

# Spectroscopy Laboratory Report

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# 1 Introduction

This set of experiments was aimed at exploring various aspects of spectroscopy. A spectrometer outputting into the Ocean Optics SpectraSuite software was used to capture emission, absorbance and transmission spectra. The investigations included determining the effect of the integration time of a CCD on the captured spectra, comparing the emission spectra of various light sources, determining the spectral characteristics of colored glass filters and determining the effect of the concentration of color additives in solution on the absorbance of that solution for the given color.

## 2 Theory

### 2.1 Spectroscopy

Spectroscopy is the scientific study of spectra of light. A spectrum is a graphical representation of the spectral components of light. In considering the shape of a captured spectrum, the pathway of the light to the detector needs to be considered. Naturally, the pathway of light begins with its emission from a particular source. After emission, light-matter interaction can change the spectrum. Lastly, the interaction of the light with the detector gives the spectrum its final shape.

### 2.2 Emission of Electromagnetic Radiation

Emission sources vary in their emitted spectra. Fundamentally, all emissions of light from a source are linked to a change in the energy state of one or more of the particles of the emitting material. Each energy level change corresponds to the creation of a photon. Disregarding frequency shifts due to the relativistic Doppler effect, the energy within the photon is directly proportional to that photon's frequency. Equation (1) shows the direct relationship mentioned above

$$E = hf. \quad (1)$$

$E$  is the energy in Joules,  $f$  is the frequency of light in  $m^{-1}$ , and  $h$  is Planck's constant with a value of  $6.626070(15) \times 10^{-34} J/s$  (1).

### 2.3 The Two-Level System

The energy that goes into the creation of a photon is in some cases due to an electronic energy level transition. Disregarding the relativistic Doppler effect once again, the energy carried by the photon is exactly equal to the energy difference between the initial electron energy and the final electron energy. This is represented by equation [2] below

$$hv = \Delta E = |E_i - E_k|. \quad (2)$$

When considering a simple two-level system, where the electron has the option of being on one of two nondegenerate energy levels, there are two overall possibilities – absorption of a photon by the electron to go from the lower energy level to the higher one and emission of a photon when the electron drops from the higher one to the lower one. The possibilities are shown in figure 1.

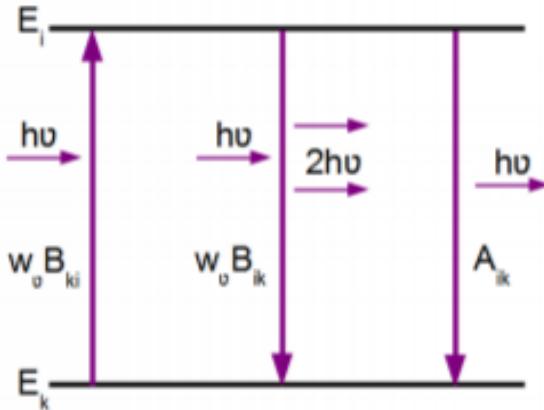


Figure 1: Electronic Energy Transitions in a Two Level System

The two energy levels are separated by the energy difference  $\Delta E = E_i - E_j$ . Possible electronic energy transitions are spontaneous emission  $A_{ik}$ , where the electron drops from the higher energy level  $E_i$  to the lower energy level  $E_k$  and emits a photon, absorption  $B_{ki}$ , where the electron absorbs a photon with energy equal to the energy difference  $\Delta E$ , or stimulated emission  $B_{ik}$ , where a passing photon causes an energy level change from  $E_i$  down to  $E_k$  and the emitted photon adds constructively with the passing photon.

The emission spectrum of a two level system is a single wavelength. A material has multiple energy levels that electrons can jump between. The emission of light due to these jumps forms a discrete emission spectrum. Furthermore, when a continuous spectrum is incident on a material with such quantized energy levels, certain photons corresponding to the energy difference between the levels will be absorbed. The spectrum, after passing through this material, will have absorption lines, or "holes," corresponding to these absorbed photons.

Actual observed spectra are subject to line broadening. This line broadening takes the shape of making a peak a Lorentzian, Gaussian, or a convolution of both called a Voigt profile. The shapes are shown in Figure 2.

Lorentzian lineshapes are much narrower than Gaussian lineshapes of the same height. Lorentzian lineshapes are due to natural broadening stemming from the Heisenberg uncertainty principle. This natural broadening is ever present, no matter the emission source. Lorentzian lineshapes can also be influenced by collisional broadening. When gas atoms collide, the kinetic energy from one atom can change the energy of the electrons of the other. This results

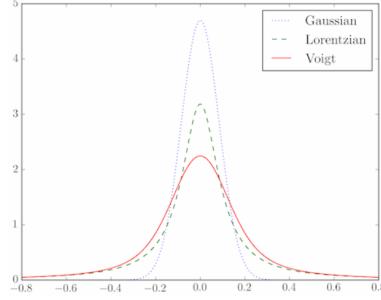


Figure 2: A Gaussian, Lorentzian and Voigt Lineshape

in a broader lineshape. Gaussian lineshapes are due to the thermal motions of electrons resulting in a frequency shift due to the relativistic Doppler effect. Voigt profiles are due to the presence of the conditions necessary for both Lorentzian and Gaussian lineshapes.

A second kind of important emission spectrum is the continuous spectrum stemming from black-body radiation. The distribution of the emitted wavelengths follows Planck's law, written in Equation (3)

$$W_v(v)dv = \frac{8\pi h v^3}{c^3} \frac{dv}{e^{\frac{hv}{kT}} - 1}, \quad (3)$$

where  $W_v(v)$  is the spectral density. As can be seen from the equation, the emission spectrum is continuous and depends on the temperature of the emission body. General black-body radiation spectrum is shown from the figure below.(?) In practice, solid, liquid and high pressured vapor will generate continuous spectrum due to thermal radiation. Based on this theory, we used halogen lamp which can generate continuous spectrum for spectrum measurement.

## 2.4 Beer-Lambert Law and Absorbance

The Beer- Lambert Law describes the attenuation of a light source when light travels through an absorbing material. It can relate the transmission of the intensity of the light to the material property that the light travels through and the depth of the material the the light penetrates through.

