

Indian Institute of Technology Gandhinagar



MATTER ENERGY & LAB BS 191 Project Report

Group Number: 03

Diffraction Grating Spectrometer

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November 24th, 2022

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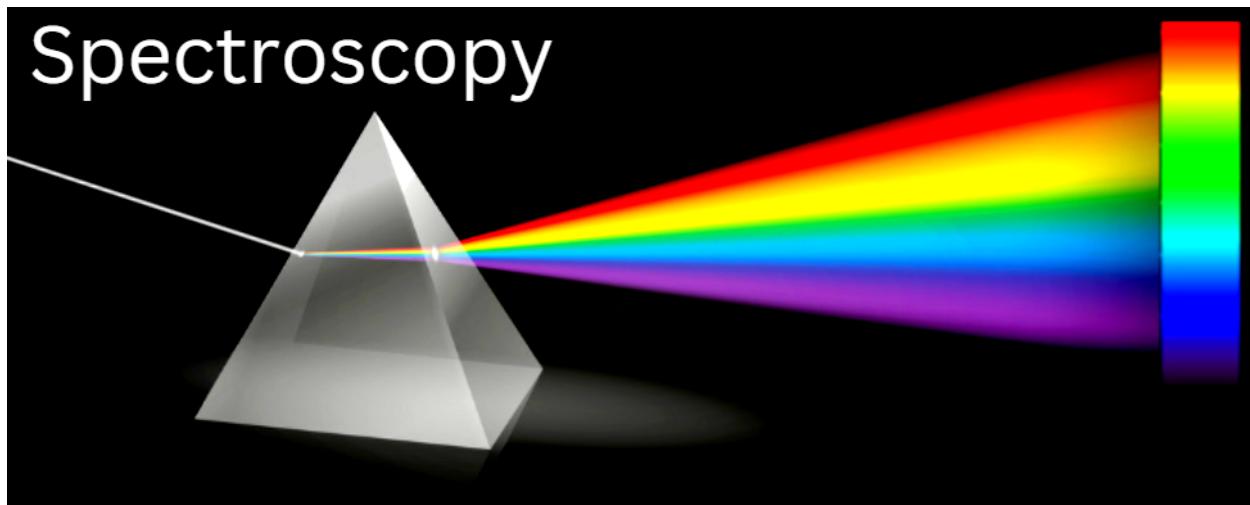
Introduction

- Developing a prototype device to quantify the absorption of light by matter

- Works on spectrometer and spectroscopy

Spectroscopy

The Latin word "spectrum," which means a vision or an item to see, is where the word "spectrum" originates. A spectrum in our context depicts the entire range of electromagnetic wavelengths, not just the visible range. The verb spoken in the Greek phrase "to stare at" (CharlestonWeb; PrincetonWeb). These spectra are displayed using a spectrograph, and the various elements of a spectrum are measured using spectrometry. These spectra are examined by spectroscopy.

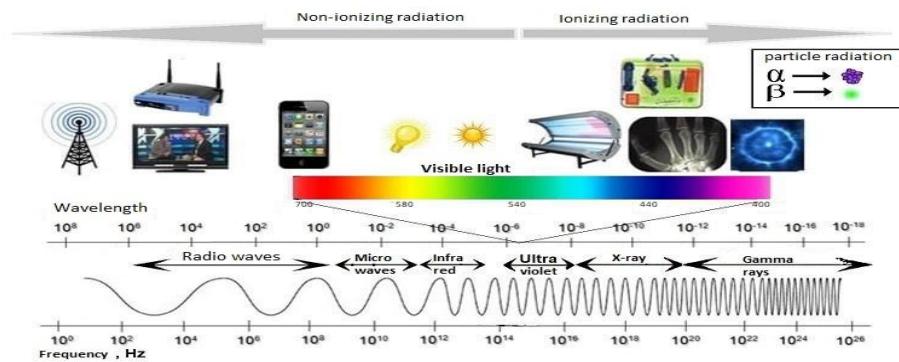


WHAT IS THE ELECTROMAGNETIC SPECTRUM?

