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Statistical Analysis on the Electrical Properties of Different Colored LEDs

Introduction:

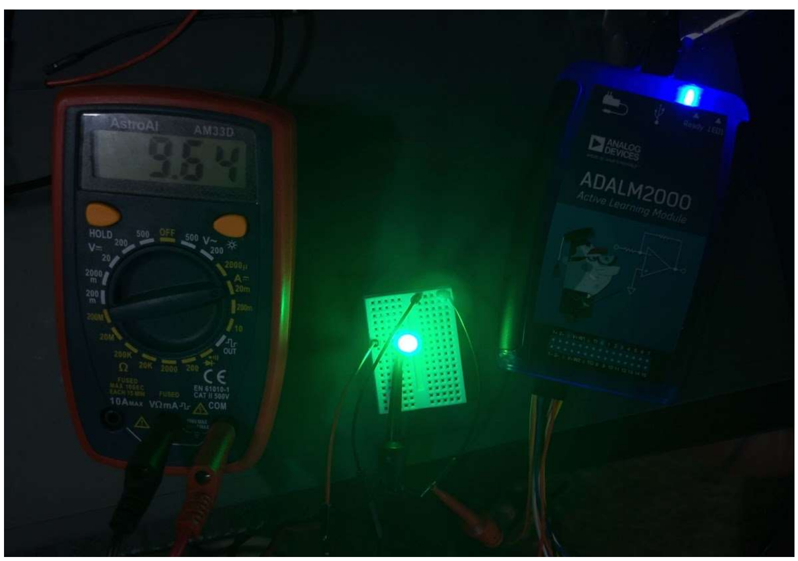
Our experiment deals with collecting data to determine the electrical properties of an LED. An LED is a light emitting diode, which emits light if a voltage is applied across the LED's terminals in a particular direction known as forward bias. This is because diodes, in general terms, are classified as semiconductors which only conduct electricity under specific conditions. LED's have many applications in modern electronics and can be found in devices such as TV's, automobiles, cellphones, computers, etc. The brightness of an LED is dependent on the current that flows through the LED and the voltage across the LED. Therefore, it is important to understand how changing those variables affects an LED's performance in order to design an appliance that will behave properly.

As mentioned before, LED's have an electrical property that causes them to restrict current flow to only one particular direction. Even when the LED is connected in the right direction (forward bias), current will only flow when a certain threshold voltage is reached. For this threshold voltage and beyond, the LED will allow current to flow and therefore glow with a brightness proportional to the current.

In the first part of our project we will be doing an experiment to determine whether the threshold voltage of different colored LEDs in our sample matches with the average threshold voltage provided by the company. We will then do a t-test to determine whether, based on our experiments, the value provided by the companies is acceptable within a certain confidence interval.

For the second part, we will be doing an experiment to determine the relationship between the current through an LED with the voltage across the LED. This will be done for the three different colors of LEDs separately as well. We will then further analyze our data by performing linear regression analysis on the section of the data where it is expected for an LED to have a linear relationship between its current and voltage.

Methods:



Digital Multimeter, LED Circuit and Power Supply

For this project we decided to use typical breadboard mountable LEDs for our experiments. We used red, green and blue LEDs for our tests as we were comparing the difference in LED properties based on their color. These LEDs were mounted on a simple breadboard circuit with a power supply. For the power supply, we used an ADALM 2000 device, which is a USB powered power supply that can be controlled using our laptop computers to drive small voltages.

Screenshot of power supply applying 3V DC voltage to circuit

Typically, LEDs are mounted into circuits using resistors. This is normally done to protect the LED from high currents that could damage it. For our applications, we were measuring the changes in current, and adding a resistor would bias our results by limiting current flow. We got our values by immediately recording the data from the digital multimeter for current and the ADALM software for voltage.