There are three major forms of light-matter interactions: transmission, absorption, and reflection. The general light-matter interaction can be expressed by the complex refractive index as in equation (4)

$$N = n + i\kappa, \quad (4)$$

where  $n$  is the refractive index in the spectral region where the material appears to be transparent to the light source, and  $\kappa$  is the extinction coefficient that relates to the energy loss, also known as the absorption of the light source in

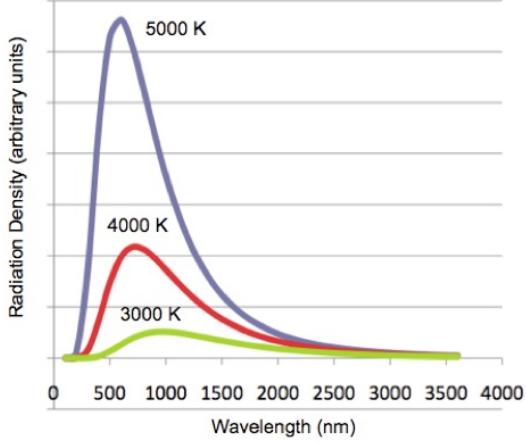


Figure 3: Black-body Radiation Spectrum

the material. From this complex refractive index, we could find the absorption coefficient of the material, which is defined as in equation (5)

$$\alpha = \frac{4\pi\kappa}{\lambda_0}, \quad (5)$$

where  $\lambda_0$  is the wavelength in vacuum.

In a solution, the absorption coefficient is defined as in equation (6)

$$\alpha = \epsilon_l c, \quad (6)$$

where  $\epsilon_l$  is the extinction coefficient of the solution, and  $c$  is the concentration of the solution.

The Beer-Lambert Law written in equation (7) states that:

$$\frac{\Delta I}{I_0} = -\alpha \Delta b \quad (7)$$

where  $I_0$  is the initial light intensity before going through the material,  $\Delta I$  the change of intensity when the light passes through  $\Delta b$  depth of the material.

The final Beer-Lambert Law after integration on both sides yields equation (8)

$$I(b) = e^{-\alpha b}. \quad (8)$$

Based on the definition of light transmission through a material, which is the ratio of the intensity of light actually passing through the material, and the initial intensity of the light, we can derive the definition of an important property of spectroscopy: the absorbance. This is given in equation (9)

$$A = \log_{10}\left(\frac{1}{T}\right) = \epsilon cb, \quad (9)$$

where  $T$  is the transmission coefficient of the material,  $c$  the concentration of the solution, and  $\epsilon$  the wavelength dependent absorption coefficient of the solution. From the equation above, we can determine the concentration of a solution to the absorbance measured from a spectrum by following equation (10)

$$c = \frac{A}{\epsilon b}. \quad (10)$$

The transmission of the material  $T$  is defined as the ratio of the transmitted intensity of light to the initial intensity of the light.

Since absorbance of a solution and the concentration of the solution has linear connection, we can estimate coefficient  $\epsilon$  with multiple measurements of  $c$  and  $A$  of the solution.

## 2.5 Spectrometer

### 2.5.1 General Set up

Optical spectrometer is a device designed to record the intensity distribution of a light source according to their wavelengths. As Figure 4 shows, a spectrometer is composed of a collimating mirror that collimates the incoming light from light source to the grating component. The grating component decompose the collimated light source into component of various wavelengths. The dispersed light travels to a focusing mirror, after which the focused light is then detected at the exit slit by a CCD camera or other light detecting sensor.

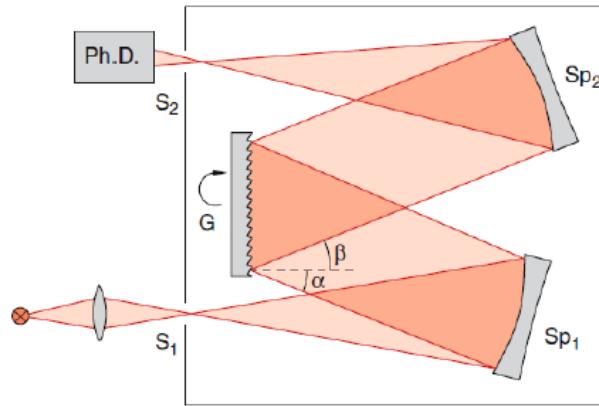


Figure 4: Spectrometer setup

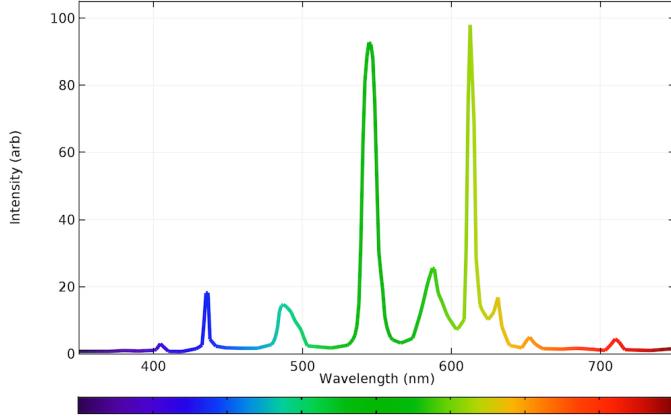


Figure 5: Emission Spectrum of Fluorescent Bulb

From the fundamentals of geometry, we may find the relation between spacial separation  $\Delta x$  and the wavelength distance  $\Delta\lambda$  as in equation (11)

$$\Delta x = x(\lambda + \Delta\lambda) - x(\lambda) = f_2 \frac{dy_g}{d\lambda} \Delta\lambda, \quad (11)$$

where  $f_2$  is the focal length of the collimated and focusing lenses of the system, and  $\frac{dy}{d\lambda}$  is the dispersion of the grating, where  $g$  is the grating index. Even though there are different mechanisms to decompose light components, a grating spectrometer was used in this experiment, due to higher resolution of wavelength than the spectrometer can detect.

The spectral resolution of a grating spectrometer is given as in equation (12)

$$R = m \times K, \quad (12)$$

where  $m$  is the interference order, and  $K$  is the number of illuminated grating grooves.

### 2.5.2 Emission, Absorbance, and Transmission Spectrum

An optical spectrometer can be used to record different spectrum that result from different kinds of light matter interaction.

Figure 5 below (7) is a typical emission spectrum of a fluorescent light bulb. From an emission spectrum, the wavelength components of the light source can be analyzed. In this example, one can conclude from the emission spectrum that the energy emission of a fluorescent light bulb is quantized, resulting in several peaks at certain wavelengths.