We must comprehend how radiation interacts with objects in order to derive information from spectroscopic investigations. Electromagnetic radiation causes molecules to be disrupted, which causes them to transition to a state with a different energy, as we'll see in more detail below. As a result, we must talk about electromagnetic radiation, molecular energy levels, and how these factors interact with radiation to cause transitions between energy levels.

- The range of electromagnetic radiation's frequencies, along with the corresponding photon energies and wavelengths, is known as the electromagnetic spectrum.

The electromagnetic spectrum



Types of Spectroscopy:

- Defining Spectroscopy
 - Infrared (IR) Spectroscopy
 - Ultraviolet-Visible(UV/Vis) Spectroscopy
 - Nuclear Magnetic Resonance (NMR) Spectroscopy
 - Raman Spectroscopy
 - X-Ray Spectroscopy
- Our project is based on Ultraviolet-Visible(UV/Vis) Spectroscopy

What is UV-VIS Spectroscopy?

"UV spectroscopy, also known as ultraviolet-visible spectrophotometric methods (UV-Vis or UV/Vis), is the term used to describe both reflectance and absorption spectroscopy in the ultra-violet spectral range. Depending on how much light an analyte absorbs, ultraviolet-visible (UV-VIS) spectroscopic techniques can measure the analyte's quantity."

Absorption spectroscopy

The term "absorption spectroscopy" refers to spectroscopic methods that assess how much radiation interacts with a sample and is absorbed as a function of frequency or wavelength.

Beer-Lambert Law

According to the Beer-Lambert law, the sample's concentration and route length for a given substance are directly related to the light's absorbance.

It is expressed as

$$A = \epsilon L c = \log\left(\frac{I_0}{I}\right)$$

where

- A = amount of light absorbed for a particular wavelength by the sample
- ϵ = molar extinction coefficient
- L = distance covered by the light through the solution
- c = concentration of the absorbing species
- I_0 = incident beam intensity.
- I = emergent beam intensity.