For the first part of our experiment, we used a total of 60 LEDs, 20 of each in colors red, blue and green. For each LED we mounted the unit onto our circuit and then we increased the supply voltage from 0 until we could see the LED glowing at its dimmest, barely visible state. We recorded this voltage and measured the corresponding current at the same time. This process was then repeated 20 times for each color, using different LEDs to make a random sample for our data. We then took the mean and standard deviation from our measurements using R and used that for further statistical analysis.

For the second part of the project, we took one LED of each color from our random sample and connected it to the same circuit. This time we started at an initial supply voltage of 1.0V and increased the voltage by 0.1V while taking subsequent current measurements in mA. We went up to a maximum supply voltage of 4.0V where most LEDs tend to “flatline” or slowly start to deteriorate due to high current. Therefore, we used the supply voltage as our explanatory variable and the current our response variable.

Results:

From the first part of the project, we used the threshold voltage data we got from our experiments to determine the mean and standard deviation using R. We then took experimentally determined threshold voltages from a reputable website to compare our data against. For each of our LED experiments (red, green and blue) we got a mean threshold voltage that was similar to that obtained from the website. Our standard deviation values were also quite low as shown in Table 1 below.

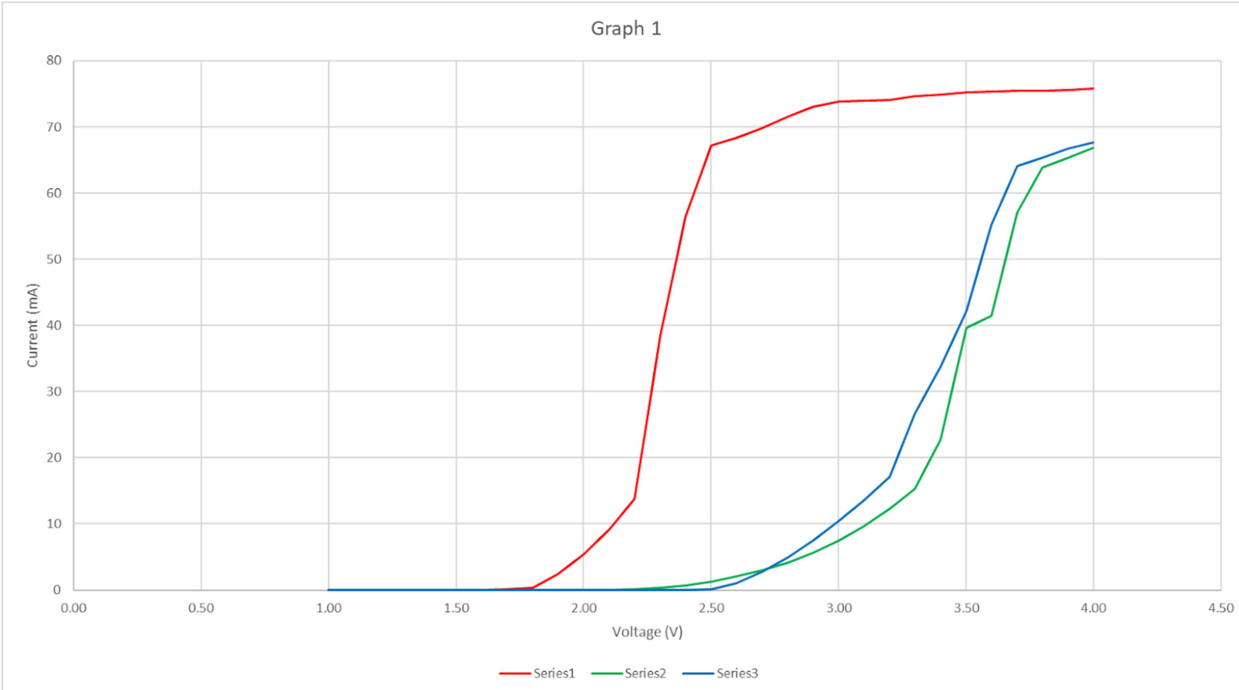
	Mean Threshold Voltage (V)	Standard Deviation (Threshold Voltage)	Mean Current (μA)	Standard Deviation (Current)	Resistance (Ω)
Red	1.570	0.03861589	9.257	1.5254925	169603.54
Green	2.000	0.085964788	2.001	0.805794794	999600.15
Blue	2.379	0.046383981	10.330	2.153564196	230306.79