Figure 6 below shows a typical absorption spectrum measured by spectroscopy. Unlike an emission of a light source, the absorption spectrum, especially in a solution, has the feature of broad band instead of spectrum with

distinguishable peaks. This is due to the fact that the absorbing molecule in a solution is surrounded by solvent molecules, which constantly dissolve and rejoin. This affect the energy level of the molecules differently for different absorbing components in the solution, resulting in a broad band spectrum.

micro red Halogen Absorbance Spectrum.png

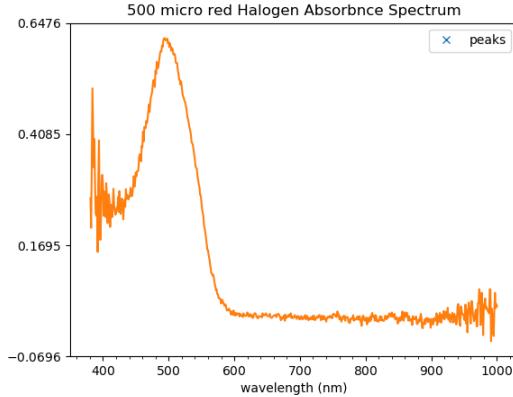


Figure 6: Typical Absorption Spectrum

Figure 7 below shows a typical transmission spectrum of a filtered glass. Based on the range of wavelength the different filter transmits through, transmission spectrum can be categorized as long pass filter and band pass filter. Figure 7 is an example of long pass filter.

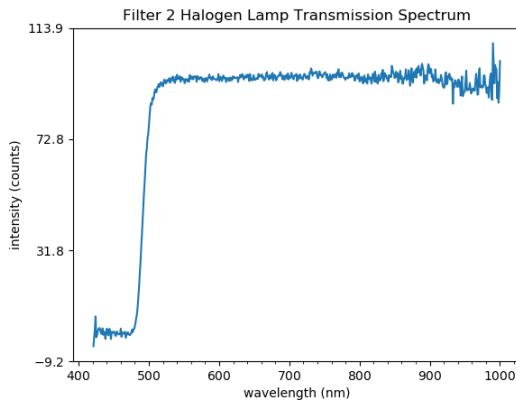


Figure 7: A Long Pass Transmission Spectrum

## 2.6 Colored Light Emitting Diodes (LEDs)

Light Emitting Diodes (LEDs) are important semiconductor devices. The LED consists of a p-n junction. Upon application of a current across the junction, electrons from the n-doped semiconductor travel to the p-doped semiconductor and fall into the valence band. This energy transition causes an emission of light. The peaks in the spectrum of the LED correspond to the energy difference between the conduction band and the valence band. This energy difference can be tuned for a particular wavelength by tuning the semiconductor's material properties.

The peak in the emission spectrum of the LED is much narrower due to this tuning of the bandgap. Typical emission spectra of colored LED's are shown in figure 8 (4).

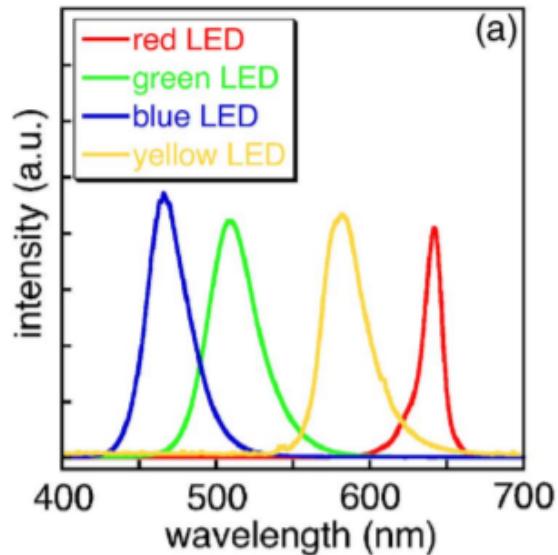


Figure 8: LED Spectra

## 2.7 White LED and Fluorescent Room Lights

White LEDs and fluorescent mercury vapour lamps are two options for room lighting in a laboratory. The spectra of these two are shown in Figure 9 (4).

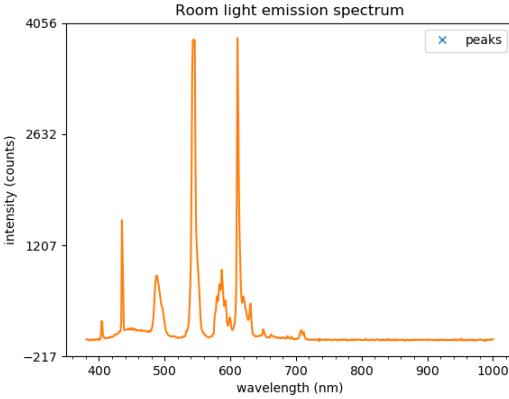


Figure 9: Typical Room Lighting Spectra

### 3 Experimental Procedures

#### 3.1 General Setup

The general setup consisted of an emission source shining light into optical fibers that led into a Red Tide USB650 grating spectrometer. The grating spectrometer had a CCD camera that converted incident photons on its pixels into counts that were communicated with a USB cable to a Windows computer running the Ocean Optics SpectraSuite software. Figure 10 below shows a picture of the general setup.

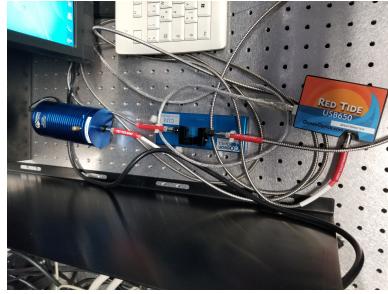


Figure 10: Experimental Setup

In the picture a halogen lamp is being used as a light source, and a stage that can be used to filter the emission source's light has been inserted between the lamp and the spectrometer. The inside of the spectrometer is shown in Figure 11 below.

The optical cable shines light onto a mirror which reflects it onto a grating. The second diffraction order lands on a second mirror and is reflected onto

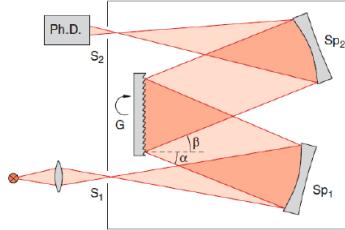


Figure 11: The Interior of the Grating Spectrometer. Image taken from Lab Handout.

a detector, in this case a CCD camera. The grating spatially separates the wavelengths within the signal and leads them onto different pixels in the CCD. This is shown in Figure 12 below.