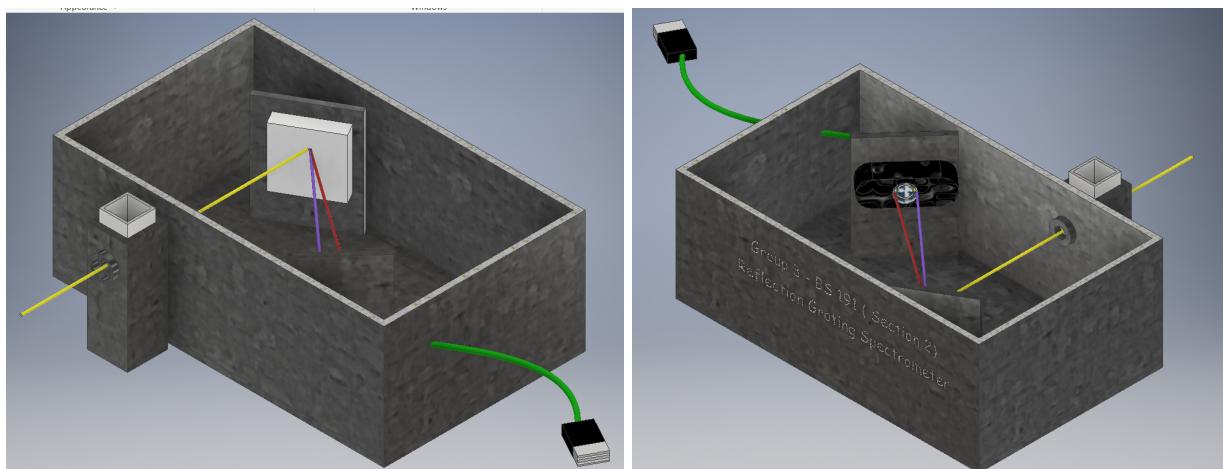
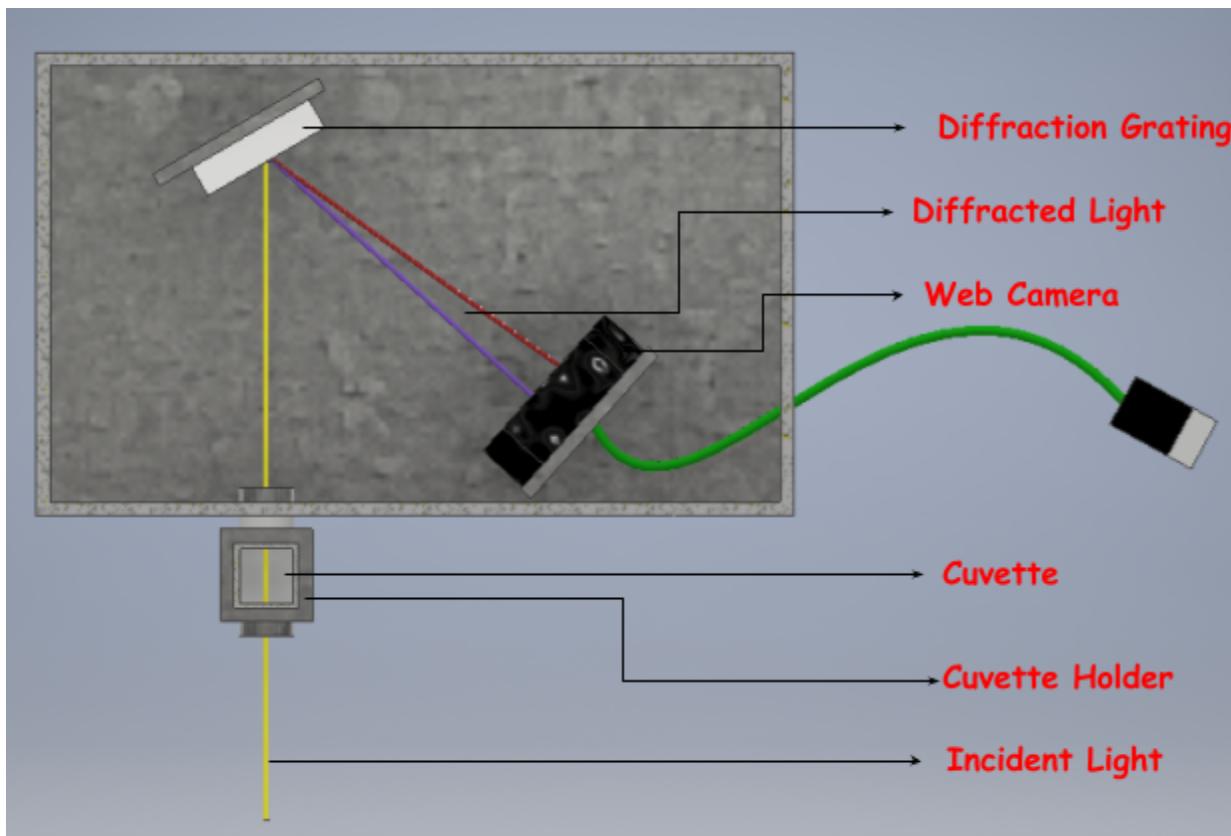
What is a Spectrometer?

A spectrometer is a type of scientific instrument that is primarily used to determine the wavelength of electromagnetic radiation by measuring and classifying the spectral components according to their physical characteristics. It is a device that analyses a continuous, non-discrete physical feature into a spectrum of its individual components before measuring it. We can measure the spectra of light by utilizing spectroscopy.

Parts of Spectrometer

- The **slit** controls the amount of light entering the spectrometer. The amount of light controls the resolution of the image.
- The **diffraction grating** splits the light and disperses individual spectra in the incident light.
- The **detector** is known as Charge Coupled Device (CCD) which detects the different wavelengths. But here we are using a web camera for it.

Setup CAD Design:



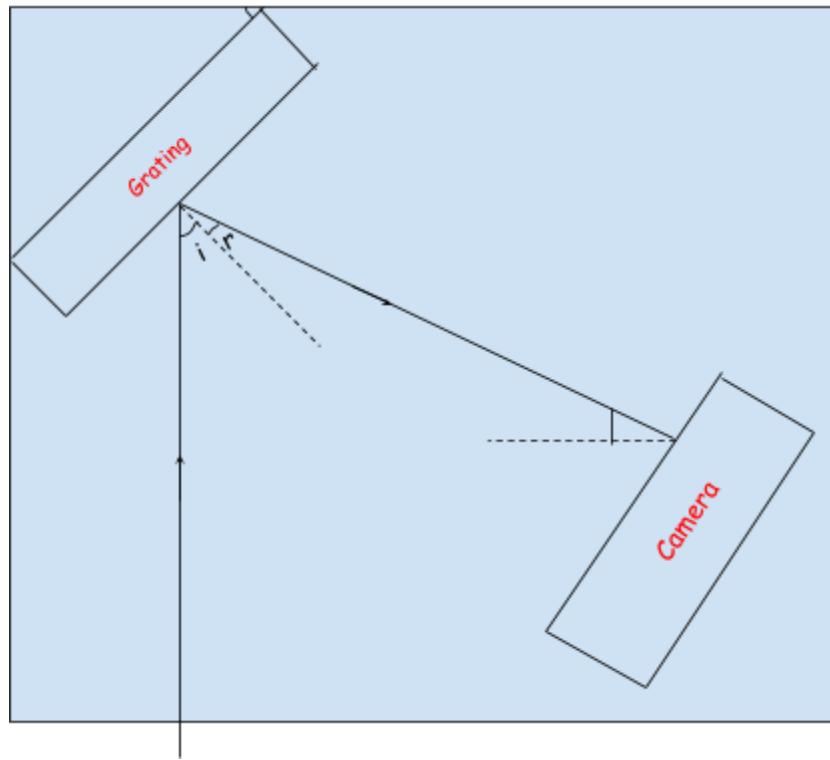
Experimental Setup:



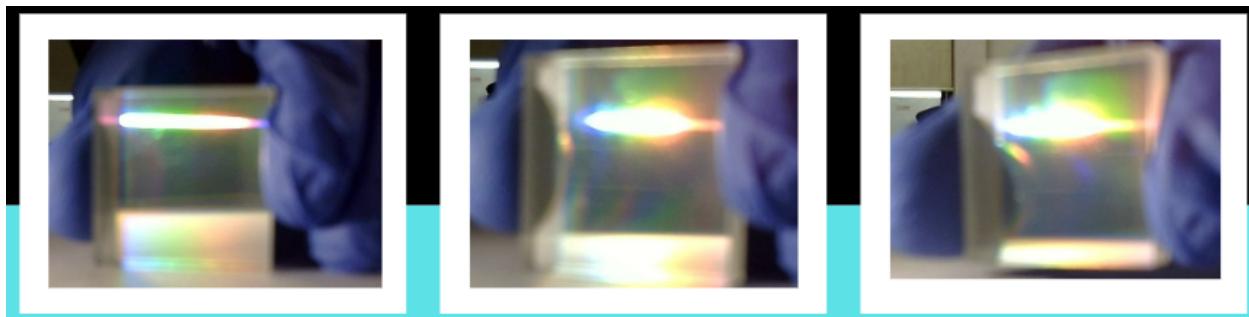
- A cuvette holder is attached to hold a standard cuvette (10mm * 10mm) at the front of the spectrometer box.
- There is a small hole in the cuvette holder through which light will enter the cuvette.
- After light falls on the substance inside the cuvette, there is a small hole at the end of the holder through which light will enter the spectrometer box.
- At the entrance, there is a small slit attached that controls the resolution of the spectrometer, i.e., it will control the amount of light entering the spectrometer.
- Then there is a diffraction grating on which light will fall and get diffracted.
- A diffraction grating disperses a beam of various wavelengths into a spectrum of associated lines because of the principle of diffraction.
- After that spectrum image is captured by a web camera, we can find the wavelength and intensities of spectral lines



To decide the incident and reflected angle between the light ray and grating, we performed one small experiment in which we put grating at an angle of 45 degrees and light is incident on it. Then we arranged a web camera according to a less ordered and less saturated spectrum and found a reflected angle.



In the above trial, we captured some images of reflected light from grating at different angles and found the images below.



The phenomenon observed in the above images is known as saturation. saturation is what happens when a pixel generates too many electrons. After a pixel exceeds its pixel well depth, the signal from the pixel stops increasing with more photons. the stored electrons can even start “leaking” into neighboring pixels and distorting the signal.

