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Two terminal devices

Abstract

The main focus of this experiment was to resolve the complexity of electronic components. This lab explores the relationship between current and voltage with resistors, batteries, and diodes. Voltage and current measurements were taken for each device, and the appropriate fit for each set of points was determined through python. Each graph has its specific and unique shape accustomed to each device. The differences between the diode shapes will be discussed, and the shapes of the other devices will also be analyzed.

Introduction

In this lab, any two-terminal devices will be measured with their voltage and current. For any non-diode devices, the current is predicted by the equation $c = av + b$ [1], where c is current, v is voltage, and a and b are constants. This is calculated through curve fitting in python, and compared to the actual values measured in the lab. Through this, the uncertainty is measured by taking the standard deviation: $\sigma = \sqrt{\frac{\Xi(x - xa)^2}{N-1}}$ [2], where σ is the standard deviation, Ξ is the sum of (x-xa). X is the measured values and xa is the average of the measured values. N is the number of measurements taken. Using the standard deviation, uncertainty is calculated by; $u(x) = \frac{\sigma}{\sqrt{N}}$ [3], where u(x) is the uncertainty calculation, σ is the standard deviation, and N is the number of observations. (“PHY224_Introslides” 2023) For predicting if the model fit is a good fit, $x(c) = \frac{1}{N-n}\Xi(\frac{y-y(xi)}{u(x)})^2$ [4], is used. x(c) is reduced chi squared, n is the number of observations, y is the measured y data, and y(xi) is the independent data of xi in relation to y. N is the number of observations, and u(x) is the uncertainty. For the diode equations, the shockley diode equation is used, $i(v) = Is[e^{\frac{Vm}{nVT}} - 1]$ [5], where i(v) is the ideal diode, Is is the reverse saturation current, Vm is the voltage measured, n is the identity factor, and VT is the thermal voltage. (“3: Ideal Diode Equation” 2023). Using python and curve fitting, both the current for non-diodes and the reverse saturation current for diodes are predicted. For diodes specifically, the identity factor is assumed to be 0, and the thermal voltage is assumed to be 0.025852 V.

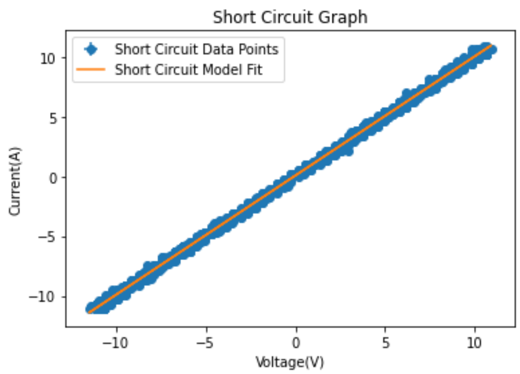
Methods

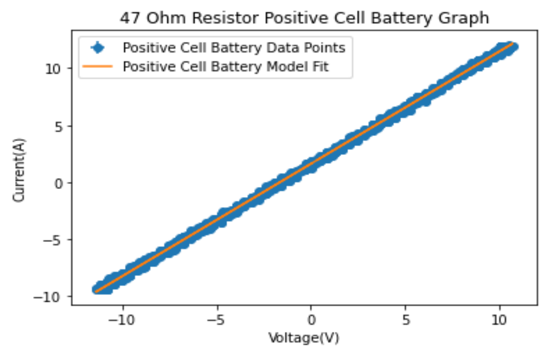
To start, we gathered the equipment needed for the lab which was the oscilloscope, diodes, resistors, and a transformer. Resistor 1 was connected to the transformer and into the device. Then, from the device, connect this to resistor 2. Resistor 2 should go back to the transformer. Also, the device and resistor 1 have to be connected with a wire on the open ends of the terminals. Using a wire for an oscilloscope, connect resistor 1 to channel 1 of the oscilloscope. Another wire is also used to connect the device to channel 2 of the oscilloscope. Ensure that the circuit is closed completely before attaching the oscilloscope cords to the entire circuit. The following devices will be used: short Circuit, 47-ohm resistor, 1000 ohm resistor, 47-ohm resistor in a series with a 1.5-volt cell(both positive and negative), a germanium diode, silicon diode, One section of the Selenium Rectifier, diode vacuum tube, zener diode, and a thermistor. Alternate between each device in the circuit and observe the oscilloscope in X-Y mode to determine the curves of each device. Take note of the intercepts, curves, and points of bending. Once this is completed, connect a USB stick and return back to normal mode. Stop the oscilloscope from running and save the data to a USB stick in order to transfer it to a computer.