Table 1

While measuring the threshold voltage, we also measured the corresponding current through the LEDs at the time. We calculated the mean of the currents using R. Then, using the formula Voltage = Current x Resistance (Ohm's Law), determined the resistance of the LED at the time. As shown above, the resistance values we received were very high and that is consistent with LED characteristics, as LEDs should allow a bare minimum amount of current to pass through at its threshold voltage resulting in a very high resistance.

In the Analysis section we will use a 't' hypothesis test to determine whether the value provided by the companies (which is the value we obtained from the website) is acceptable within a certain confidence interval based on our data.

For the second part of the project, we used the values obtained from our experiments to plot a curve of current against voltage. This was repeated for all three colors of LED we used and the results are shown in Graph 1 below.



As shown above, all LEDs have zero current flow before the threshold voltage is applied. After the threshold voltage is reached, the current gradually begins to increase, initially at a non-uniform rate until the LED reaches what is called its forward operating region where the current rises very fast with a small change in voltage. However, after that forward operating region is surpassed, the change in current again becomes non-uniform as the LED begins to deteriorate due to the heat from high current flow. Thus, our data is consistent with general LED properties.

Later, in the Analysis section we will carry out Linear Regression analysis to determine the relationship between voltage and current of an LED in that forward operating region and compare our results for the three different colored LEDs.

Analysis:

We used the data obtained from the first part of the project to carry out a t-test. First, we calculated a t-value in R using $\boldsymbol{\alpha}$ = 0.05 and a degrees of freedom value based on our sample size. We then calculated the t-test statistic using the following equation:

$$\frac{m - \mu}{\frac{s}{\sqrt{n}}}$$

Where 'm' is the mean threshold voltage from our experiments, 'μ' is the value obtained from the website, 's' is the standard deviation and 'n' is our sample size. The calculations for the three colors of LEDs and our t-value are shown below:

$$H_0: \ m = \mu \qquad\qquad H_n: \ m \neq \mu$$

(where μ is 1.6, 1.9, and 2.5 for Red, Green and Blue respectively)

