ENSC 470/894

Optical Engineering and Laser Applications
Lab 2 – Spectrometer

Group 12

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1 Introduction

In this lab, we have been introduced to use spectrometer to measure the intensity of light as a function of wavelength. We used regular light bulbs, white/color LED, inferred, HeNe laser, laser pointer and colored filter as the subject. This lab will give us a better understanding of black body radiation and Thermal radiation through Planck's Law and Wien's Law.

2 Formulas information

2.1 Planck's Law

Planck's Law tells us the spectral density of electromagnetic radiation emitted by a black body in thermal equilibrium at a given temperature T. (Wikipedia)

$$\mathrm{E}(\lambda, \mathrm{T}) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{\left[e^{\frac{hc}{\lambda KT}} - 1\right]} \frac{W}{m^3}$$

Where, $\mathrm{h} = \text{Planck's constant} = 6.63\times10^{-34}\,Js$

$\mathrm{c} = \text{speed of light} = 3\times10^{8} m/s$

$\lambda = \text{wavelength (m)}$

$\mathrm{T} = \text{Temperature (°K)}$

$\mathrm{K} = \text{Bolyzman constant} = 1.38\times10^{-23} J/K$

2.2 Wien's displacement Law

Wien's Law described the relationship between the change of the wavelength will decrease while the temperature increase

$$\lambda_{max} = \frac{2897}{T} \mu m$$

2.3 Full width half Maximum range (FWHM)

$$\mathrm{FWHM} = \text{the middle part of the wavelength with half the magnitude}$$

$$= \lambda_{right} - \lambda_{left}$$

2.4 Symmetry

The symmetry is calculated by the formula below:

$$\text{symmetry} = \left|0.5 - \frac{\lambda_{max} - \lambda_{left}}{FWHM}\right|$$

The higher of the symmetry value the less symmetry the graph.

3 Spectrum Analysis

3.1 Regular light Bulbs Spectrum

3.1.1 Experiment

This section contains the test of 4 different kinds of light source: incandescent source, fluorescent light bulb, Halogen light bulb, and mercury vapour source. The graphs of the relationship between the wavelength and magnitude of each light source is provided below:

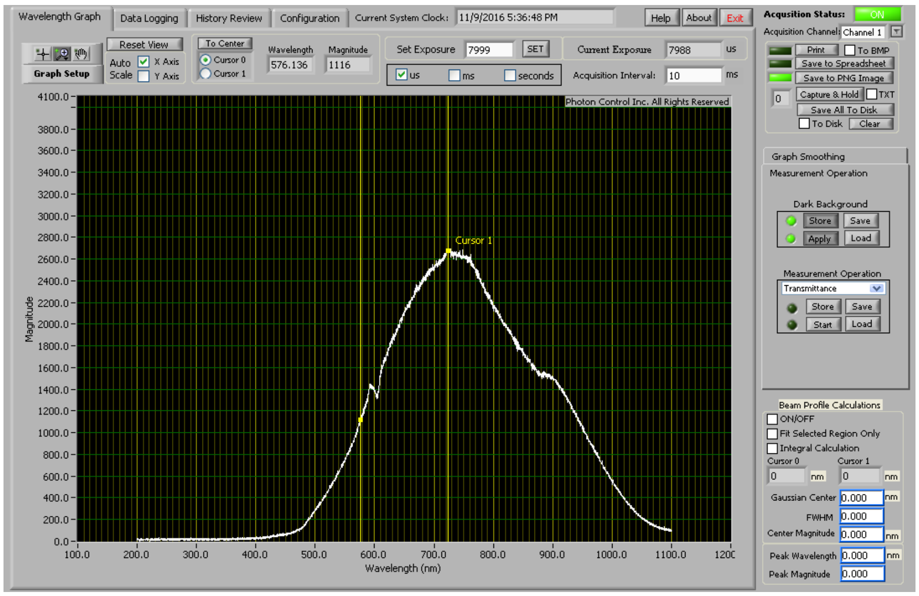

Figure 1: Incandescent Light Source

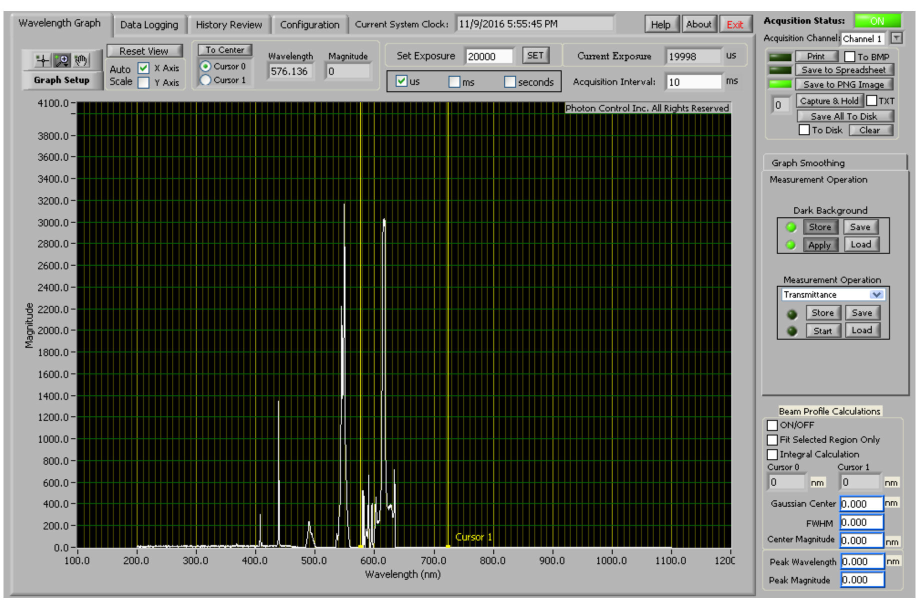

Figure 2: Fluorescent Light Bulb

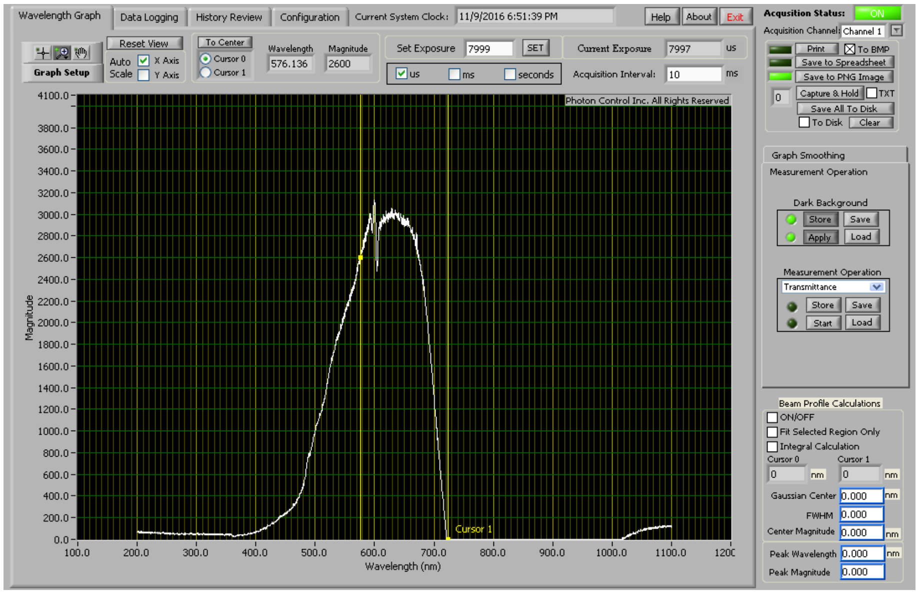

Figure 3: Halogen Light Bulb

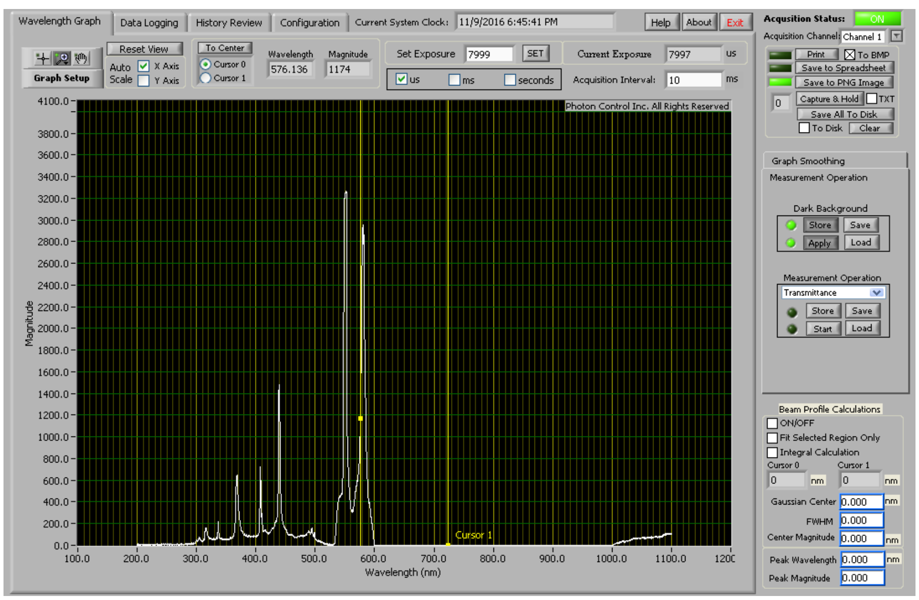

Figure 4: Mercury Vapour Source

3.1.2 Analysis

First, the peak wavelength (the wavelength of the maximum magnitude) of the incandescent source can be found in the spreadsheet:

$$\lambda_{max} = \frac{1}{2}(726.815491 + 726.5354) = \ (nm) \approx 726.68\ \pm 0.14\ (nm)$$

Then the color temperature of the incandescent light source is:

$$\mathrm{T} = \frac{2897}{\lambda_{max}} = \frac{2897}{726.815\times10^{-3}} = 4115.6\ (K)$$

For allocating the Full Width Half Maximum spectral range, we should first get the half of the maximum magnitude:

$$\frac{1}{2}\ Max = \frac{1}{2}\times2708 = 1354$$

The wavelengths of the magnitudes which is most close to 1354 are:

$$\lambda_{half1} = \frac{1}{2}\times(589.19928 + 589.4773) = 589.34\ \pm 0.14\ (nm)$$

$$\lambda_{half2} = \frac{1}{2}\times(920.668762 + 920.951172) = 920.81\ \pm 0.14\ (nm)$$

Now we can check how asymmetric it is:

$$\mathrm{symmetry} = \left|0.5 - \frac{\lambda_{max} - \lambda_{half2}}{\lambda_{half1} - \lambda_{half2}}\right|\times100\%$$

$$\mathrm{symmetry} = \left|0.5 - \frac{726.815 - 920.81}{589.34 - 920.81}\right|\times100\%$$

$$\mathrm{symmetry} = 8.526\%$$

which is less than 10%. It means the curve is symmetric.

Similarly, we can repeat the calculation above for the Fluorescent and Halogen. The data is provided in the table below:

Table 1: Light bulbs values

Light Source	Peak Wavelength (nm)	Colour Temperature (K)	Full Width Half Maximum (nm)		Full Width Half Maximum Range(nm)
			λ_{half1}	λ_{half2}	
Incandescent	726.68 $\pm$ 0.14	4115.6	589.34 $\pm$ 0.14	920.81 $\pm$ 0.14	331.47
Fluorescent	549.2083 $\pm$ 0.139	5274.9			
Halogen	628.3115 $\pm$ 0.139	4610.8	523.2959 $\pm$ 0.139	696.7212 $\pm$ 0.139	173.43

The formula for Black Body radiation is:

$$\mathrm{E}(\lambda, \mathrm{T}) = \frac{2\pi hc^2}{\lambda^5}\frac{1}{\left[exp\left(\frac{hc}{\lambda KT}\right) - 1\right]}$$

And the unit is W/m^3. Then the Black Body radiation of those three light sources are:

$$E_{incandescent} = 1.494 \times 10^{13}$$

$$E_{fluorescent} = 5.183 \times 10^{13}$$

$$E_{halogen} = 2.6448 \times 10^{13}$$

3.2 White LED Spectrum (Alex)

3.2.1 Experiment

In this section, we measured for the White LED light source. It has two peak wavelengths which is shown in the following image:

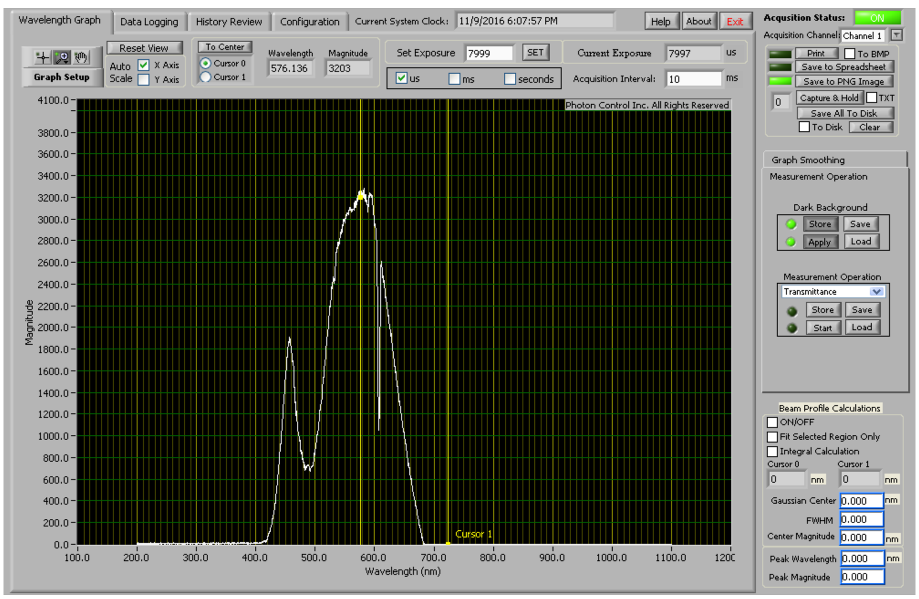

Figure 5: White LED

3.2.2 Analysis

For the two peaks, the data is provided below:

Table 2: Peaks for the White LED

	Peak Wavelength (nm)	Color Temperature (K)	Full Width Half Maximum (nm)		Full Width Half Maximum Range(nm)
			λ_{half1}	λ_{half2}	
Peak 1	456.7133 $\pm$ 0.138	6343.1	442.3876 $\pm$ 0.14	473.8131 $\pm$ 0.14	15.713
Peak 2	575.4412 $\pm$ 0.139	5034.4	515.5447 $\pm$ 0.139	633.8863 $\pm$ 0.139	59.171

And the Black Body radiation (with the unit of W/m^3) for the peak wavelength of white LED is:

$$E_{peak\ 1} = 1.303 \times 10^{14}$$

$$E_{peak\ 2} = 4.104 \times 10^{13}$$

3.2.3 Comparison

The following image contain the plots of incandescent, fluorescent, halogen and white LED sources:

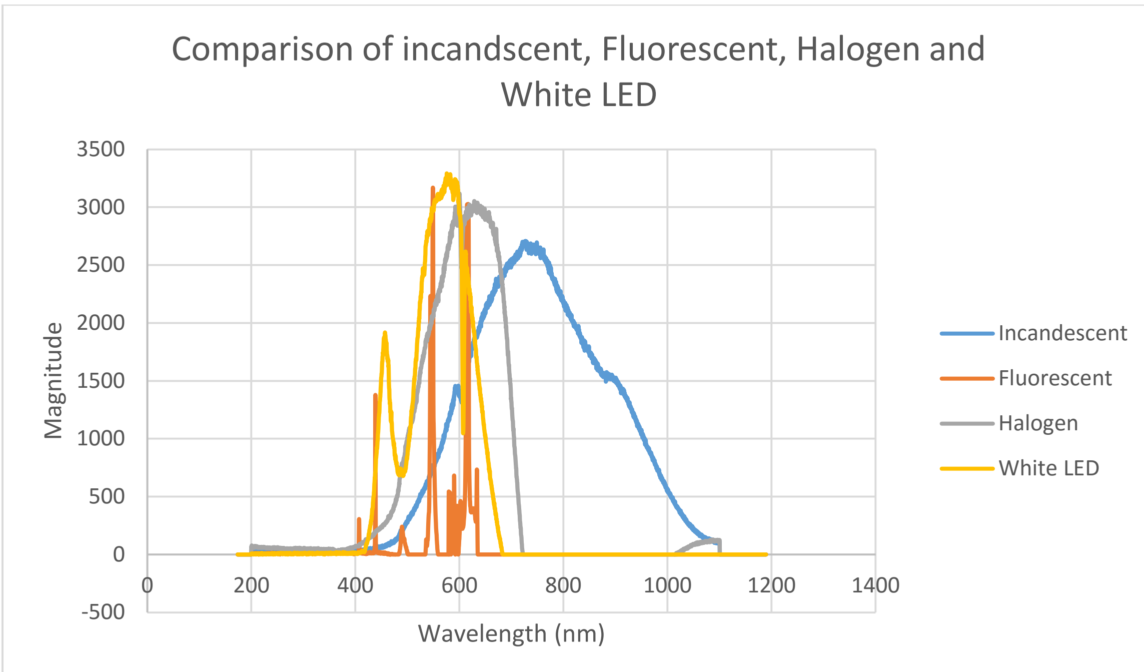

Figure 6: The comparison for the incandescent, fluorescent, halogen and white LED spectrum

So according to the peak wavelength, it is obvious that the Incandescent light source is the warmest one. Then following the Halogen light source. It is hard to tell whether the Fluorescent light source or the White LED light source is warmer since they all have multiple peak wavelength.

Comparing with the sun light, both incandescent and halogen light source has higher light temperature.

3.3 Color LED Spectrum (Jay)

3.3.1 experiment

We used 3 prong source mount to place the Christmas LED light, but the spectrometer didn't catch the light well, since the light intensity of the Christmas light was weak. We set the exposure time to be 79990 for color red and 799900 for color orange to get a better graph.

The figure showing below is the Red LED spectrum.