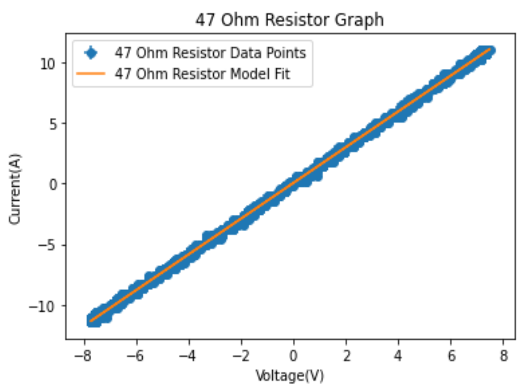
Once this has been completed, use an ohmmeter on each device in order to measure the resistance of each(Lee 2023). Take note of such resistances. The oscilloscope that will be used is the Keysight DSOX 1202G.

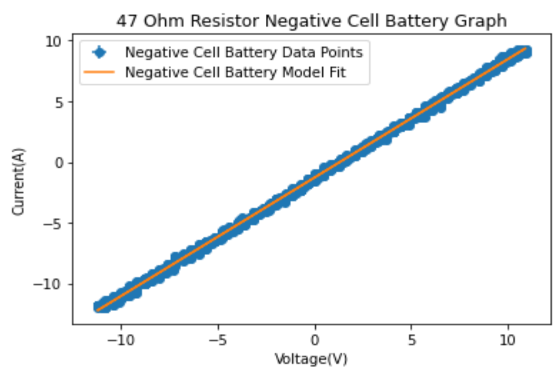
Results:

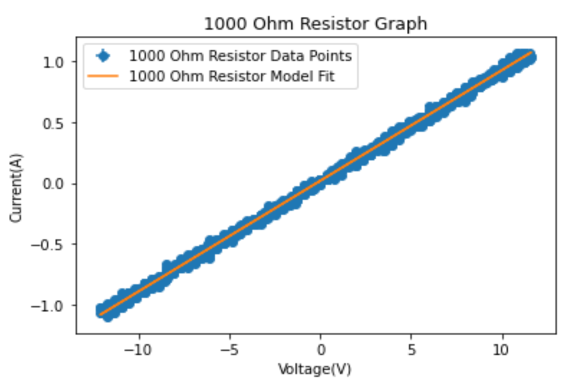
Figures 1-6:











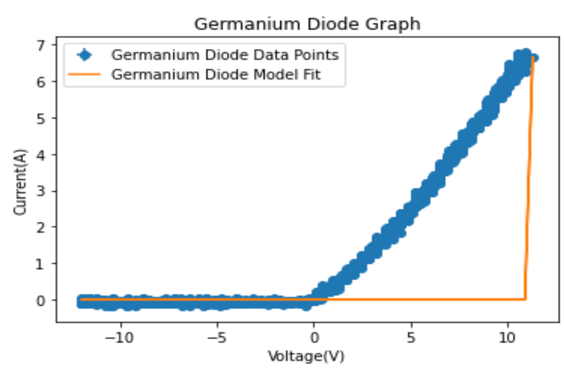
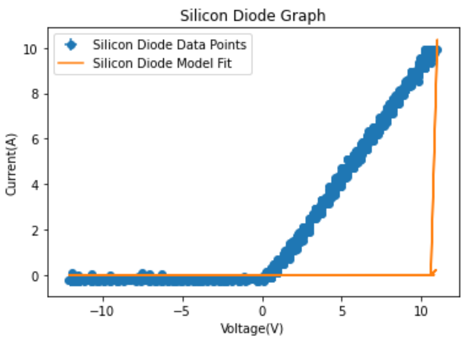
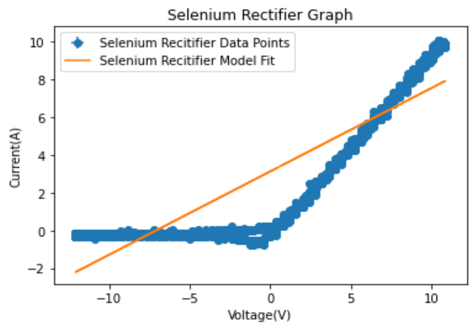
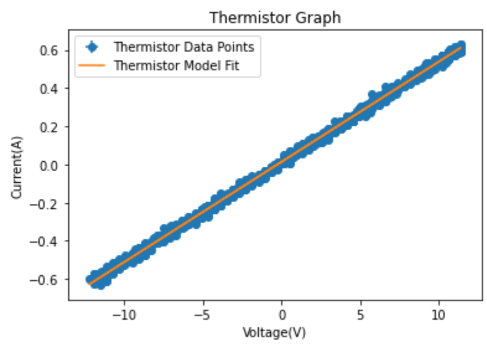


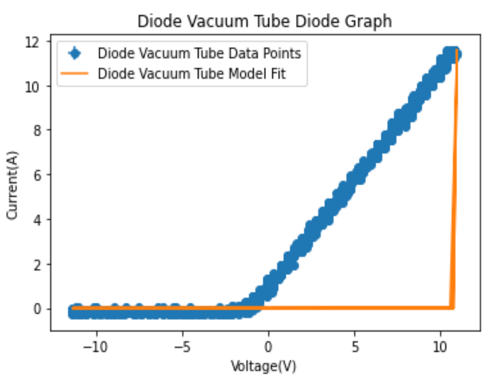
Figure 1-6: The orange lines correspond to the curve fitting in python. They are the model fits. The blue dots represent the data points for each. The uncertainties are included, however are extremely difficult to see.

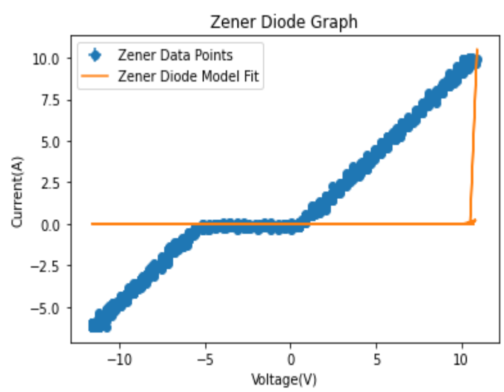
Figures 7-11:





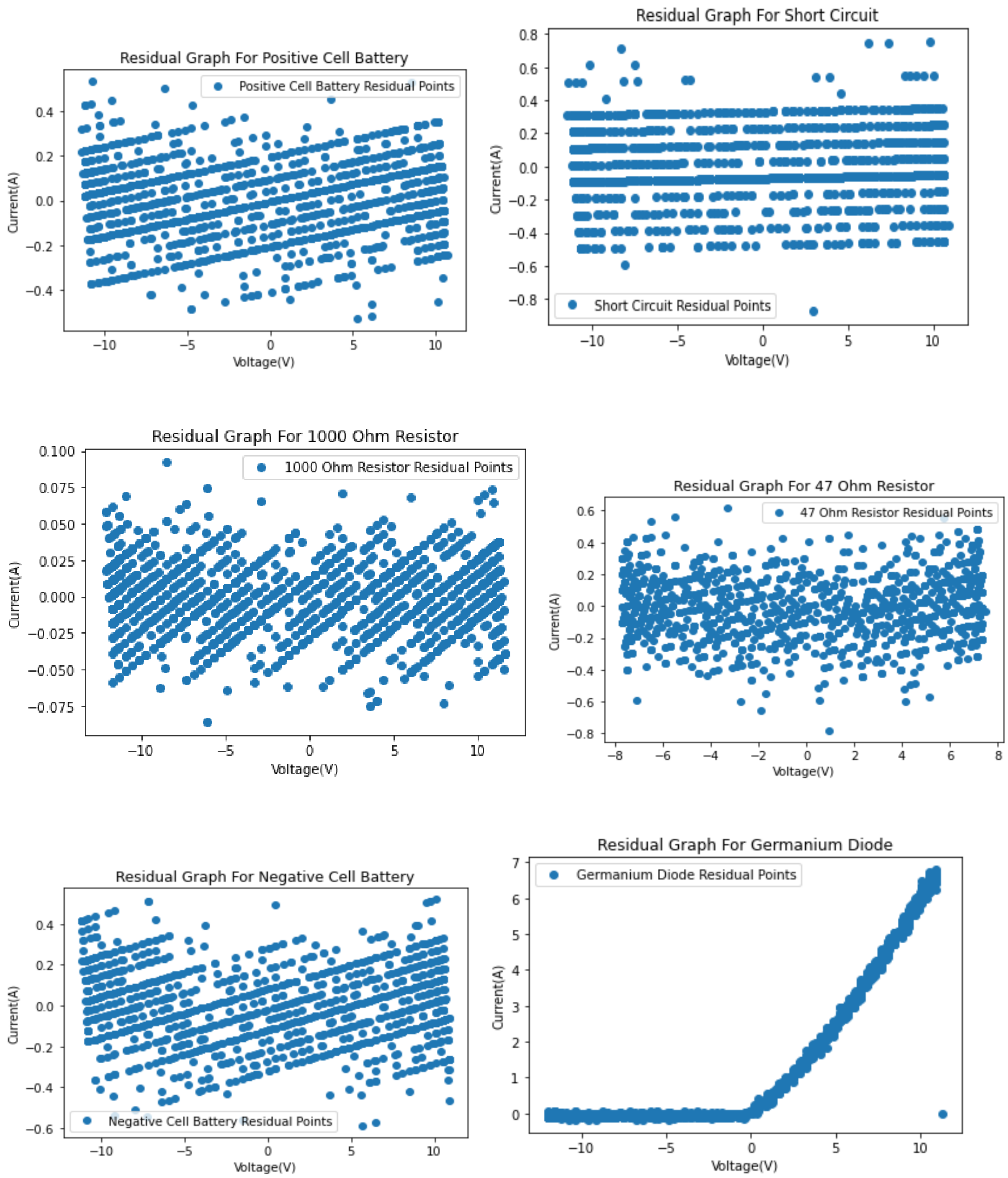






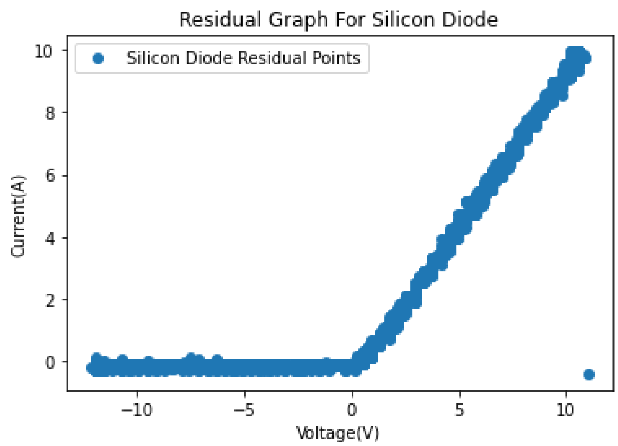
Figures 7-11: The blue dots indicate the data points measured from the lab, with the orange lines corresponding to the model fitting of each device. The uncertainties are included, but are extremely difficult to view.