Figure 12: Ocean Optics Spectrometer

In the experiments that follow, a color filter or color additive solution is placed in the filtering stage and analyzed in the SpectraSuite software. A schematic of the general setup is shown in Figure 13 below.

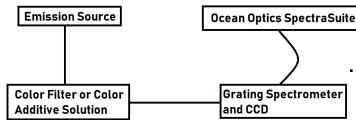


Figure 13: General Setup for all Experiments.

The straight lines in the figure above represent light transmission through optical fibers, whereas the curved line represents the output of the CCD being communicated to a computer with an electronic cable. Light is generated in the emission source, can be filtered by the color filter or color additive solution, and is analyzed by the spectrometer. The SpectraSuite software is able to tune the integration time of the CCD and can compute absorption and transmission

spectra from the measured spectrum on the CCD, which is given in counts per wavelength.

### 3.2 CCD Integration Time Investigation

The first part of the experiment involved determining the effect of changing the integration time of the CCD in the SpectraSuite software. The spectrum of a halogen lamp was recorded with an integration time of 100 milliseconds. The integration time was incrementally decreased until it was at 20 milliseconds, with the effect being determined. At 20 milliseconds the halogen lamp spectrum was once again recorded.

### 3.3 Absorption and Transmission of Colored Glass Filters

A Thorlabs FGK01S set of 2" by 2" square colored glass filters was investigated. First, the shutter on the halogen lamp was shut and the dark spectrum was recorded. The spectrum of the halogen lamp was recorded with the dark spectrum subtracted. Filter 1, a filter transparent to all wavelengths of light able to be analyzed by the Red Tide USB650 spectrometer, was put into the filter slot as a reference filter. As it was noticed that any tilt to the filter would alter the shape of the spectrum, the group chose to stand the filter upright and flush against the lower side of the filter stage, as shown in Figure 14 below.

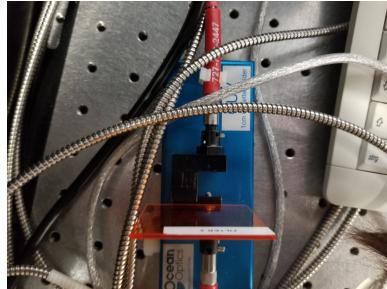


Figure 14: Method of Placing Color Filters in Holder

All filters were placed like this into the stage in order to have their reflections be similar. The reference spectrum was saved into the program. The group recorded the spectrum, absorption spectrum, and transmission spectrum of filters labeled two, three, four and five. From the transmission spectra on SpectraSuite, these were classified as either bandpass or longpass optical filters. Using the spec sheet of the optical filter kit, the filters were matched according to their transmission spectra with the filter's product numbers as listed by ThorLabs. Two longpass filters, Filters 3 and 4, were used at the same time in order to determine the effect on the cutoff wavelength. Lastly, using trial and error, a bandpass filter passing light roughly in the 500-700 nanometers was created by using two of the filters in the kit.

### **3.4 Absorption in Color Additive Solutions**

The second part of the experiment involved placing color additive solutions filled into a cuvette in the filtering stage and measuring the resulting absorption spectra. A halogen lamp was used as a light source. A reference spectrum was found by placing a cuvette filled with 1 mL of water into the filtering stage and saving the reference spectrum into the program. Then .2 mL of blue food coloring was added to the cuvette. When the solution was homogeneous, the cuvette was placed into the filtering stage and the absorption spectrum was recorded. This was repeated until the total volume of the solution in the cuvette was 2 mL. A cuvette with an unknown amount of blue food coloring mixed with water was then placed into the filtering stage. The absorption spectrum was recorded.

The effect of mixing two color additives into the same solution was investigated next. The colors used were red and purple. Two cuvettes were prepared, both containing a solution that had 1 mL of water and roughly .5 mL of the respective color additive. The group was only interested in the location of the peaks of the absorption spectrum. Next, roughly .5 mL of purple dye was added to the cuvette containing the red solution. The absorption spectrum of this new solution was recorded.

### **3.5 Emission Spectra of Light Sources**

The third part of the experiment consisted of measuring the emission spectra of various sources in order to qualitatively compare them. The filtering stage was omitted for these measurements, and the light of the sources was coupled into the fiber by aiming the fiber at the various sources. The spectra which the group recorded were of a halogen lamp, room light, white LED, yellow LED, red LED, blue LED, blue LED on the Cooler Master desktop, red laser, green laser, and the LCD computer monitor showing the color white. The peaks of the spectra were then read from the spectra as well as linewidths whereever possible.

## **4 Results**

### **4.1 CCD Integration Time Investigation**

Longer integration times lead to higher photon counts in a linear manner. Furthermore, pixel saturation for a given wavelength manifesting itself at around 4000 counts was observed for integration times that were too high given the source brightness. Besides there being a maximum number of counts able to be registered by the CCD, there was a roughly direct proportionality observed between the integration time and the counts per wavelength. The characteristic peaks of the spectrum did not change and their relative intensities were not impacted by the integration times, with the exception of the wavelengths that had

reach the maximum photon counts. The signal-to-noise ratio was not observed to necessarily increase with higher integration times.

## 4.2 Absorption and Transmission of Colored Glass Filters

### 4.2.1 Software Setup

The group obtained the dark spectrum shown in Figure 15 below.

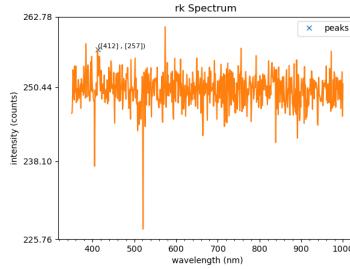


Figure 15: Dark Spectrum of CCD

The halogen lamp spectrum taken after the dark spectrum was subtracted is shown in Figure 16 below.

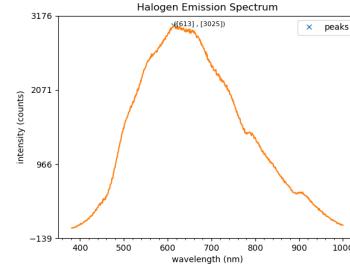


Figure 16: Halogen Emission Spectrum

The reference filter spectrum is shown in Figure 17 below.