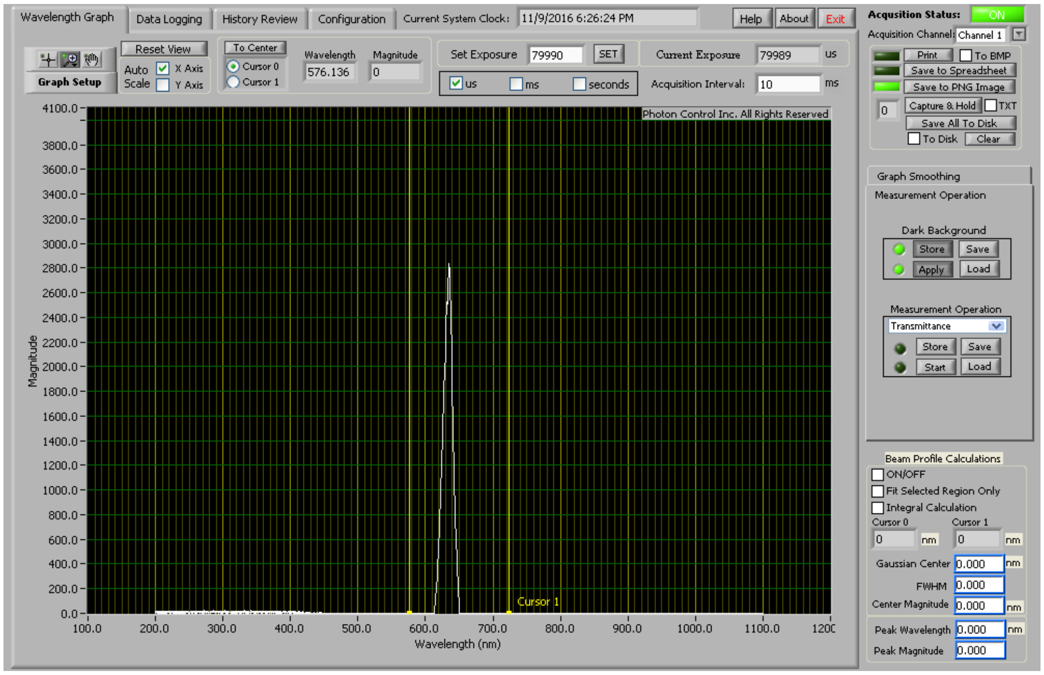

Figure 7: Red LED Spectrum

Our group was assigned to measure the orange Christmas light. The figure showing below is the Orange LED spectrum.

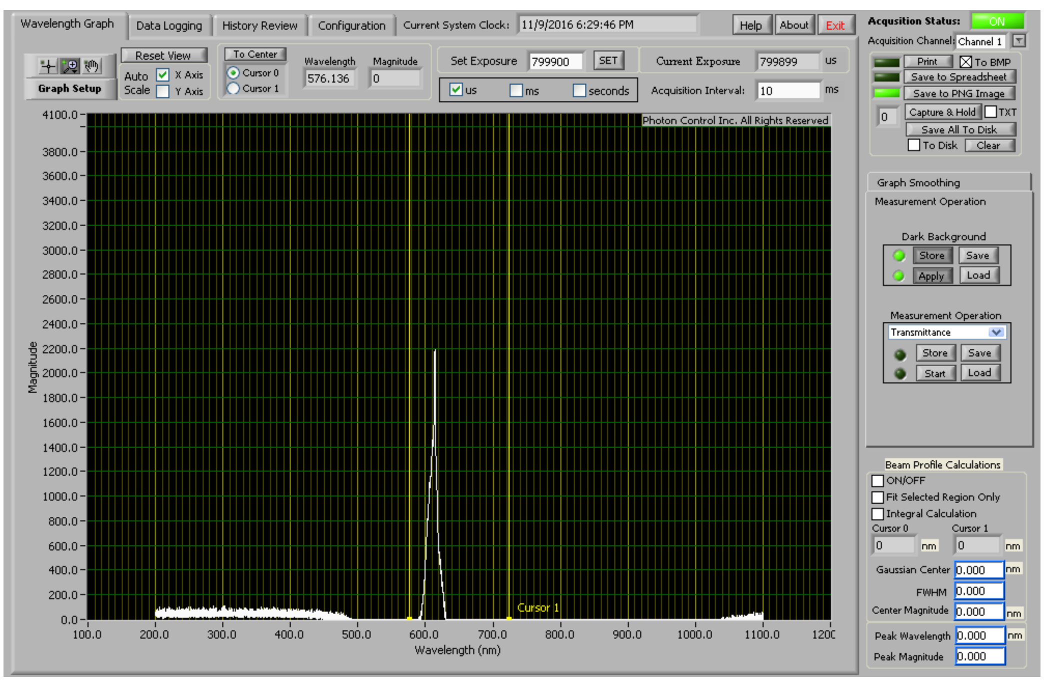

Figure 8: Orange LED Spectrum

Table 3: Parameters for the Colored LED

	Red LED	Orange LED
Peak Wavelength (nm)	634.58	613.96
Color Temperature (°K)	$\frac{2897}{634.58} = 4565.22$	4718.55
FWHM Range (nm)	$639.88 - 625.11 = 14.78$	$616.75 - 606.79 = 9.96$
Symmetry	$0.5 - \frac{634.58 - 625.11}{14.78} = 0.141$	0.220

3.3.2 Discussion

In conclusion, we have the red LED at peak wavelength as the same as the color temperature wavelength, also the orange LED has the same wavelength as the color temperature wavelength. As the symmetry, because we had two weak LEDs, the spectrum we got was partially unstable leads to unstable symmetry value as shown above. But the symmetry value is acceptable.

3.4 IR Remote Control Spectrum (Jay)

3.4.1 Experiment

For this IR remote control experiment, we couldn't get the spectrum at first cause we couldn't hold the controller stable enough to capture the graph. Then, we put the controller on a box to fixed the position, and change the height of the spectrometer. The exposure time we set for this experiment is 10000. The figure shown below is the spectrum for IR remote controller

