E5
Current-Voltage (I-V) Characteristics of resistors and semiconductor diodes

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1 Introduction:

Up until now we have used simple circuits to determine the correlation between Current and Voltage, in previous experiments we have used components such as lightbulbs or resistors, however an extremely common component that is often included in many electrical circuits is the Light Emitting Diode or LED. Although we have previously determined that an increase in Voltage will affect the brightness of a bulb when it comes to LED's the requirements are a bit more complicated. The difference between these components is that Lightbulbs exist as conductors which simply follow the relationship:

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

LED exist as semiconductor diodes which follows the relationship:

$$I = I_0 \left[exp(\tfrac{eV}{kT}) - 1\right] \tag{2}$$

where I_0 is the magnitude of the reverse current, V is the voltage across the diode, T is the absolute temperature, e is the charge of the electron and k is the Boltzmann constant.

In our circuit the reverse current is extremely small, so we can reduce Eq.2 to:

$$I = I_0\ exp(\tfrac{V}{25mV}) \tag{3}$$

The equation including an Exponential function gives us some insight into what we can expect our graphs to look like.

When we plot our graphs of the Current vs Voltage for our Ohm's Law Experiment we can expect the slope of our graph to represent the resistance of the circuit, due to the relationship described by Ohm's Law (Eq. 1):

$$\tfrac{V}{I} = R$$

We will be calculating these slopes using the equation:

$$\tfrac{y_2 - y_1}{x_2 - x_1} = m \tag{4}$$

Where y_2 will be our max voltage, y_1 will be our minimum voltage, x_2 will be our maximum current and x_1 will be our minimum current.

Finally we found the band gap energy (E_g) and the gap voltage (V_g)using the equations:

$$\tfrac{hc}{\lambda} = E_g \tag{5}$$

Where h = 6.62×10^{-23}, c = 3×10^8 and λ = the wavelength of each LED
and

$$\tfrac{E_g}{e} = V_g \tag{6}$$

Where e = 1.6×10^{-19}.

2 Method Experimental Set-up:

(A) Ohm's Law For the first part of the experiment our aim was to use a simple circuit involving a battery and a resistor to verify ohms and law, before switching out the resistor for another value and testing the validity of ohms law. We first set up our circuit as represented below in Fig. 2.1:

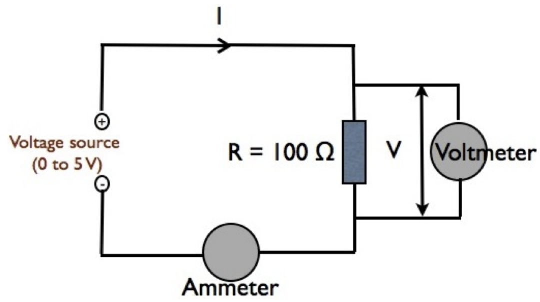

Figure 2.1: Circuit 1

We used two multimeters, one connected in series which measured the current I in amps that is passing through the resistor, and one connected in parallel which measured the voltage / potential difference across the resistor.

We then had to change the voltage coming into the circuit through the power supply and see how the current and voltage passing through the resistor changes. After we recorded the values we repeated this for the second resistor provided.

(B) Diode We first began by setting up the circuit as shown in Fig. 2.2, we recorded the current using a multimeter set up to function like an ammeter and recorded the different values as we changed the voltage going through the circuit from 0.1 up to 0.75, aswell as 1 V, 1.5V up to 2.2 V, we then carried out this process again for the two other LED's in the circuit.

Once we had gathered all of those values for the three LED's we then reversed the direction of the current by switching the connections around and measuring the current at 5V for each LED, which is commonly known as the reverse current.