### 4.2.2 Filter 2 Identification

The spectrum of Filter 2 is shown in Figure 18 below.

The absorbance spectrum of Filter 2 is shown in Figure 19 below.

The transmission spectrum of Filter 2 is shown in Figure 20 below.

This transmission spectrum is characteristic of a longpass wavelength filter. When compared to the spec sheet from ThorLabs, this resembled the transmission spectrum of FGL495S.

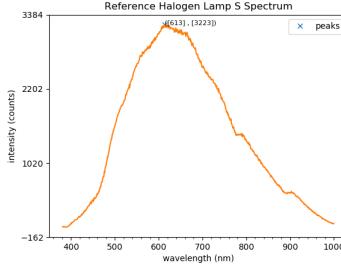


Figure 17: Reference Spectrum

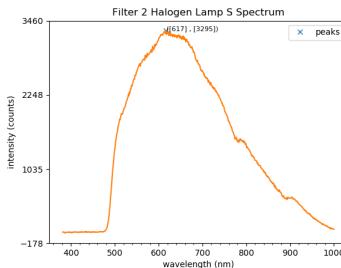


Figure 18: Halogen Lamp with Filter 2 Spectrum

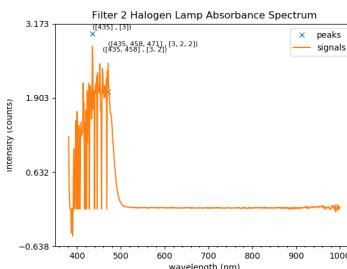


Figure 19: Filter 2 Absorbance Spectrum

#### 4.2.3 Filter 3 Identification

The spectrum of Filter 3 is shown in Figure 21 below.

The absorbance spectrum of Filter 3 is shown in Figure 22 below.

The transmission spectrum of Filter 3 is shown in Figure 23 below.

This transmission spectrum is characteristic of a longpass wavelength filter. When compared to the spec sheet from ThorLabs, this resembled the transmission spectrum of FGL550S.

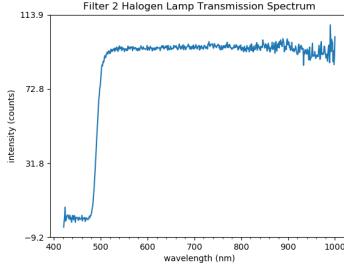


Figure 20: Filter 2 Transmission Spectrum

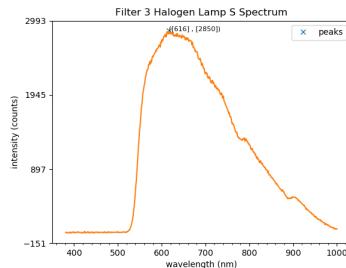


Figure 21: Filter 3 Spectrum

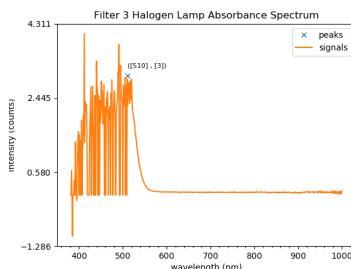


Figure 22: Filter 3 Absorbance Spectrum

#### 4.2.4 Filter 4 Identification

The spectrum of Filter 4 is shown in Figure 24 below.

The absorbance spectrum of Filter 4 is shown in Figure 25 below.

The transmission spectrum of Filter 4 is shown in Figure 26 below.

This transmission spectrum is characteristic of a longpass wavelength filter. When compared to the spec sheet from ThorLabs, this resembled the transmission spectrum of FGL610S.

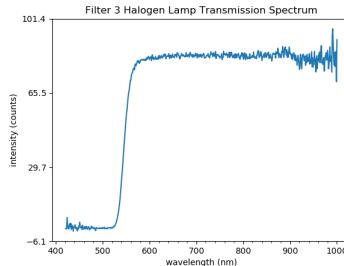


Figure 23: Filter 3 Transmission Spectrum

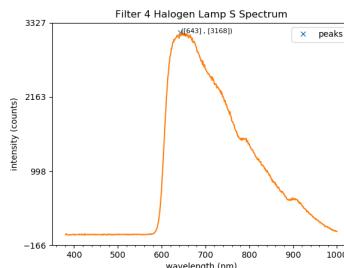


Figure 24: Filter 4 Spectrum

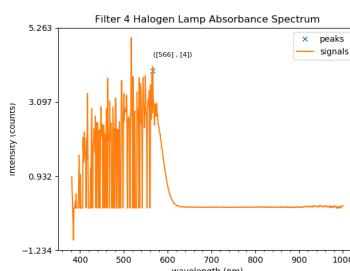


Figure 25: Filter 4 Absorbance Spectrum

#### 4.2.5 Filter 5 Identification

The spectrum of Filter 5 is shown in Figure 27 below.

The absorbance spectrum of Filter 5 is shown in Figure 28 below.

The transmission spectrum of Filter 5 is shown in Figure 29 below.

This transmission spectrum is characteristic of a longpass wavelength filter. When compared to the spec sheet from ThorLabs, this resembled the transmission spectrum of FGL780S.

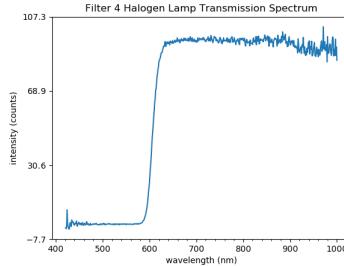


Figure 26: Filter 4 Transmission Spectrum

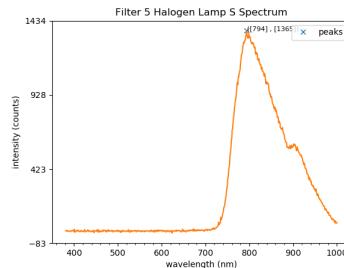


Figure 27: Filter 5 Spectrum

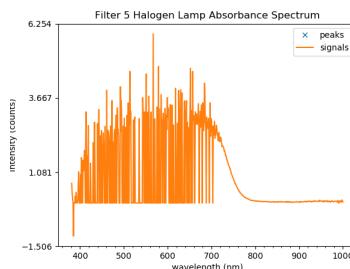


Figure 28: Filter 5 Absorbance Spectrum

#### 4.2.6 Effects of Two Filters

The group combined Filters 3 and 4 and recorded the transmission spectrum shown in Figure 30 below.