$$Degrees\ of\ Freedom = n - 1 = 20 - 1 = 19$$

$$Critical\ t_{value} = qt(0.975,\ 19) = 2.093024$$

$$t_{red} = \frac{1.57 - 1.6}{\frac{0.038616}{\sqrt{20}}} = -3.47$$

$$t_{green} = \frac{2.0 - 1.9}{\frac{0.038616}{\sqrt{20}}} = 5.20$$

$$t_{blue} = \frac{2.379 - 2.5}{\frac{0.046384}{\sqrt{20}}} = -11.67$$

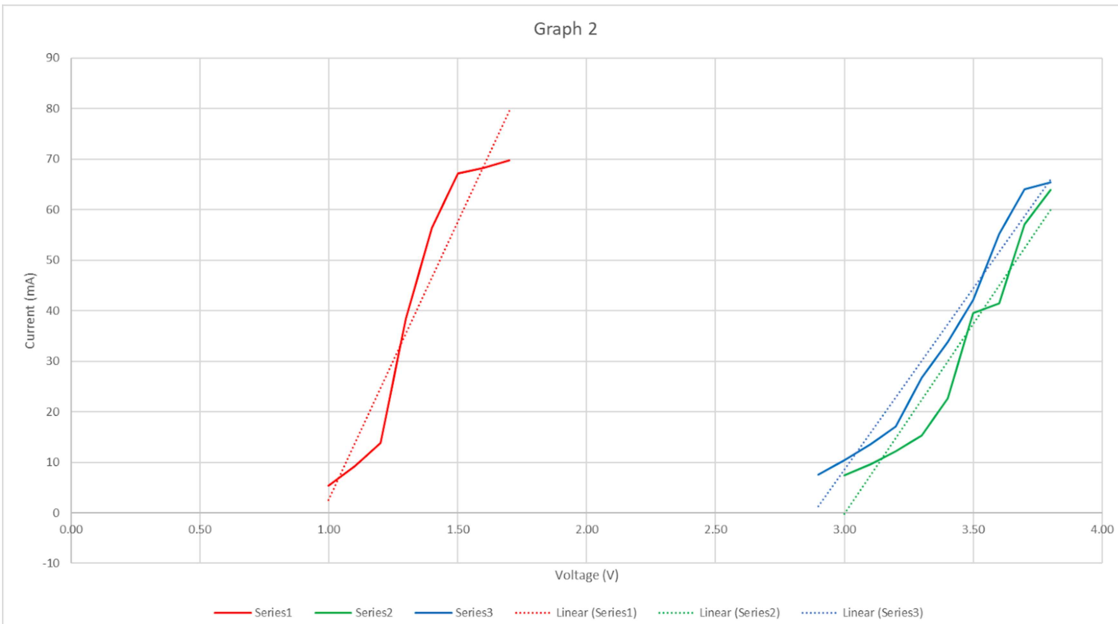
We then compared the absolute value of the test statistic with our t-value:

For Red, 3.47 > 2.09 (Reject null Hypothesis)

For Green, 5.20 > 2.09 (Reject null Hypothesis)

For Blue, 11.67 > 2.09 (Reject null Hypothesis)

Next, we used the data from the second part of the project to carry out linear regression analysis for the three different colors of LEDs. As mentioned before, we will analyze the LED's forward operating region only as in that region, we expect the voltage and current to have an almost linear relationship. Graph 2 below shows the forward operating regions from the data in Graph 1 with a linear trendline.



We then obtained the linear correlation coefficient using R for each color:

$$R_{red}^{\ \ 2} = 0.9208$$

$$R_{green}^{\ \ 2} = 0.9376$$

$$R_{blue}^{\ \ 2} = 0.9662$$

Conclusion:

We had to reject the null hypothesis for all three colors of LEDs as our data did not fall within the 95% confidence interval (α = 0.05) that we were testing with. This makes sense as the company data posted on the website was approximated to one decimal place whereas we obtained data to an accuracy of three decimal places. This coupled with the fact that we had relatively low standard deviation values in our experiment leads us to infer that the true LED threshold voltage is not equal to the value provided by the company.

We compared the linear regression data to see which color of LED behaves the most linearly in the forward operating region. A linear regression coefficient closer to 1 means better linear relationship between voltage and current. Therefore, we can see that the Blue LED (0.9622) has the best linear relationship followed by the Green (0.9376) and Red (0.9208) LEDs in that order. This implies that the Blue LED had the most steady forward operating region. Properties like this are important in applications such as LED dimming circuits where an LED's brightness is controlled by varying current or voltage.

It is important to note that our experiments were not carried out in a professional laboratory setting, so it is safe to assume that our measurements have a certain degree of error. For example, external factors such as power supply accuracy, wire resistance, ambient temperature etc. can affect voltage and current readings.

For future research we could study the material properties of different LEDs. LEDs can be manufactured using different molecular compounds such as Gallium Arsenide Phosphide, Aluminum Gallium Indium Phosphide etc. These differences may also significantly affect an LED's characteristics.

Appendix:

Snippets of R-code used for our project:

````
```{r}
#for mean
mean(data)

#for standard deviation
sd(data)

#for finding t-value
qt(confidence interval, degrees of freedom)

#for linear correlation coefficient
cor(voltage, current)
```
````

References:

LED manufacturing data obtained from CircuitBread:

https://www.circuitbread.com/ee-faq/the-forward-voltages-of-different-leds