Ohm's Law

Introduction

When a potential difference is applied across an assortment of devices made from different materials, the resulting currents, passing through the devices, are, generally, different. The microscopic property of the material responsible for this behavior is called resistivity. A related macroscopic property is resistance. The resistance R of a device is defined as

$$R \equiv \frac{V}{I}\ , \tag{1}$$

where V is the potential difference (voltage) applied between two points on the device, and I is the current passing between the two points. According to Eq. 1 the resistance, in general, is functionally dependent on the applied voltage; however, for some devices the resistance is a constant independent of the applied voltage, i.e. the current is directly proportional to the potential difference. Such devices are called Ohmic and are said to obey Ohm's Law.

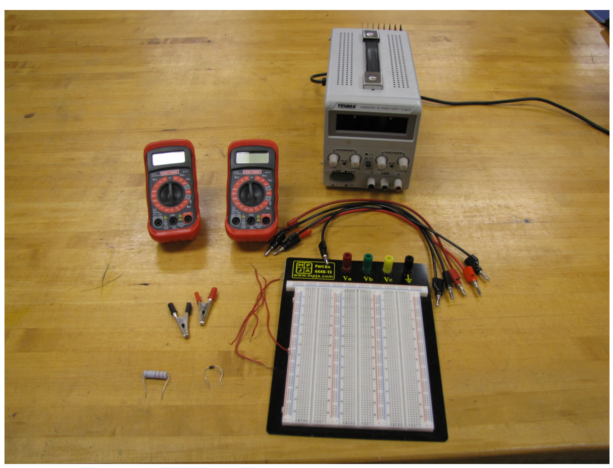

Figure 1: Shown is the equipment used in performing the experiment. It includes two multimeters, a power supply, a breadboard, a 220 Ω resistor rated at 5 W and a diode rated for a maximum current of one amp at 250 volts (code number: MCC SR1010).

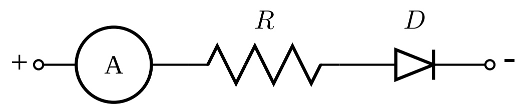

Figure 2: A schematic of the circuit comprising an ammeter, set for 200 mA maximum, a resistor, and a diode, all connected in series.

Procedure

1. One multimeter will function as an ammeter, and the other as voltmeter. Set the ammeter to 200 mA maximum current and the voltmeter to 20 V maximum potential difference.

2. On the breadboard assemble the circuit whose schematic is shown in Fig. 2. The ammeter, the resistor, and diode are connected in series.[1] Connect the circuit to the power supply. The circuit as assembled is shown in Fig. 3.

3. Adjust the power supply to protect the circuit and components. Place the volt meter in parallel with the resistor and diode (See the schematic in Figure 4 and and the circuit, itself, in Figure 5.) First, set the power supply to limit its maximum current output when there is, approximately, a 3.0 volt potential difference across the resistor and diode. The current setting on the power supply will be left at this position for the duration of the experiment. The voltage setting on the power supply should now be set to zero.

4. Connect the voltmeter in parallel with the diode as shown in Fig. 6. The circuit, as assembled is shown in Fig. 7. Obtain five different voltage and current readings for the diode. The voltage readings should range between 0 and approximately 0.36 V. Record your data in Table 1.

5. Using Microsoft Excel plot a graph of voltage vs. current for the diode (Voltage is the ordinate, and current is the abscissa.). Does the diode appear to be an ohmic device?

[1]Note: the end of the diode with the silver band should be forward biased, i.e. closer to the negative terminal of the power supply.

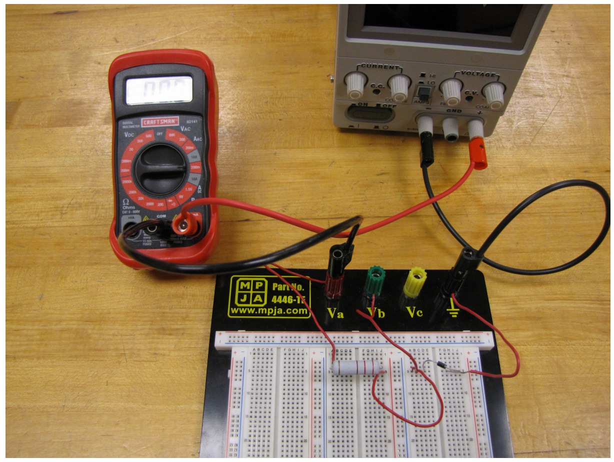

Figure 3: The circuit corresponding to the schematic in in Fig. 2 assembled on the breadboard.

6. Connect the voltmeter in parallel with the resistor as shown in Fig. 8. The circuit, as assembled is shown in Fig. 9. Obtain five different voltage and current readings for the resistor. The voltage readings should range between 0 and approximately 2.50 V volts. Record your data in Table 1.