The new cutoff wavelength was measured to be at  $590 \pm 10$  nanometers.

In order to create a bandpass filter that passed wavelengths between 500 and 700 nanometers, the group combined Filters 2 and 7. The transmission spectrum is shown in Figure 31 below.

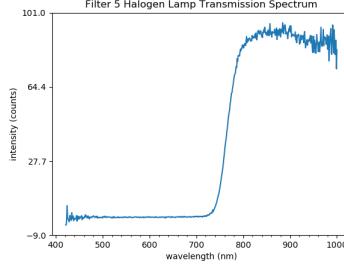


Figure 29: Filter 5 Transmission Spectrum

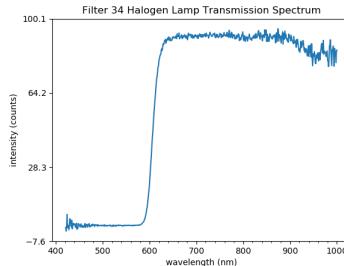


Figure 30: Combination of Filter 3 and Filter 4 Transmission Spectrum

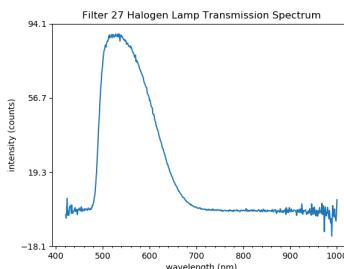


Figure 31: Filter 2 and Filter 7 Transmission Spectrum

### 4.3 Absorption in Color Additive Solutions

The width of the plastic cuvette we used is  $5 \pm 0.1\text{mm}$ , the absorption spectrum we measured for blue-dyed solution with different concentration excluding the noisy spectral ranges is shown in the Figure 32 below.

We can calculate the transmission of each solution from the relation below:

$$T = \frac{I_T - I_d}{I_0 - I_d} \quad (13)$$

solution absorbance result.png

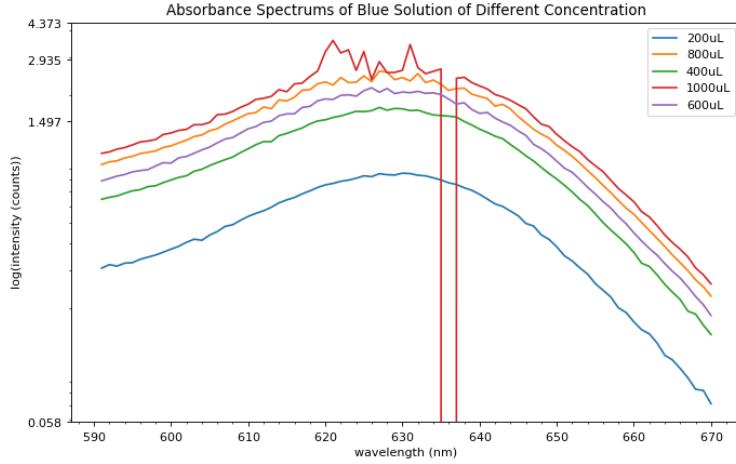


Figure 32: Absorption Spectrum of Blue Dyed Solution with Different Concentration

where  $I_T$  can be calculated from subtracting the reference water spectrum and the absorption spectrum.

With the transmission of each solution, we could find the abosrbance of the solution with the relation below:

$$A = \log\left(\frac{1}{T}\right) \quad (14)$$

For each solution, we selected the peak value of the spectrum and their corresponding wavelength to measure the absorbance of the solution. The result of wavelength , maximum intensity, reference intensity, dark intensity , transmission, and absorbance, to the corresponding solution were calculated by Python and is shown in the Table 1 below.

Solution	200 ml	400 ml	600 ml	800 ml	1000 ml
Wavelength nm	$630 \pm 5$	$627 \pm 5$	$626 \pm 5$	$627 \pm 5$	$627 \pm 5$
Absorption Intensity	$0.857 \pm 0.1$	$1.743 \pm 0.1$	$2.156 \pm 0.1$	$2.579 \pm 0.1$	$2.858 \pm 0.1$
Reference Intensity	3.763	3.722	3.744	3.722	3.753
Absorbance	0.122	0.302	0.417	0.59	0.735

Table 1: Experiment Data of Blue Dye Solution Absorption Spectrum

We plotted the values of absorbance calculated from the table above, as shown in Figure 33 and evaluated the result with Scipy's linear fit method, we can see that the linear relation of the absorbance and the concentration of the blue dye solution.

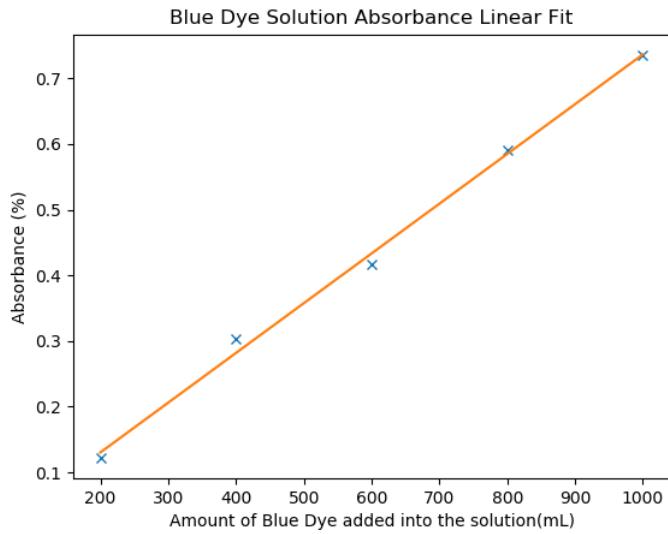


Figure 33: Blue Solution Absorbance Linear Fit Result

The scipy program calculated that the slope of the line is 0.00075, the interception is  $-0.021$ , the p value is  $0.99 \times 10^{-5}$ , the standard deviation of the data points from the fitted line is  $2.581 \times 10^{-5}$ .