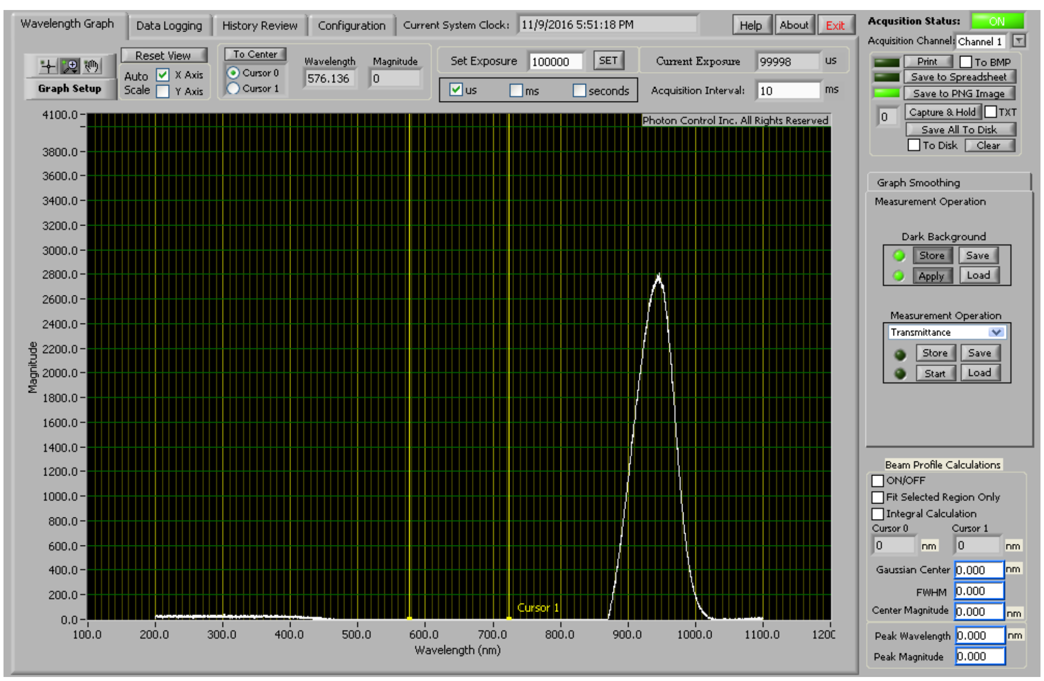

Figure 9: The spectrum for the IR remote controller

Table 4: Parameters of IR remote control

	IR remote control
Peak Wavelength (nm)	943.84
Color Temperature (°K)	$\frac{2897}{943.84} = 3069.38$
FWHM Range (nm)	$972.96 - 904.58 = 68.38$
Symmetry	$0.5 - \frac{943.84 - 904.58}{68.38} = 0.074$

3.4.2 Discussion

The peak wavelength of the IR remote control is sited in the IR wavelength range. And the symmetry of the experiment is low

3.5 Laser source Spectrum

3.5.1 Experimentation

We used an HeNe laser and an Nd:Yag 2nd harmonic green laser pointer for our laser sources. We used the default exposure time of 7999μs to capture both these laser sources.