7. Using Microsoft Excel plot a graph of voltage vs. current for the resistor (Voltage is the ordinate, and current is the abscissa.). Does the resistor appear to be an ohmic device? Perform a linear regression of the data, setting the intercept to zero. Report the value of the squared correlation coefficient, r^2, obtained from the regression in Table 2.

8. Measure the resistance of the resistor using the multimeter. Remove the resistor from the breadboard. Disconnect the banana plugs of the multimeter used as a voltmeter from the breadboard. Set the multimeter for measuring resistance. Attach the alligator clips to the banana plugs. Measure the resistance of the resistor. Report its value in Table 2.

9. Using Eq. 6 calculate the standard error of the slope, δM. Report the experimental value of the slope in Table 2 in the form $M_{\text{est}} \pm \delta M$, where M_{est} is the value of the slope obtained from the regression.

10. According to Eq. 1, for an Ohmic device the slope of the graph corresponds to the resistance of the device. Compare the value of resistance measured directly using the multimeter to that obtained from the slope of the graph. Specifically, calculate the 95% confidence interval using Eq. 8. Report the values in Table 2. Are theory and experiment consistent?

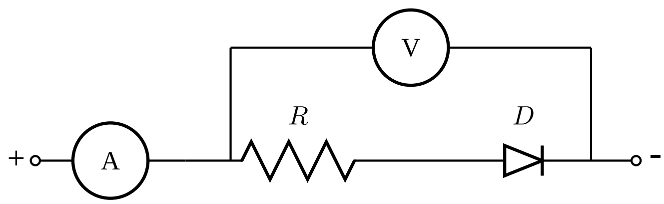

Figure 4: The schematic of the circuit for adjusting the power supply.

Appendix

Consider two sets of data y_i and x_i ($i = 1 \ldots N$) where the y_i are assumed to be linearly related to the x_i according to the relationship

$$y_i = Mx_i + B + \epsilon_i \; . \tag{2}$$

The ϵ_i is a set of uncorrelated random errors. Estimates of the slope M_{est} and y–intercept B_{est} can be obtained using a variety of techniques, such as the method of least squares estimation. The degrees of freedom $\nu = N-2$, since the number of parameters being estimated is 2, i.e. M and B. It can be shown that the standard error of the slope δM is

$$\delta M = \sqrt{\frac{1-r^2}{N-2}} \frac{\sigma_y}{\sigma_x} \; , \tag{3}$$

and the standard error of the intercept δB is

$$\delta B = \sigma_y \sqrt{\frac{1-r^2}{N-2}} \sqrt{\frac{N-1}{N} + \frac{\bar{x}^2}{\sigma_x^2}} \; , \tag{4}$$

where r is the estimated correlation coefficient between the y_i and x_i, σ_y and σ_x are the estimated standard deviations of the y_i and x_i, and $\bar{x}$ is the estimated average of the x_i.[2] The quantities $\bar{x}$, σ_x, and σ_y can straightforwardly be calculated using function keys on a scientific calculator or defined functions in Excel. If, in the regression equation, Eq. 2, the quantity B, the y-intercept, is required to be zero, i.e. the regression equation is now

$$y_i = Mx_i + \epsilon_i \; , \tag{5}$$

[2]Note: in Equation 4 σ_x and σ_y are unbiased estimates.

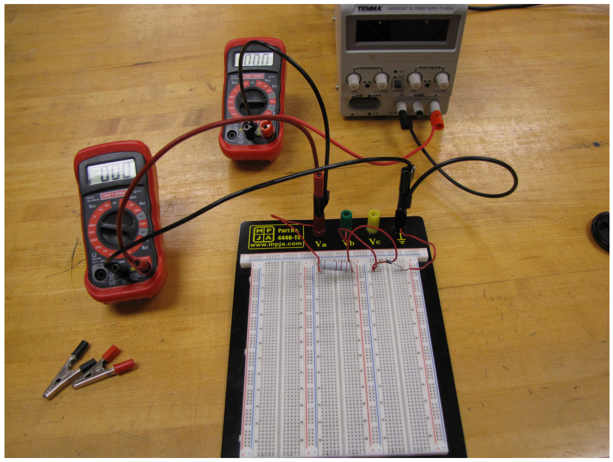

Figure 5: The circuit corresponding to the schematic in in Fig. 4 assembled on the breadboard.

then the degrees of freedom $\nu = N - 1$ so that

$$\delta M = \sqrt{\frac{1 - r^2}{N - 1}} \frac{\sigma_y}{\sigma_x} \ . \tag{6}$$