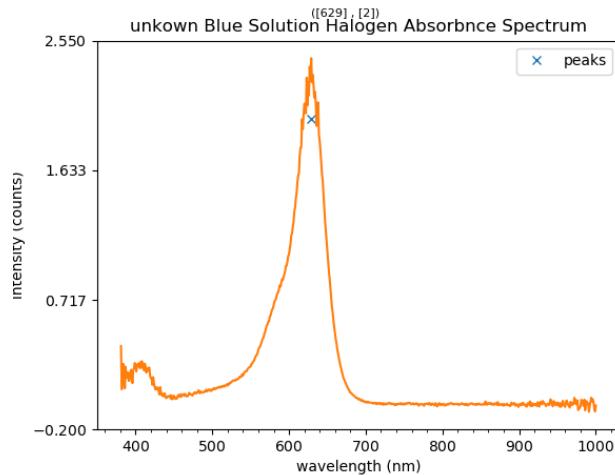


Figure 34: Unknown Blue Solution Halogen Absorbance Spectrum

From Python's data analysis program, we can find that the peak absorption

happened of the unknown solution happens at wavelength  $629\text{nm}$  with an absorption intensity of 2.425 counts. From Equation 13), our reference data and dark spectrum, we can calculate the absorbance of the blue dye with unknown concentration.

$$A_{\text{unknown}} = 0.452 \quad (15)$$

With equation 10) from the theory section, we can calculate the volume of blue dye added to the original solution.

$$V_{\text{unknown}} = 597\text{mL} \quad (16)$$

## 4.4 Emission Spectra of Light Sources

### 4.4.1 Halogen Lamp and Mercury Vapor Lamp

The measured emission spectrum of the Halogen lamp is shown in figure 35.

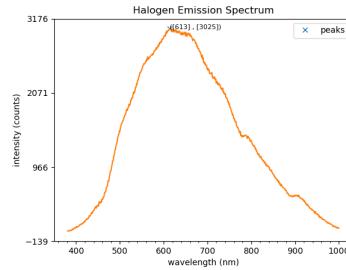


Figure 35: Halogen Lamp Emission Spectrum

The measured emission spectrum of the room light is shown in figure 36.

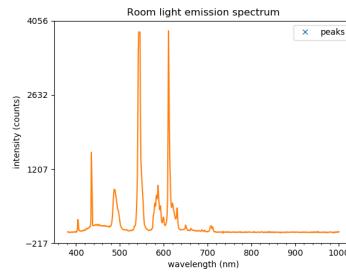


Figure 36: Room Light Emission Spectrum

The five most prominent peaks from left to right are located at points [434 nm, 15131 counts], [487nm,837 counts], [543.82nm, 3855 counts], [587nm,906.67 counts], and [610nm, 387.8 counts] by our Python program. As our measured

room light spectrum is with close fit with the room light spectrum of literature, we can conclude that the type of light source of the room light in the lab is made out of vapor mercury. The most prominent peaks in the spectrum are mercury absorption spectrum, and the other prominent peaks correspond to the absorption peaks of different chemical that are involved in the chemical reaction process.

#### 4.4.2 Laser Spectra

The measured emission spectrum of the red laser is shown in figure 37 .

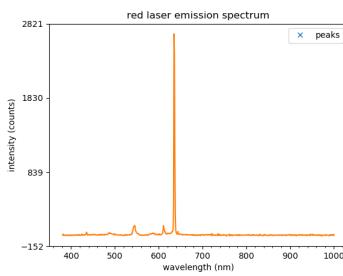


Figure 37: Red Laser Emission Spectrum

The peak is at 635 nanometers. The FWHM is found to be  $2 \pm 1$  nanometers. The measured emission spectrum of the green laser is shown in figure 38 .

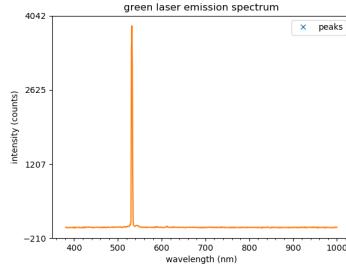


Figure 38: Green Laser Emission Spectrum

The peak is at 532 nanometers. The FWHM is found to be  $2 \pm 1$  nanometers.

#### 4.4.3 LED Spectra

The measured emission spectrum of the red LED is shown in figure 39.

The peak of the red light LED is 685 nm with a FWHM of 70 nm. The measured emission spectrum of the blue LED is shown in figure 40 .

The peak of the blue LED is 436 nanometers with a FWHM of 30 nanometers.

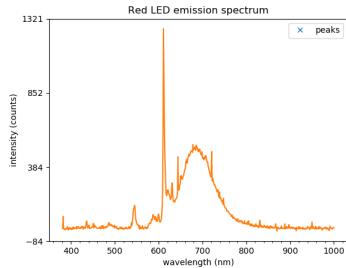


Figure 39: Red LED Emission Spectrum

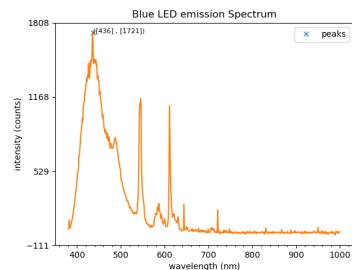


Figure 40: Blue LED Emission Spectrum

The emission spectrum of the yellow LED is shown in figure 41.

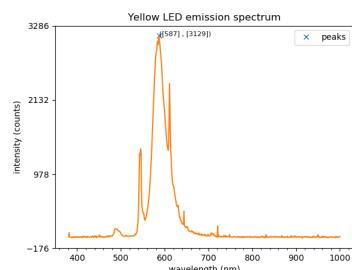


Figure 41: Yellow LED Emission Spectrum

The emission spectrum of the white LED is shown in figure 42.

The peaks are at 454 nm with a linewidth of 31 nm and 544 nm with a linewidth of 100 nm.

The emission spectrum of the white computer screen is shown in figure ???.  
The only peak not included in the room light spectrum is at 445 nm.