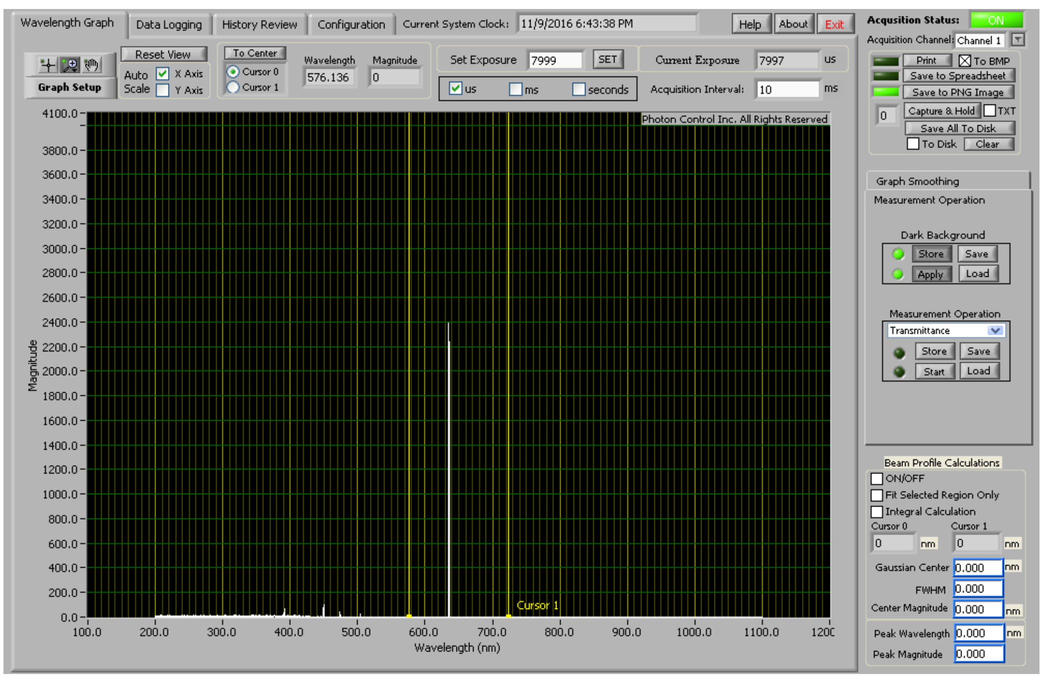

Figure 10: Screenshot of the spectrometer capturing the HeNe laser

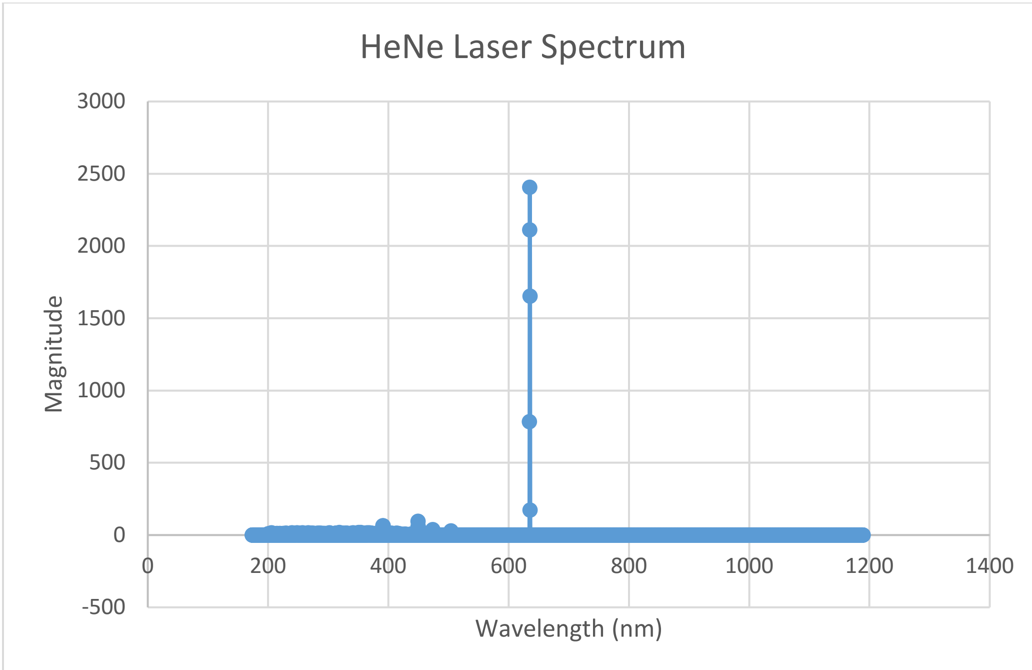

Figure 11: Plot of the HeNe laser spectrum

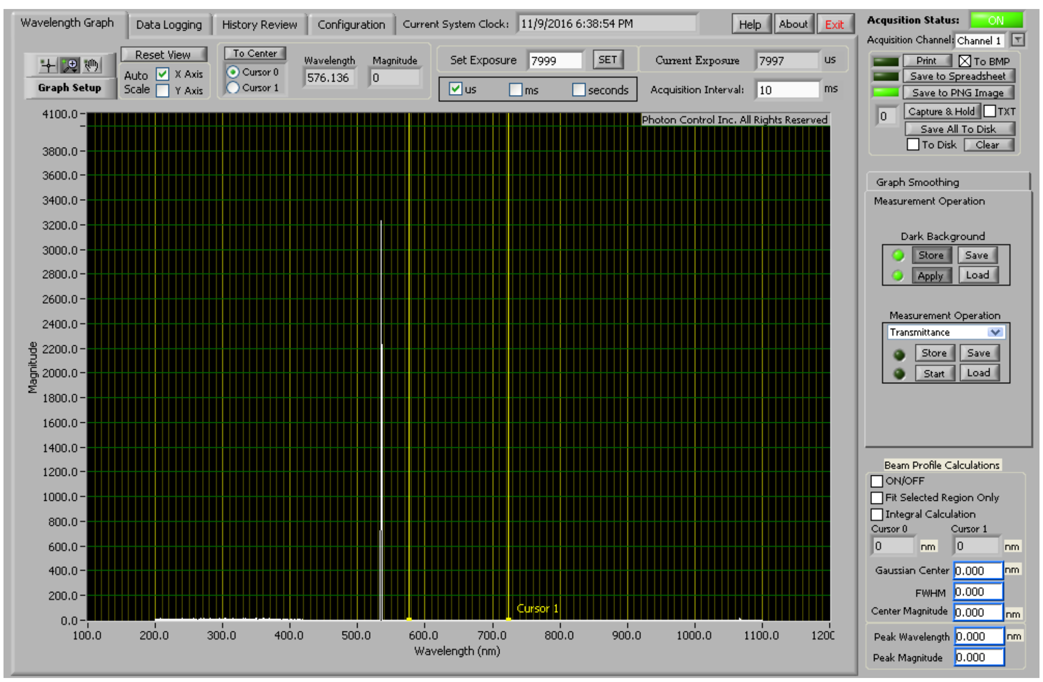

Figure 12: Screenshot of the spectrometer capturing the Nd:Yag 2nd harmonic green laser

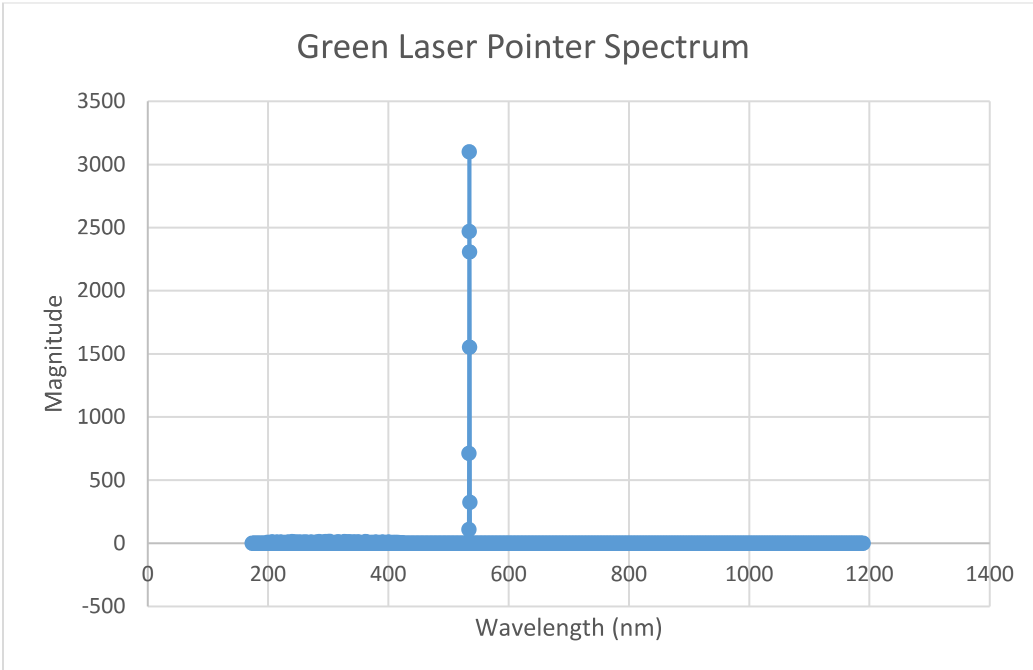

Figure 13: Plot of the green laser spectrum

Table 5 below shows the values for the relevant values calculated for the two laser sources.

Table 5: Laser Source Calculated Values

Light Source	Peak Wavelength (nm)	Colour Temperature (°K)	Full Width Half Maximum (nm)		Full Width Half Maximum (nm)	Coherent Time (ns)
			λ_{half1}	λ_{half2}		
HeNe Laser	635.1409 ± 0.1394	4564.1926	634.8621 ± 0.1394	635.6985 ± 0.1394	0.8364 ± 0.2788	1.6078×10^{-4}
Green Laser	534.7917 ± 0.1386	5417.0624	534.5146 ± 0.1386	535.3459 ± 0.1386	0.8313 ± 0.2771	1.1468×10^{-3}

3.5.2 Discussion

For the HeNe laser the difference between the peak to the short wavelength is 0.2788 nm while the distance from the peak to the long wavelength is 0.5576 nm. So we can tell from these distance values that the HeNe laser is almost two times bigger on the long wavelength side than the short wavelength. It peaks fast, but drops off slower showing a bigger side on the long wavelength side.

For the green laser pointer, the difference between the peak to the short wavelength is 0.2771 nm while the distance from the peak to the long wavelength is 0.5542 nm. It is similar to the HeNe laser in its asymmetry. The green laser is almost two times bigger on the long wavelength side than on the short wavelength.