- How to avoid saturation:**
- 1) Reduce the intensity of Incident light
 - 2) Use optical Filters

Calibration

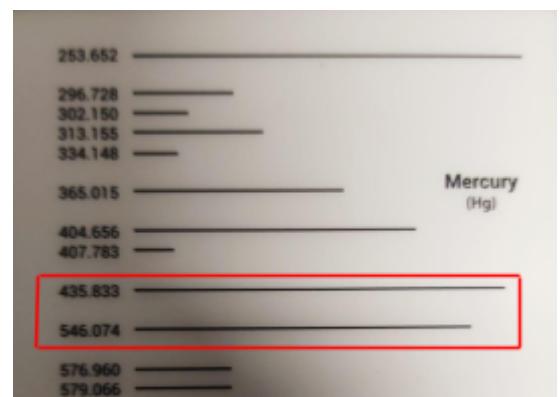
Web cameras will capture the image of the spectrum but we will get information about the intensity of the pixel. So we have to convert it into wavelength vs intensity. For that calibration of light is important. Here we used a Mercury lamp for calibration.

These two light points were visible in the camera.

Blue point wavelength = 435.833 nm [467, 551]

Green point wavelength = 546.074 nm [544, 551]

$$\text{Intensity per pixel} = \frac{546.074 - 435.833}{544 - 467} = 1.4317$$



So we will mark these two pixels with the two wavelengths and interpolate wavelengths for another pixel. According to calibration wavelength was changing 1.4317 nm per pixel.

The visible spectrum range is from [440,551] to [620,551] pixels.

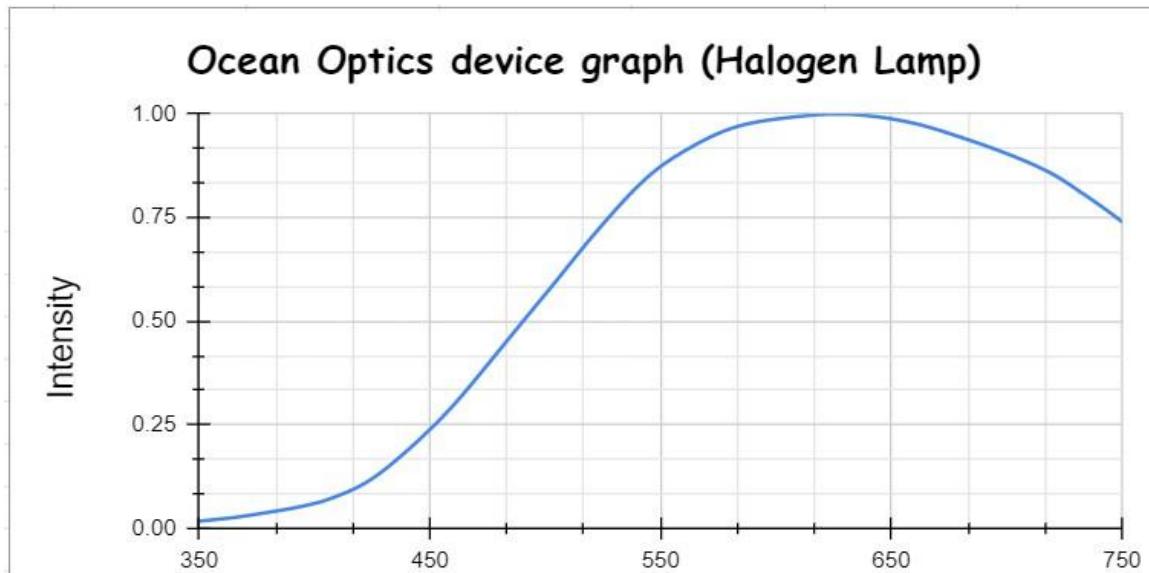
So wavelength for pixel [440,551] is given by