We then estimated the wavelength of each LED based on the colour of the light emitted compared to a colour vs wavelength chart

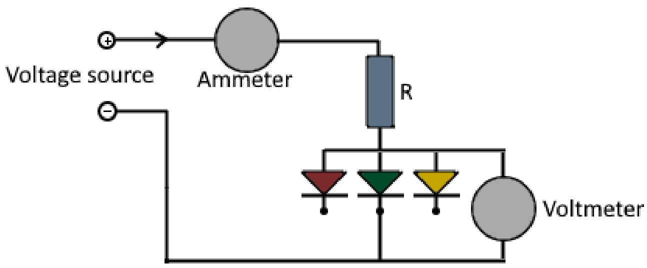

Figure 2.2: Circuit 2

3 Results:

Ohm's Law:

100Ω

Meter Voltage	Multimeter Amps	Multimeter volt
0 V	-0.89 mA ±0.00005	0.087 V ±0.00005
1 V	9.02 mA ±0.0005	0.881 V ±0.00005
2 V	16.69 mA ±0.005	1.64 V ±0.0005
3 V	26.93 mA ±0.005	2.634 V ±0.0005
4 V	36.70 mA ±0.005	3.60 V ±0.0005
5 V	46.3 mA ±0.005	4.52 V ±0.0005

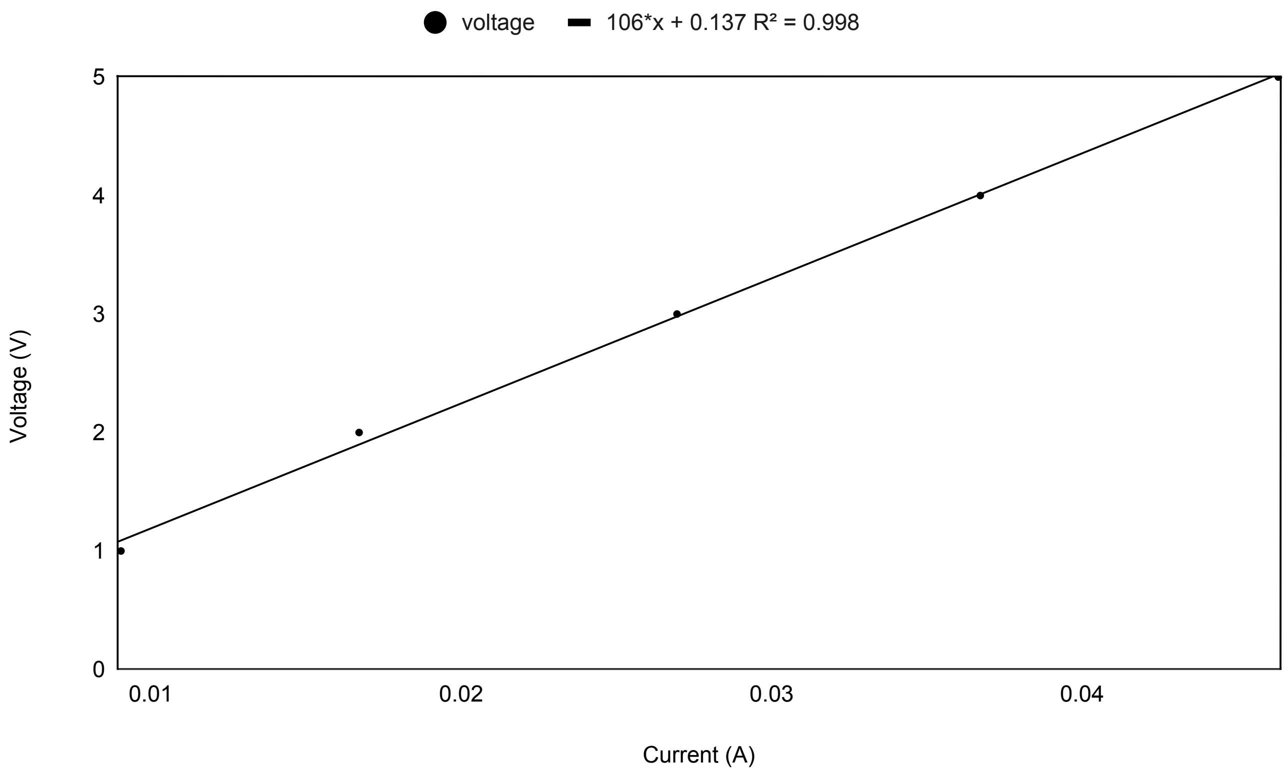

Figure 3.1: Current vs Voltage (100Ω)