3.6 Colored Filter Transmission Spectrum

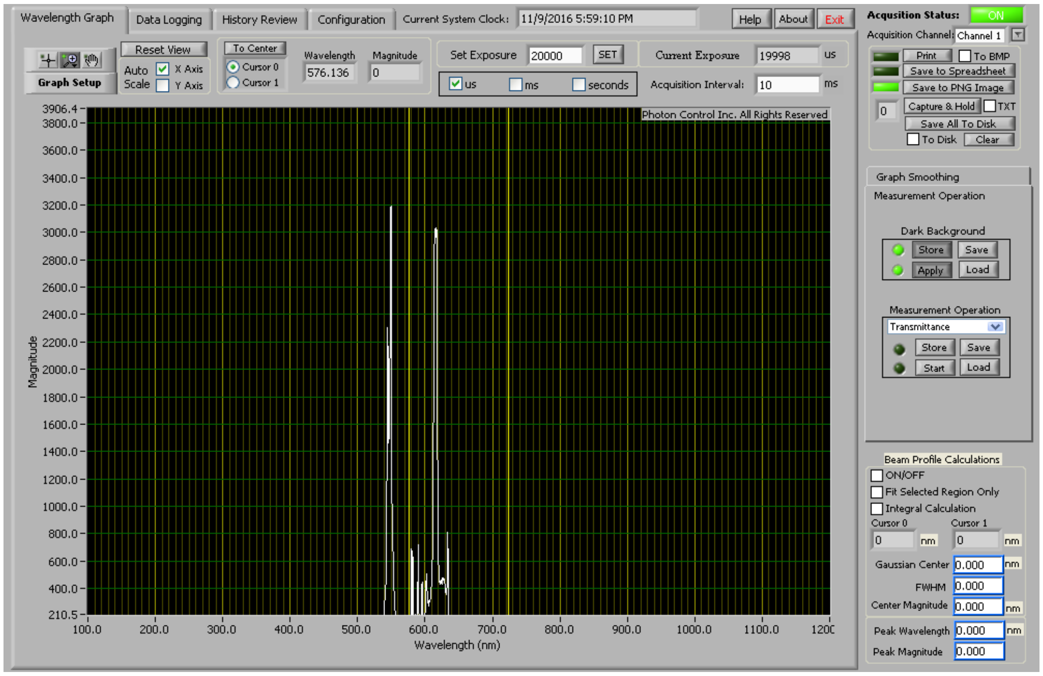

Figure 11: Screenshot of the spectrometer capturing the Fluorescent spectrum filtered by a yellow filter