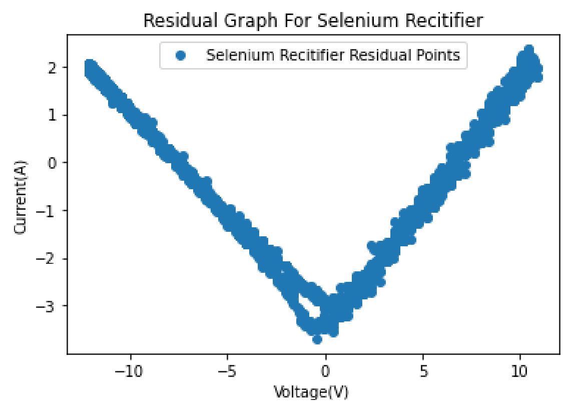
Figures 12-17:

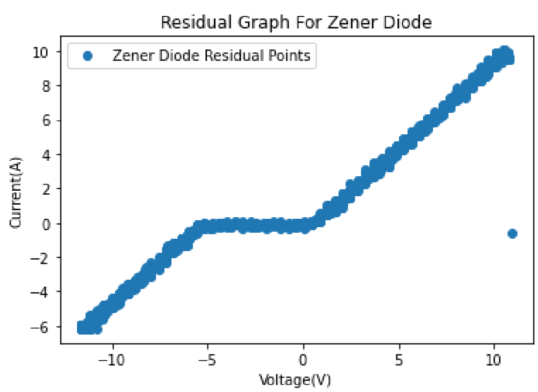


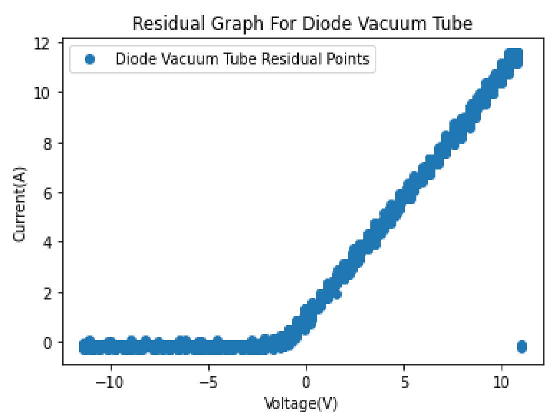
Figures 12-17: Each of the figures have blue points that indicate the residual points. Specifically for germanium diodes, this has a pattern for the residual points, indicating that the model may not be the best fit. These residual plots give an understanding of if the fitting of the model function was decent.

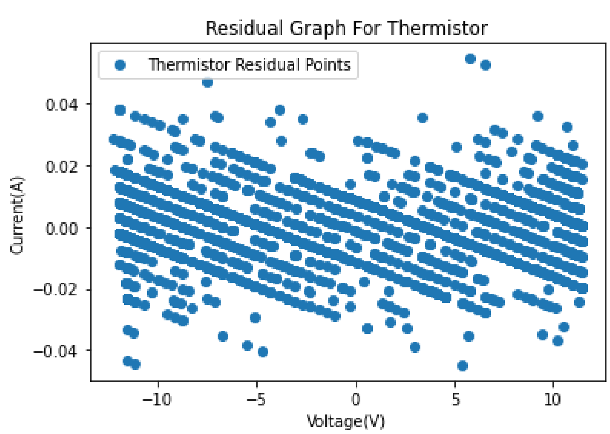
Figures 18-22











Figures 18-22: The residual graphs for the silicon diode, selenium rectifier, zener diode, and diode vacuum tube all have residual points that follow a pattern. This may indicate that a better model fit is able to be used for the data points. Each graph has residual values that visually measure the quality of each fit.