Using the equation for the slope of a line (Eq.4):

$$\frac{5-0}{(46.3\times10^{-3})-(-0.89\times10^{-3})} = 105.95$$

We can determine the slope of this graph to be 106, which implies the resistance of the circuit $\approx$ 106 Ω

Using the LINEST function we can determine the error associated with the slope is ±2.68

$$\text{Resistance: } 106\ \Omega \pm 2.68$$

13Ω

Meter Voltage	Multimeter Amps	Multimeter volt
1 V	58.7 mA ±0.005	0.749 V ±0.00005
2 V	107 mA ±0.05	1.4V ±0.0005
3 V	166.5 mA ±0.05	2.440 V ±0.0005
4 V	220 mA ±0.05	3.49 V ±0.0005
5 V	255 mA ±0.05	4.31 V ±0.0005

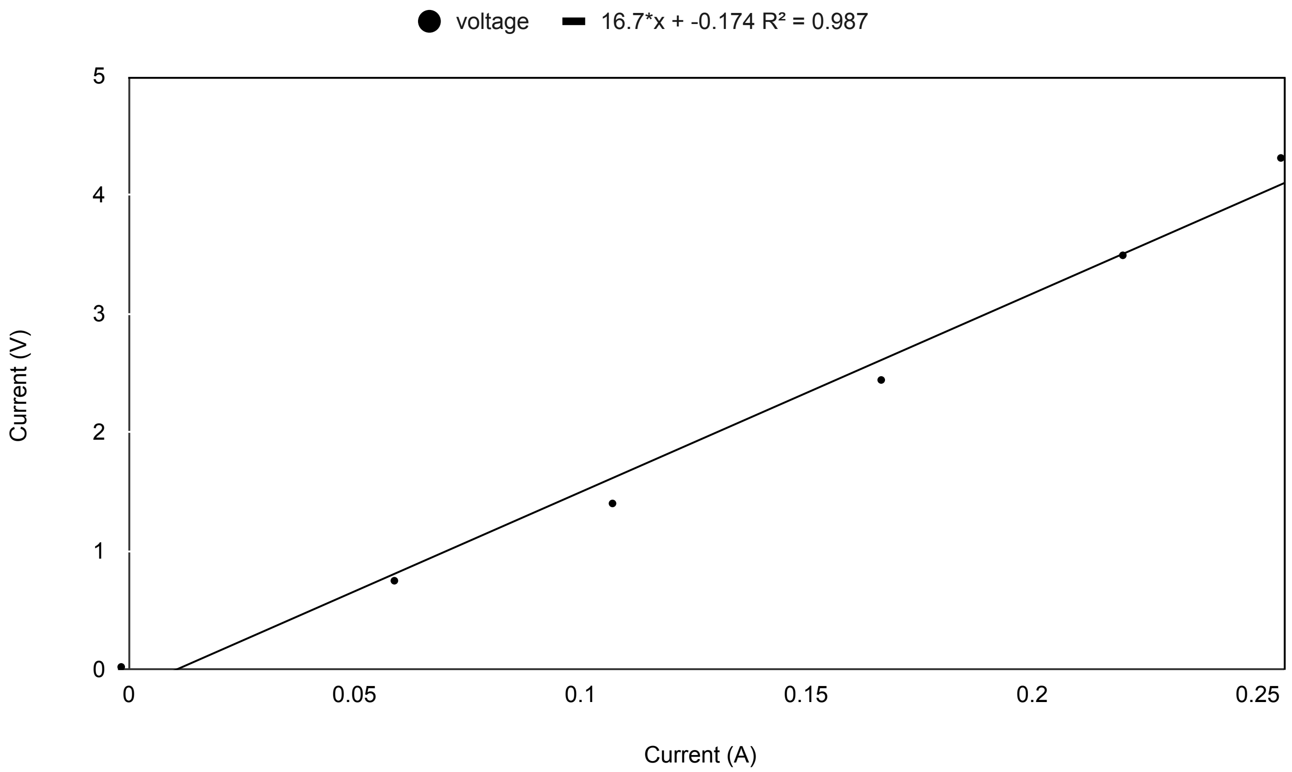

Figure 3.2: Current vs Voltage (13Ω)

Using the equation for the slope of a line (Eq.4):

$$\frac{5-1}{(255\times10^{-3})-(58.7\times10^{-3})} = 15.68$$

We can determine the slope of this graph to be 16.7, which implies the resistance of the circuit $\approx 16\ \Omega$

Using the LINEST function we can determine the error associated with the slope is ±0.97

$$\text{Resistance: } 16\ \Omega \pm 0.97$$

Diode:

Red

Voltage	Amps
-5.10 V	-5.09 mA
0.105 V	0.10 mA
0.202 V	0.19 mA
0.292 V	0.29 mA
0.395 V	0.4 mA
0.506 V	0.51 mA
2.079 V	2.11 mA