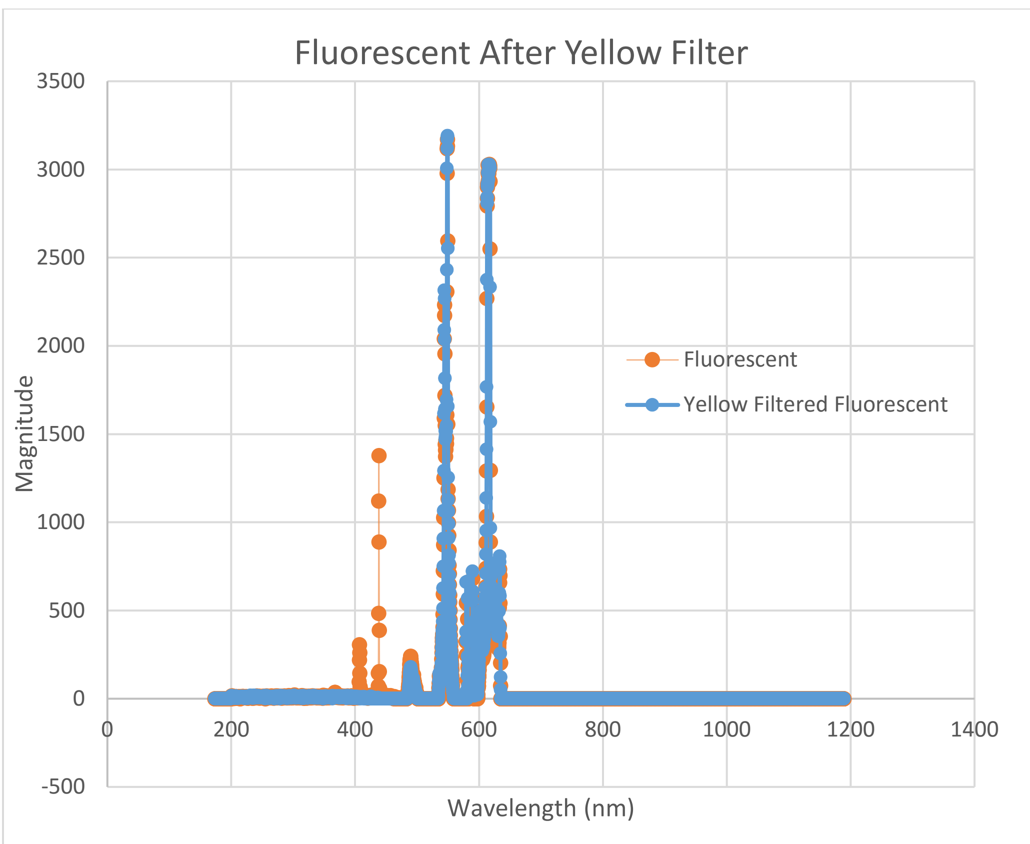

Figure 12: Plot of the fluorescent spectrum after yellow filter

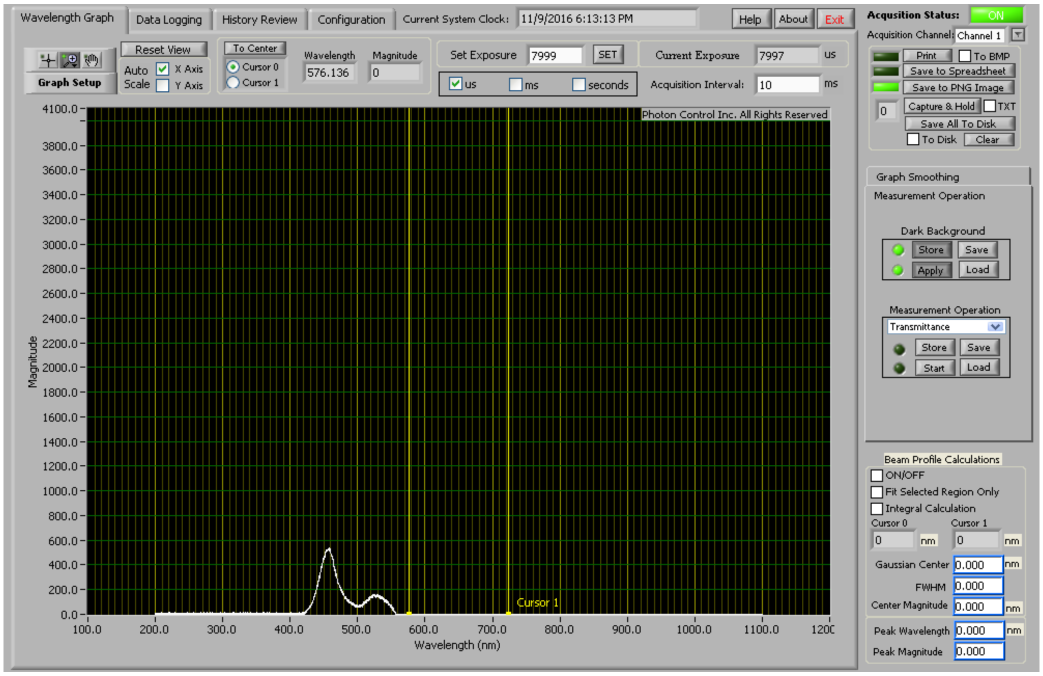

Figure 13: Screenshot of the spectrometer capturing the White LED spectrum filtered by the Nd:Yag laser Goggles

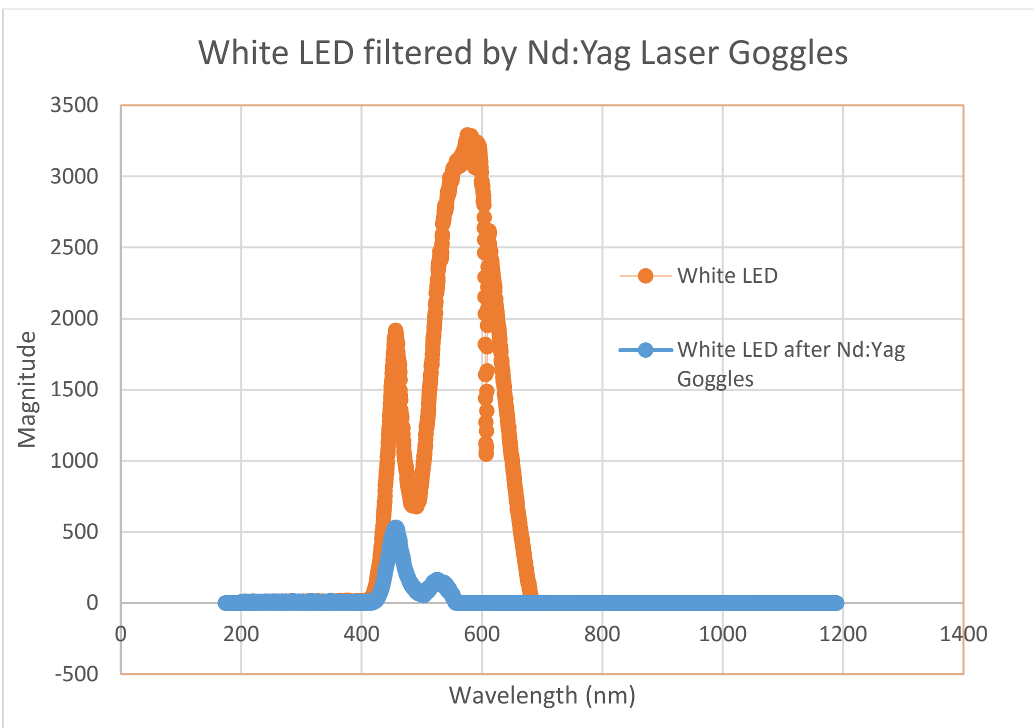

Figure 14: Plot of the White LED spectrum after Nd:Yag goggles filter

Table 6: Filtered Source Calculated Values

Light Source	Peak Wavelength (nm)	Colour Temperature (°K)	Full Width Half Maximum (nm)		Full Width Half Maximum (nm)	Coherent Time (ns)
			λ_{half1}	λ_{half2}		
Fluorescent on Yellow Filter	549.2083 ± 0.1387	5274.8657	547.5441 ± 0.1387	550.0404 ± 0.1387	2.4963 ± 0.2774	4.0277×10^{-4}
White LED on Nd:Yag Laser Goggles	456.5755 ± 0.8269	6345.0623	441.9746 ± 0.2277	470.3639 ± 0.1380	28.3893 ± 0.3657	0.2448×10^{-4}

3.6.1 Discussion

We can see from the comparisons of the fluorescent light and White LED that the filter is working. The superimposed fluorescent light with when it is filtered with the yellow light shows that it cuts out the wavelengths less than 500 nm. This makes sense because the yellow wavelength is around 570 to 590 nm. Therefore, only those wavelengths around those parameters will be shown in the spectrometer because all other wavelengths would be absorbed by the filter.

This also applies to the white LED being filtered by the Nd:Yag goggles. The goggles absorbed most of the white LED except at the 400 to 600 nm range. It also decreased the intensity at those wavelengths by a factor of 4 times.

3.7 Conclusion

When we gathered our light data into the spectrometer we found that it was a bit difficult. There were uncertainties when taking the measurements of the light sources we used. Our data could have been more accurate if the room was pitch black, but this is not allowed inside the lab room.

We found that the incandescent light source was the warmest one followed by the halogen light source. It was hard to distinguish which of the white LED or fluorescent were warmer because of their multiple peak wavelengths.

The colored LED data gathering was difficult as the lights were scattered in different angles because of the design of the Christmas lights. However, we were able to gather the spectrum of these lights after some difficulty. We found that the symmetry of the LEDs were unstable because of the weak light coming from the light source.

For the laser sources our data was not as uncertain because the laser source was beamed directly into the spectrometer. This was proven by the plots showing that the wavelengths matched the expected wavelength for that color. The symmetry for these laser sources were surprisingly not even. They were smaller on the lower wavelength side and bigger in the longer wavelength side. So, even though our plots only show a line, the data suggests that it is actually a lopsided figure.

After using the yellow coloured filter on the fluorescent, we found that it filtered every other wavelength but the yellow wavelength. Which makes sense because since the filter is yellow colored, it means it is absorbing all other wavelengths except the yellow wavelength, thus the yellow color. This also applied to the Nd:Yag goggle filter. Except that the goggles filtered the 400 to 600 nm filter. Which means it should be a blue-greenish color theoretically and it was exactly that color in real life. The goggles also decreased the intensity of the white LED by around a factor or 4.