$$= 435.833 - (467 - 440) * 1.4317 = 397.1771 \text{ nm}$$

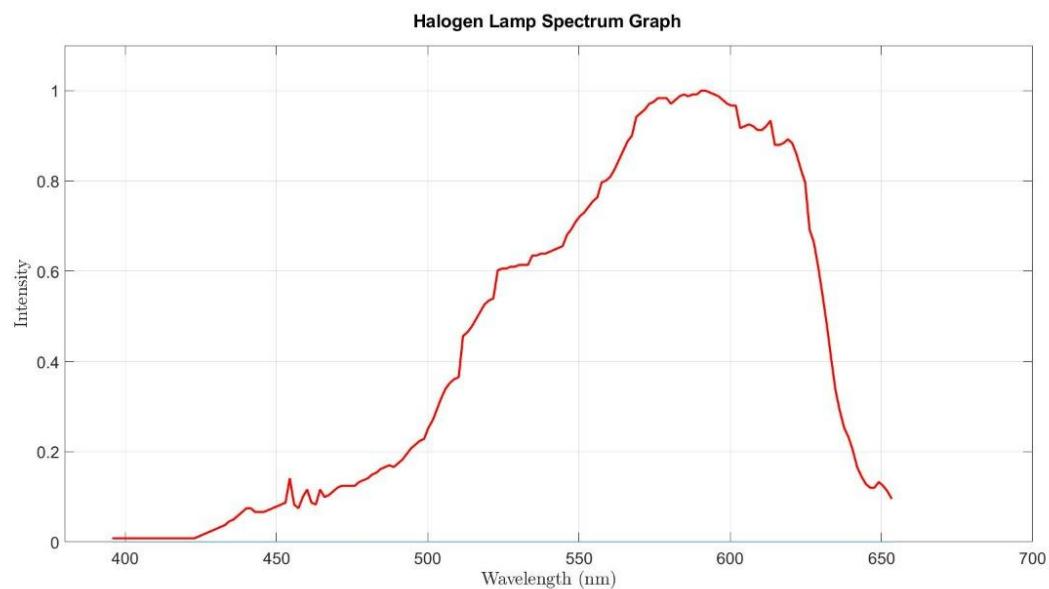
Now we can find wavelength for each pixel.

COMPARISON WITH OCEAN OPTICS SPECTROMETER

For testing and verification of our handmade device, we used a halogen lamp for reference. We took the aid of a commercial spectrometer called Ocean Optics Spectrometer which helped us in providing an “intensity vs wavelength” graph of the incident halogen light.



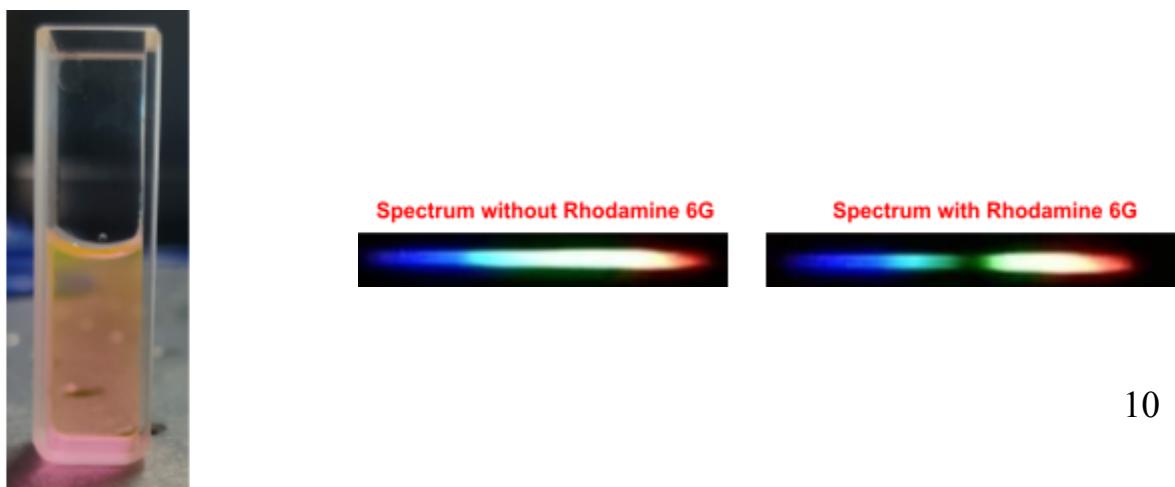
Hence, we got a graph as shown below for our halogen lamp using our spectrometer.