All Reduced Chi Squared Values:

Figure 23:

Device	**Reduced Chi Squared**
Short Circuit	**5.751 x 10^-13**
47 Ohm Resistor	**5.118 x 10^-14**
1000 Ohm Resistor	**1.928 x 10 ^-13**
Positive Cell Battery	**2.008 x 10 ^-16**
Negative Cell Battery	**1.391 x 10 ^-14**
Germanium Diode	**2,342,000**
Silicon Diode	**2,339,000**
Selenium Rectifier	**1.109 x 10^-13**
Diode Vacuum Tube	**2,740,000**
Zener Diode	**353,700**
Thermistor	**3.483 x 10^-13**

Figure 23: The reduced chi squared values specifically measure the quality of fit numerically. This is able to be paired with a residual plot for an accurate determination if each model function is a good fit.

Figure 24:

Device	X-Intercept(V)	Y-Intercept(A)
Short Circuit	-0.234	0.0312
47 Ohm Resistor	-0.625	0.0375
1000 Ohm Resistor	-0.156	0.00125

Cell Battery(Positive)	0.00135	None
Cell Battery(Negative)	-0.00135	None
Germanium Diode	-0.125	0.0125
Silicon Diode	0.0625	0.0187
Selenium Rectifier	-0.375	0.0550
Diode Vacuum Tube	-0.390	0.00717
Zener Diode	None	None
Thermistor	-0.0250	-0.00500

Figure 24: This is a table of the respective x and y intercepts of each device.

Figure 25:

Device	Points of Bending(V)
Germanium Diode	0.0625
Silicon Diode	0.0125
Diode Vacuum Tube	0.0125
Zener Diode	0.0312

Figure 25: This is a table of each of the diodes' points of bending.

Device	X Uncertainty	Y Uncertainty
Short Circuit	0.1699	0.1696
47 Ohm Resistor	0.1699	0.1696
1000 Ohm Resistor	0.1812	0.0164
Cell Battery(Positive)	0.1700	0.1674
Cell Battery(Negative)	0.1698	0.1658

Germanium Diode	0.1787	0.05560
Silicon Diode	0.1767	0.08504
Selenium Rectifier	0.1766	0.08644
Diode Vacuum Tube	0.1722	0.0995
Zener Diode	0.1738	0.1171
Thermistor	0.1810	0.0095

Analysis:

The residual plots in figures 12-17 for the positive cell battery, the short circuit, 1000 ohm resistor, 47 ohm resistor, negative cell battery and germanium diode generally all seem scattered with the exception of the Germanium diode indicating that the model is generally a good fit for most of these. The best fit was probably the 47 ohm resistor since that one was the most scattered but the rest of these show that this is a good fit for these. However the residual plots in figures 18-22 for silicon diode, selenium rectifier, zener diode, diode vacuum tube and the thermistor do not indicate a good fit from the residual plots since the residual points are all patterned, with the exception of the thermistor. The chi squared values for the short circuit, 47 ohm resistor, 1000 ohm resistor, positive cell battery, negative cell battery, Selenium Rectifier and the thermistor had relatively small chi squared values of 5.751 x 10^-13, 5.118 x 10^-14, 1.928 x 10 ^-13, 2.008 x 10 ^-16, 1.391 x 10 ^-14, 1.109 x 10^-13 and 3.483 x 10^-13 respectfully. This means that this can be attributed to overestimating the uncertainty values for each of these devices. However, the germanium diode, silicon diode, diode vacuum tube and zener diode had extremely large chi squared values of 2,342,000, 2,339,000, 2,740,000 and 353,700, respectively. This is able to be attributed to underestimating the uncertainties. As far as all the uncertainties are concerned, they are relatively high in comparison to some of the points. Again, standard deviation was the method of calculation here, however another uncertainty such as instrument uncertainty is able to be used. This may provide a better explanation and reasoning for the uncertainty.