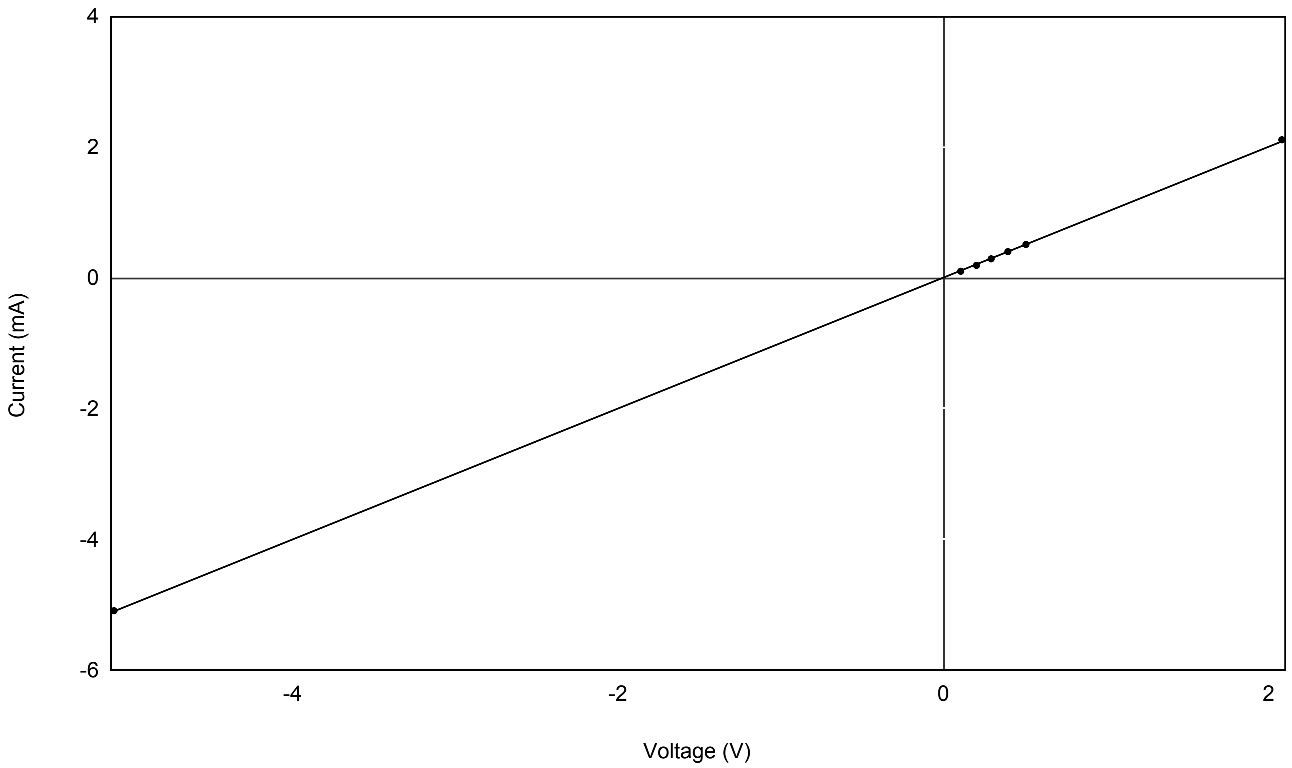

Figure 3.3: Red LED Voltage vs Current

$$\lambda_{Red} = 680 \text{ nm}$$

Using Eq. 5:

$$E_g = \frac{(6.62\times10^{-34}Js)(3\times10^{8}ms^{-1})}{680\times10^{-9}m} = 2.921 \times 10^{-19} \text{ J}$$

$$V_g = \frac{2.921\times10^{-19}}{1.6\times10^{-19}} = 1.83 \text{ V}$$

Green

Voltage	Amps
-5.03 V	-5.13 mA
0.103 V	0.10 mA
0.195 V	0.2 mA
0.286 V	0.29 mA
0.393 V	0.4 mA
0.504 V	0.51 mA
0.75 V	0.75 mA
1.032 V	1.05 mA
1.483 V	1.52 mA
1.747 V	1.86 mA
1.824 V	2.5 mA
1.998 V	8.09 mA
2.022 V	13.99 mA
2.193 V	20.21 mA