To reflect the statistical uncertainty in a quantity Q, where Q is either the slope M or y-intercept B, the quantity Q is typically reported as

$$Q_{\text{est}} \pm \delta Q \ , \tag{7}$$

which can be understood informally to mean that, assuming the experimental results are consistent with theory, then the value of Q, predicted by theory, is likely to lie within the limits defined by Equation 7. This informal interpretation can be made more precise. Specifically, one specifies a confidence interval, e.g. the 95% confidence interval (See below.). Then assuming that the theory accounts for the experimental results, there is a 95% probability that the calculated confidence interval from some future experiment encompasses the theoretical value. If, for a given experiment the theoretical value Q lies outside of the confidence interval, the assumption that theory accounts for the results of the experiment is rejected, i.e. the experimental results are inconsistent with theory. The confidence interval is expressed as

$$[Q_{\text{est}} - X\,\delta Q, Q_{\text{est}} + X\,\delta Q] \ , \tag{8}$$

The quantity X is obtained from a Student's t-distribution and depends on the confidence interval and the degrees of freedom. A detailed and illuminating discussion of the Student's t-distribution can be found in the Wikipedia on-line free encyclopedia. [1] There are various ways of obtaining or calculating the value of X. For example, the spreadsheet Microsoft Excel includes a library function T.INV.2T for calculating X

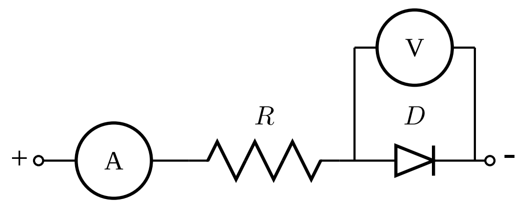

Figure 6: A schematic of the circuit for measuring voltages and currents of the diode.

based on a two-tailed t-test. Specifically,

$$X = \text{T.INV.2T}(p, \nu) \;, \tag{9}$$

where the probability $p = 1 - \frac{\text{(the confidence interval)}}{100}$ and ν is the degrees of freedom. Consider the following example for illustrative purposes. The number of data points is 5; the confidence interval is 95%. The data are assumed to be linearly related with an intercept of zero so that Equation 5 applies. Therefore

$$X = \text{T.INV.2T}(1 - \frac{95}{100}, 5 - 1) = 2.776 \;, \tag{10}$$

References

[1] Wikipedia. Student's t-distribution. `https://en.wikipedia.org/wiki/Student%27s_t-distribution`, 2017. [Online; accessed 22-March-2017].

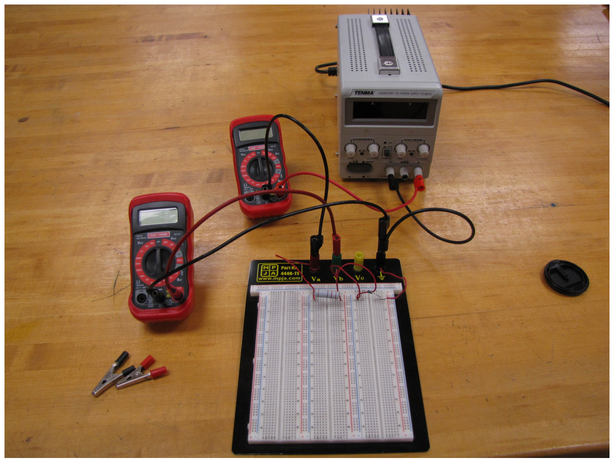

Figure 7: The circuit corresponding to the schematic in in Fig. 6 assembled on the breadboard.

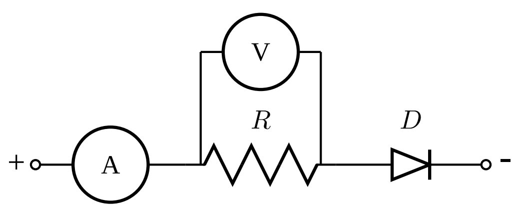

Figure 8: A schematic of the circuit for measuring voltages and currents of the resistor.

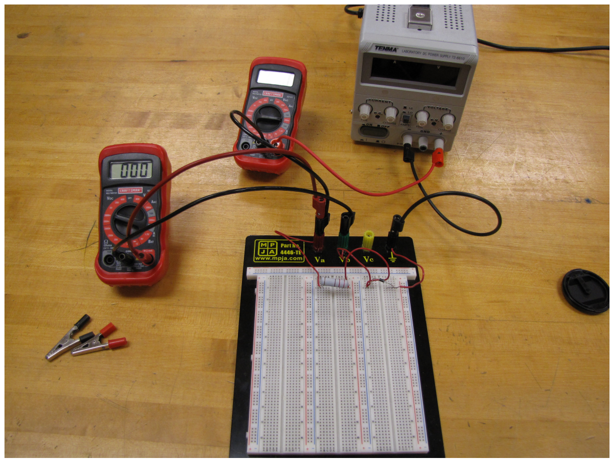

Figure 9: The circuit corresponding to the schematic in in Fig. 8 assembled on the breadboard.

	Diode		Resistor	
	I (amps)	V (volts)	I (amps)	V (volts)
1				
2				
3				
4				
5				

Table 1: Data

	Resistor
r^2	
Slope(exp) $(M_{\text{est}} \pm \delta M)$	
95% confidence $(M_{\text{est}} - X\delta M)$ $(M_{\text{est}} + X\delta M)$	
Resistance (multimeter)	
Are theory and experiment consistent? (y or n)	

Table 2: Results