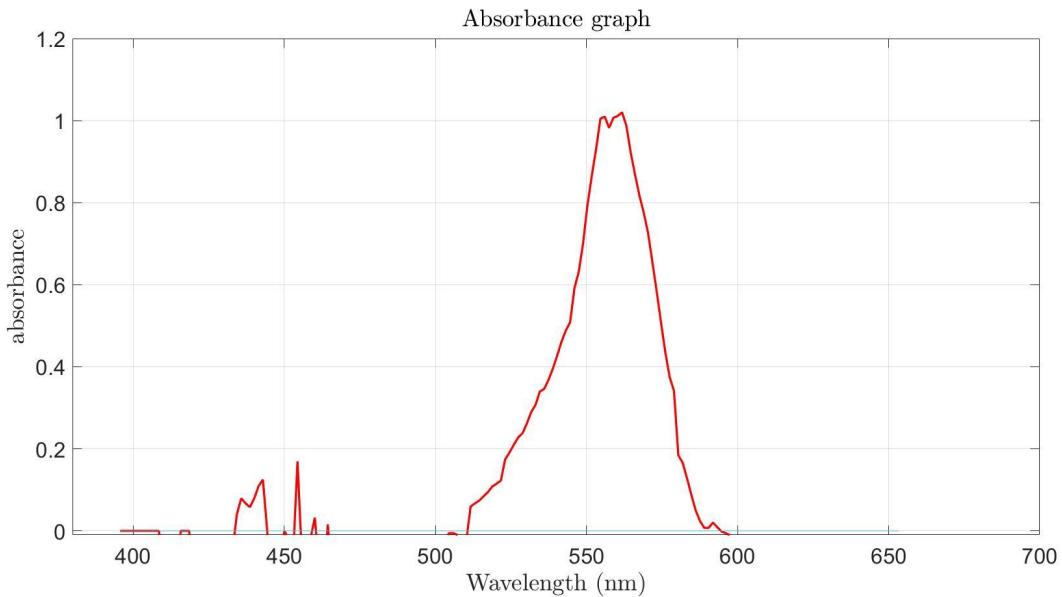
We can see that in the first graph, the peak intensity is around 620 nm wavelength. In the second graph, 590 nm is the peak intensity. The results of wavelength after comparing a practical spectrometer with our device are very close.

Results and Conclusions

Now, we tested our spectrometer with a Rhodamine 6G sample.