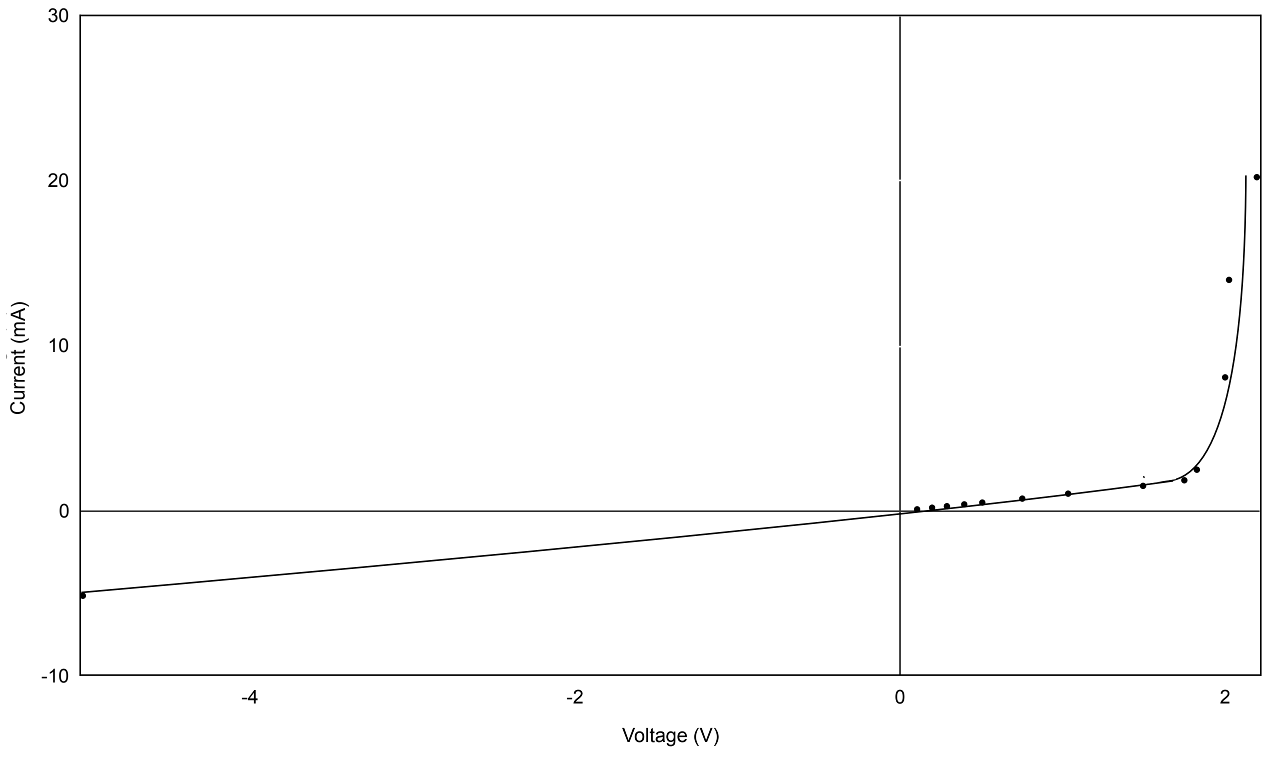

Figure 3.4: Green LED Voltage vs Current

$$\lambda_{Green} = 500 \text{ nm}$$

Using Eq. 5:

$$E_g = \frac{(6.62\times10^{-34}Js)(3\times10^{8}ms^{-1})}{500\times10^{-9}m} = 3.972 \times 10^{-19} \text{ J}$$

$$V_g = \frac{3.972\times10^{-19}}{1.6\times10^{-19}} = 2.48 \text{ V}$$

Yellow

Voltage	Amps
-5.04 V	-5.11 mA
0.102 V	0.1 mA
0.198 V	0.2 mA
0.284 V	0.28 mA
0.395 V	0.4 mA
0.497 V	0.5 mA
0.75 V	0.75 mA
1.027 V	1.03 mA
1.551 V	1.86 mA
1.75 V	2.3 mA
1.998 V	9.96 mA
2.053 V	19.9 mA
2.058 V	20.52 mA