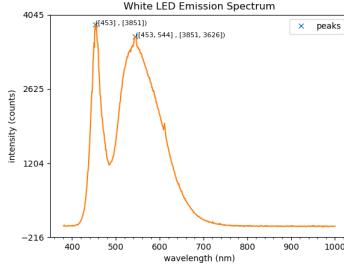


Figure 42: White LED Emission Spectrum

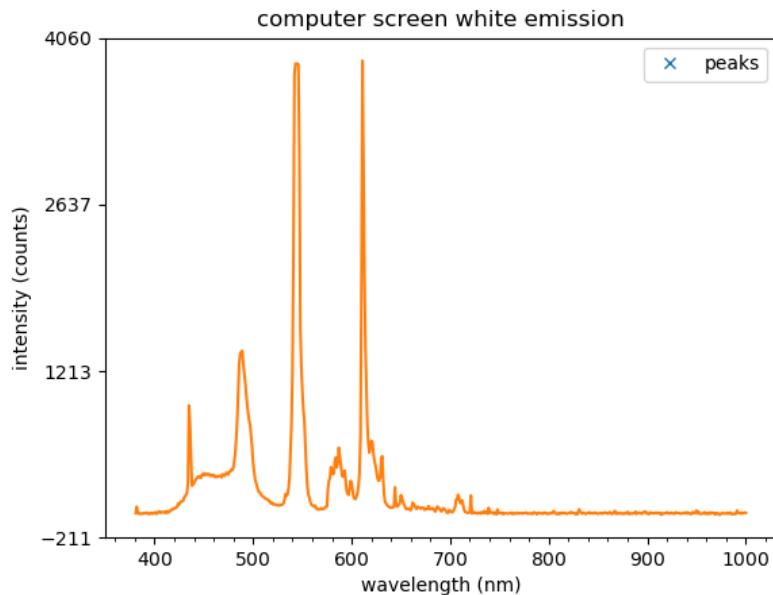


Figure 43: Computer Screen Emitting White Light Spectrum

## 5 Discussion

### 5.1 CCD Integration Time Investigation

The effect of changing the CCD Integration Time was found to be analogous to the effects of altering the shutter position of the light source, which limits the amount of photons incident on the CCD. When the light source has a perfectly stable brightness, or the light source is giving off the same amount of photons in each unit of time, the integration time should be directly proportional to the counts registered in the program up until the effect of pixel saturation can be

observed. The conclusion of the investigation is that altering the integration time is a tool most useful for avoiding pixel saturation for a given wavelength, which would otherwise obscure the peak wavelength(s) of a spectrum. The self-calculated transmission and absorption spectra matched the computer simulated ones.

## 5.2 Absorption and Transmission of Colored Glass Filters

The spectra that were recorded showed a lot of noise at lower wavelengths. This was likely due to the lower amount of counts that the Halogen lamp registered, leading to a higher percentage uncertainty that was transferred to the transmission spectra.

Another possible source of error that may have resulted in skewed spectra are that the filters may or may not have the same cut. If they were not perfectly parallel, then light would have reflected off of them with different reflectivities. This would have skewed the transmission peaks.

The transmission graphs of the filters indicated each of the filters measured were longpass filters. When considering the spec sheet from ThorLabs, the cut-off wavelengths matched those given online for the filter kit FGK01S for 2 inch by 2 inch colored glass filters (8).

## 5.3 Absorption in Color Additive Solutions

The calculation result of absorbance of the blue dye solution with different concentration shows linear relation between the concentration of the solution and the absorbance of the solution as predicted by the Beer's Law. The standard deviation of our five data points collected are very small, which show that no out-liner data point exists in the calculation. However, the interception of the line is not at the origin of the coordinate as predicted by the theory, which shows some possible errors from the measurement must exist.

One of the errors might arise from the air bubbles inevitably created in the pipette, which results in inaccurate reading of volume of solution. In this measurement, our integration time is very small, which gives rise to fluctuation of the values of peak, increasing the uncertainty of our result.

In the future, the integration time could be calibrated more accurately such that a more stable peak absorption value could be measured to use in the equations.

## 5.4 Emission Spectra of Light Sources

### 5.4.1 Characterization of Peaks

The emission spectrum of the halogen lamp was a continuous spectrum operating over all wavelengths. It was in accordance with the typical black-body radiation spectrum (? ).

The fluorescent room lights had a multitude of wavelength that stem from the chemical reactions taking place in the pressurized mercury vapour that is

acted on by a high voltage (5). These are broadened due to natural broadening as well as collisional broadening. The fluorescent room lights closely matched typical spectra (4).

The sharpest peaks with the smallest linewidths were the lasers. Lasers should have both Lorentzian and Gaussian elements to their linewidths stemming from the ever-present Heisenberg uncertainty principle as well as thermal effects on the electrons inside the lasing medium causing Gaussian broadening. The lasers had operating wavelengths that indicated that the green laser was a frequency-doubled Nd:YAG crystal laser operating at 532 nm and that the red laser was a He-Ne laser operating at 635 nanometers (6). The exact value of the wavelengths in these lasers can vary based on the manufacturing of the laser, and so the 635 nanometer peak was matched to the 632 nanometer He-Ne laser listed in (6).

The LEDs had peaks with much wider linewidths. The spectra of the LEDs agreed with the spectra in figure 8. There was thus close agreement with literature values (4). The reason for this broadening may be due to the nature of the electronic recombination at the bandgaps coupled with Gaussian broadening due to thermal effects at the laser diode.

#### 5.4.2 Spectral Contamination by Room Light

The spectra of the red laser, the blue, yellow, red and white LEDs, and the desktop monitor displaying white all showed the peaks associated with the room lights. This was due to the measurement taking process. The room lights were left on and were able to reflect off surfaces into the optical cable.

In the future, in order to measure the spectra of emission sources, more care needs to be taken to exclude the light of all other light sources, beginning with turning off the room lights while other light sources are being measured.

## 6 Conclusion

In conclusion, this set of experiments aimed to test the functions of integration time and the reliability of the generated absorbance and transmission spectra in Ocean Optics SpectraSuite software, measure a set of colored glass filters and match them to their product names given their measured transmission functions, create a bandpass filter operating between 500 and 700 nanometers from two different filters in the filter set, measure the absorbance of various concentrations of dyes and observe the combined effects of multiple dyes, and lastly measure the emission spectra of a halogen lamp, fluorescent room lighting, a white LED, a red LED, a blue LED, a yellow LED, a green laser, a red laser, and a computer screen showing the color white. The results obtained were that the integration time influences the amount of incident photons on the CCD camera, and that the absorbance and transmission spectra functions on SpectraSuite were reliable. The measured colored glass filters acted as longpass filters and were easily matched with the corresponding filters. A bandpass filter

operating between 480 and 680 nanometers was created by mixing two different filters together. The absorbance of dye was determined to act in accordance to the Beer-Lambert Law, and the effect of multiple dyes in the same solution was an additive effect to their absorbance functions. The emission spectra of the halogen lamp, the LEDs, the room lights and the lasers were in accordance with typical spectra for these light sources. The room lights contaminated the emission spectra, as these were not turned off throughout the experiments.

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