Discussion:

As for the theory used in the calculations, they most accurately represented the graphs. However, each diode value regarding the reverse-bias saturation current, is extremely small when looking at example data for these diodes. Each yielded about some arbitrary number, but to the exponent of 10 x ^-150. When analyzing the diode equation, this may be due to the voltage data not being accurate, resulting in this extremely low value. If the data collected for the voltage was too large, or the thermal voltage being too small, the resultant reverse-bias saturation current will be too small. For the overall resistances that are taken from each device, the ohmmeter is actually measuring the resistance value for each device separately. This gives a good way to compare to the current values obtained by using ohm's law. Regarding the points of bending for each diode, these points refer to the diode reaching a limit in which it exponentially increases. The diode must first reach a point at which a certain voltage value triggers an exponential increase in the current value. As far as the short circuit graph not being vertical, the oscilloscope is still measuring the current running through the device, which in turns transmits a signal to the oscilloscope, resulting in such a reading. For the results depicted in the results section, the points on the graphs themselves truly and accurately represent the oscilloscope points. The actual fitting is good for any graph with a linear data set, however for the diodes, the fits poorly estimate the data. Since the reverse current saturation values are extremely low, is it reasonable to believe that the equation used for the fitting may be incorrect. Again, this could be due to an incorrect data set taken, or the constants used to predict the reverse saturation current, may be incorrect as well.

Conclusion

The fitting for all the devices besides the diodes, present an accurate representation for the data set given. However, the diode fitting is not accurate and can be improved upon. The sources of uncertainties are relatively high, which could be attributed to using standard deviation over instrumental uncertainty. The high reduced chi squared values for diodes indicate that the model is an overall poor fit. This could be due to the complexity of the shockley diode equation, meaning that the uncertainty calculation used, is an underestimate. Reversely, the non-diode devices all have extremely low reduced chi squared values. This is able to be attributed to an overestimation of the uncertainties. Each point of bending in the diodes represents a value at which the current exponentially increases, once a voltage passes a limit. The resistances of all devices indicate the resistance values of each device, and even give a reference to compare to for the voltage and current values.

Appendix:

Example Calculations:

1. Current equation

Let the voltage (v) be 10 volts, and the two constants a and b be 2 and 4 respectfully.

$c = av + b$

C=2(10)+4

C=20+4

C=24 amps (rounded to one sig fig)

2. Standard deviation equation

Let the measured value (x) be 16 ,the average of the measured values (xa) be 8.4 , Number of measurements (N) be 21 and Ξ be 7.6.

$$\sigma = \sqrt{\frac{\Xi(x - xa)^2}{N-1}}$$

$\sigma = \sqrt{(7.6(16 - 8.4)^2)/(21 - 1)}$

$\sigma = \sqrt{438.98/20}$

σ=21.95 (rounded to 2 sig figs)

3. Uncertainty equation

Let the standard deviation be 21.95 , the Number of observations be 21.

$$u(x) = \frac{\sigma}{\sqrt{N}}$$

u(x)=21.95/$\sqrt{21}$

u(x)=4.78 (rounded to 2 sig figs)

4. Reduced chi squared equation

Let Number of measurements be 21, Ξ be 7.6, measured y data (y) be 12.1, independent xi data (y(xi)) be 4.1, uncertainty (u(x)) be 4.78, number of observations be 11.

$$x(c) = \frac{1}{N-n}\Xi(\frac{y-y(xi)}{u(x)})^2$$

x(c) = (1/(21-11))(7.6)((12.1-4.1)/4.78)^2

x(c) = 0.10(7.6)(2.8)

x(c)=2.128 (rounded to 3 sig figs)

5. Shockley diode equation

Let the reverse saturation current (Is) is 0.01, the voltage measured is 5 volts, the identity factor is 1, and the thermal voltage is 4 volts.

$$i(v) = Is[e^{\frac{Vm}{nVT}} - 1]$$

i(v) = 0.01[e^(5/4)-1]

i(v) = 0.01[2.49]

i(v)=0.00249 (rounded to 3 sig figs)

References

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