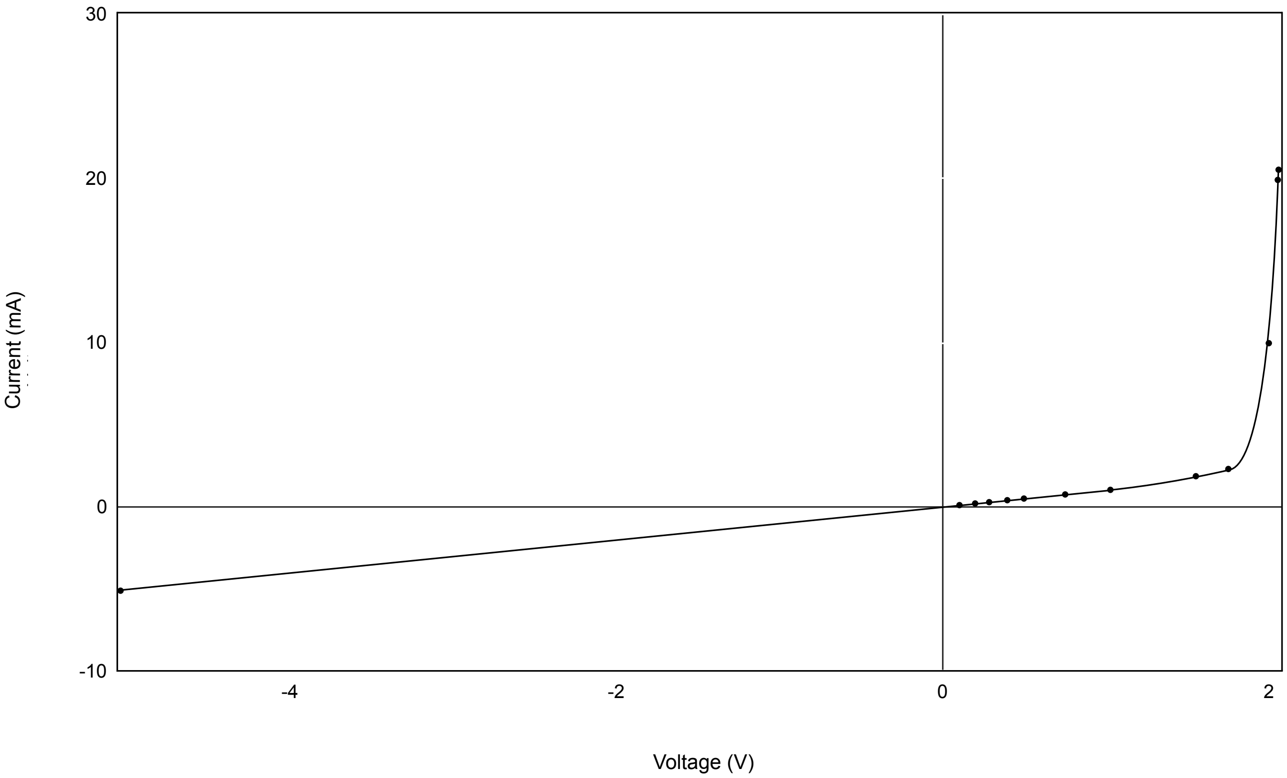

Figure 3.5: Yellow LED Voltage vs Current

$$\lambda_{Yellow} = 580 \text{ nm}$$

Using Eq. 5:

$$E_g = \frac{(6.62{\times}10^{-34}Js)(3{\times}10^{8}ms^{-1})}{580{\times}10^{-9}m} = 3.424 \times 10^{-19} \text{ J}$$

$$V_g = \frac{3.424{\times}10^{-19}}{1.6{\times}10^{-19}} = 2.14 \text{ V}$$

4 Discussion:

Ohm's Law:

When analysing the results of the Ohm's Law experiment we noticed that the calculated resistance didn't match up with the expected resistance even when taking the uncertainty into account, for both of the experiments, the calculated resistance differs from the expected resistance by about 2 - 3 Ohms. This is most likely due to the calculations in our experiment taking into account the resistance of every component in the circuit, although every effort was made to reduce this unwanted resistance it is still a factor when it comes to the overall resistance of the circuit.

In an effort to reduce this effect in future, it would be recommended that the resistance associated with each other component in the circuit be recorded and subtracted from the final calculated resistance, this would hopefully get the resistance down to within the margin of uncertainty.

Diodes:

When working with the LED Diodes the first thing we noticed is how the Red LED wasn't behaving similarly to the other two, we were unable to get the Red LED to light up regardless of how many volts we supplied to the circuit, and we also noticed an almost complete 1:1 ratio of voltage supplied to