero.

D. Set the DMM measuring current to “4 mA.” You will need this resolution to determine when the diode “turns on.”

E. ***Slowly*** rotate the voltage knob until the DMM measuring current reads 0.001 mA. Record this voltage. This is the “turn-on” voltage.

F. The Voltage vs. Current curve will look better if you can take many data points. Try to follow the intervals in Table 1 below.

G. Rotate the voltage knob fully CCW. Turn the diode around so that the white band is on the **positive (red)** side of the power supply.

H. Take data every 5 volts.

Table 1: Diode Current Measurements

Current is between	**Try to take data every**
0.01–0.1 mA	0.01 mA
0.1–0.5 mA	0.1 mA
0.5–5.0 mA	0.5 mA
5.0–50 mA	5 mA
50–390 mA	50 mA

Troubleshooting Capstone’s Curve Fitting Algorithm

To determine the slope of the Voltage vs. Current curves, you will use Capstone’s curve fitting algorithm (most notably, the “proportional fit”). Sometimes this algorithm needs help in finding the correct fit. You can tell that this is true when the drawn curve poorly matches the data points. The Mean Squared Error (MSE) will also be over 0.1.

To help Capstone attempt a better fit, first, click on the box where the incorrect values are reported. On the left pane will be a “Curve Fit Editor” tab that you should click. Within that tab are the starting values Capstone is assuming. Some of these values will be “locked” (not be allowed to vary) when they should be and vice versa. You will need to make some educated guesses as to the correct fit parameters, enter them into the boxes, and click “Update Fit.”

Clean Up

Once you've completed the experiment, return your apparatus to a safe state by following these steps *in this order*:

1. Rotate all knobs on the Power Supply fully CCW and turn the Power Supply off.
2. Rotate the knobs on the DMMs to “OFF” and turn off the rocker switch on the back.
3. Remove the diode from the set-up and set the three components aside where the next class can find them.
4. Ensure you have all the data you need to write your report (see the next page). You might consider uploading your data to your Google Drive.
5. Shut down the Capstone program and reboot the computer.

Raw Data

Nominal Resistor Value (color bands):

Measured Resistor Value (DMM):

Measured Light bulb resistance (DMM):

Measured Diode resistance (DMM):

Diode forward-biased “turn on” voltage:

Your Lab Report

Introduction

Write a few sentences about what you set out to measure and how you will compare the measured values with theory. Do *not* include details here. That is the job for the rest of your report. (Hint: write this section *last*. This way you'll have the whole experiment in your head when you write it and can properly foreshadow the results.)

Theory

Your theory section should describe the mathematical model that you expect the experiment to match. It should also detail the mathematical method by which you will compute your uncertainties. Make a prediction of your results in this section. Read your Lab Manual for instructions on how to format equations for this section.

Procedure

In one or two paragraphs, describe the methods you used to take your data, any problems you encountered and how you solved them. **You will be graded on your ability to clearly describe what <u>you</u> did.** The description should be clear enough that someone else could reproduce your results by reading this section. **Never use the second person "you" in your lab report.** ***Be Careful:*** There is a fine line between giving enough information so that a competent student could reproduce your results and writing *way too much detail.* The idea is to be <u>concise.</u> If this section is longer than two pages, it is too long.

Data

You must include a Voltage vs. Current graph for each device. State the average resistance value (with uncertainties) for each device and determine if it is ohmic or non-ohmic.

Read your Lab Manual for instructions on proper formatting of graphs.

Results and Conclusion

This is the most important section of your report as this section must compare your results with your theoretical predictions. It must be in paragraph form. Make sure you address the following points:

- What are your percent errors between the resistances measured by the DMM and the slopes of your Voltage vs. Current graphs?
- If you found that any of the devices are non-ohmic, why might the resistance change with voltage?
- If you found that any of the devices are non-ohmic, do they follow another Voltage vs. Current relationship (*i.e.* exponential, logarithmic, etc.)?
- What sources of error/uncertainty did you have? How could you have removed or reduced them?

Every comparison you make must be numerical!! Use percent errors. You will lose points if you use subjective comparisons such as (but not limited to): "about," "almost," "close to," "kind of," "roughly," or "sort of." You must quote uncertainties for every value you present!

Appendix

Include your signed and completed raw data sheet(s)
Include a sample calculation for every computation you made.