current output, however when we reversed the flow of current we noticed that the Red LED began to glow at -5V, while neither of the other two did. For these reasons we decided that the Red LED should be excluded from the analysis and we should just focus on the results of the Green and Yellow LED's

When comparing our value for our gap voltage (V_g) to the threshold (knee) voltage we see that they are similar, but not identical. For the Green LED we have calculated the gap voltage to be around 2.48 V, however our graph appears to represent a gap voltage of around 1.95 V. For the Yellow LED we have calculated the gap voltage to be around 2.14 V, however our graph appears to represent a gap voltage of around 1.8 V.

If we were to repeat this experiment in an effort to increase accuracy, it would be beneficial to record values closer to the now known threshold voltage range (1.95 - 2.48) and (1.8 to 2.14) respectively in order to get a better representation of the graph, We could also use a piece of equipment to better determine the wavelength of light given off by each LED

5 Conclusion

The value of the first resistor was determined to be $106\Omega \pm 2.68$ which is an error of 6%, the second resistor was determined to be $16\Omega \pm 0.97$ which is an error of 23% The value of the gap voltage for the Green LED was determined to be 2.48 V, while the graph displayed 1.95 V which is an error of 21%, the gap voltage for the Yellow LED was determined to be 2.14 V, while the graph displayed 1.8 V which is an error of 39%