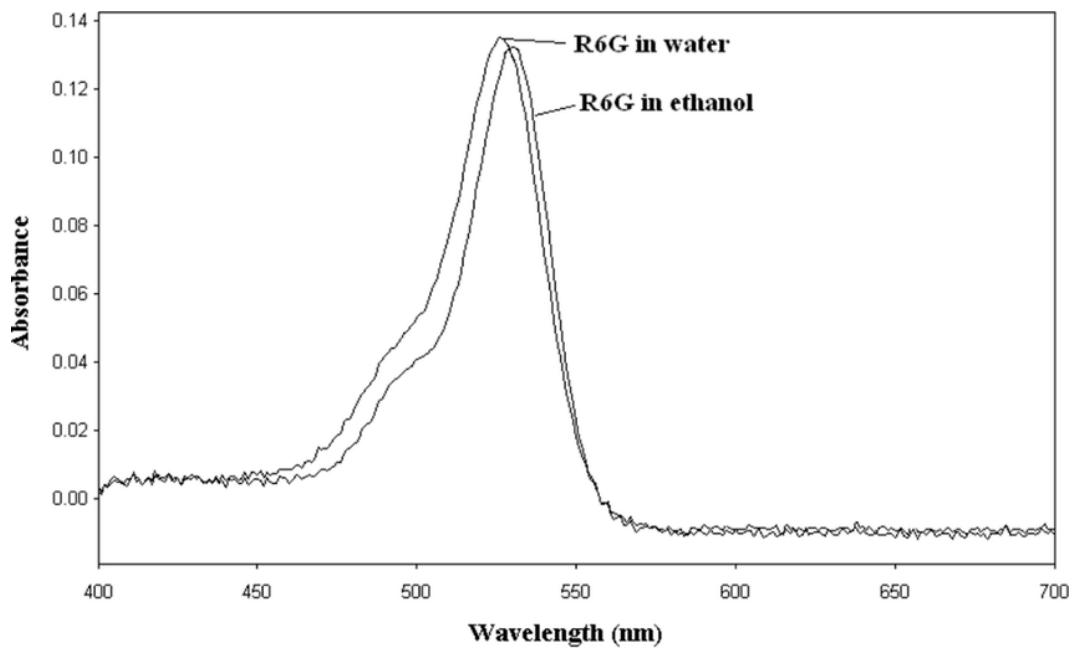


Rhodamine 6G absorption graph is,



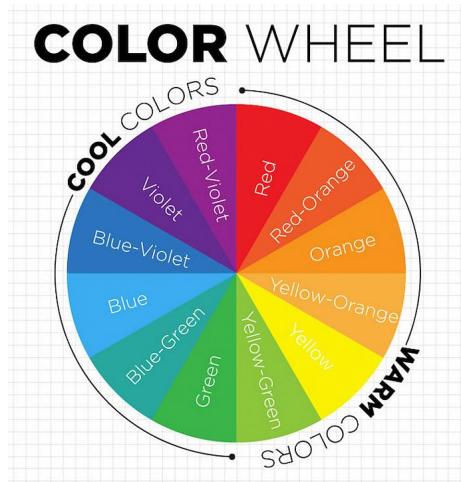
Here, the peak is at wavelength 560 nm.

Literature Graph,



Here we can see the peak is at 530 nm, and in our spectrometer graph, it is at 560 nm. So it is giving quite close results.

Here, rhodamine is absorbing the energy of wavelength around 550 nm which is green in color and emits all other wavelengths. The red color is a complementary color of green in the color wheel that's why rhodamine is red in color.

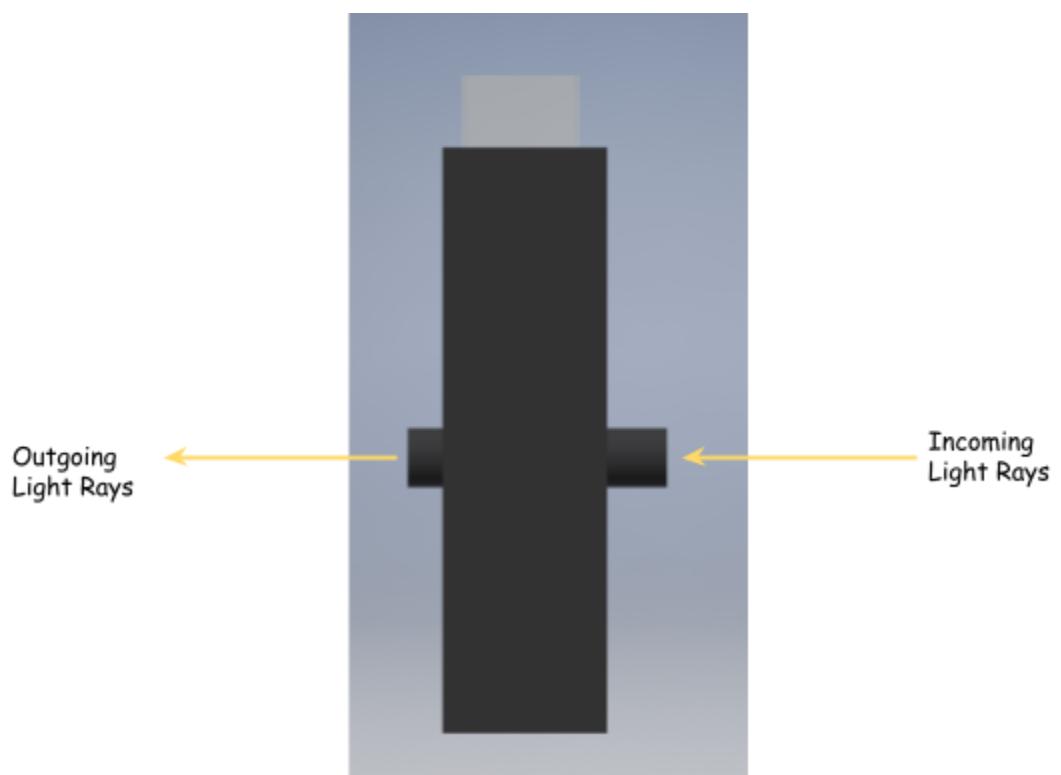
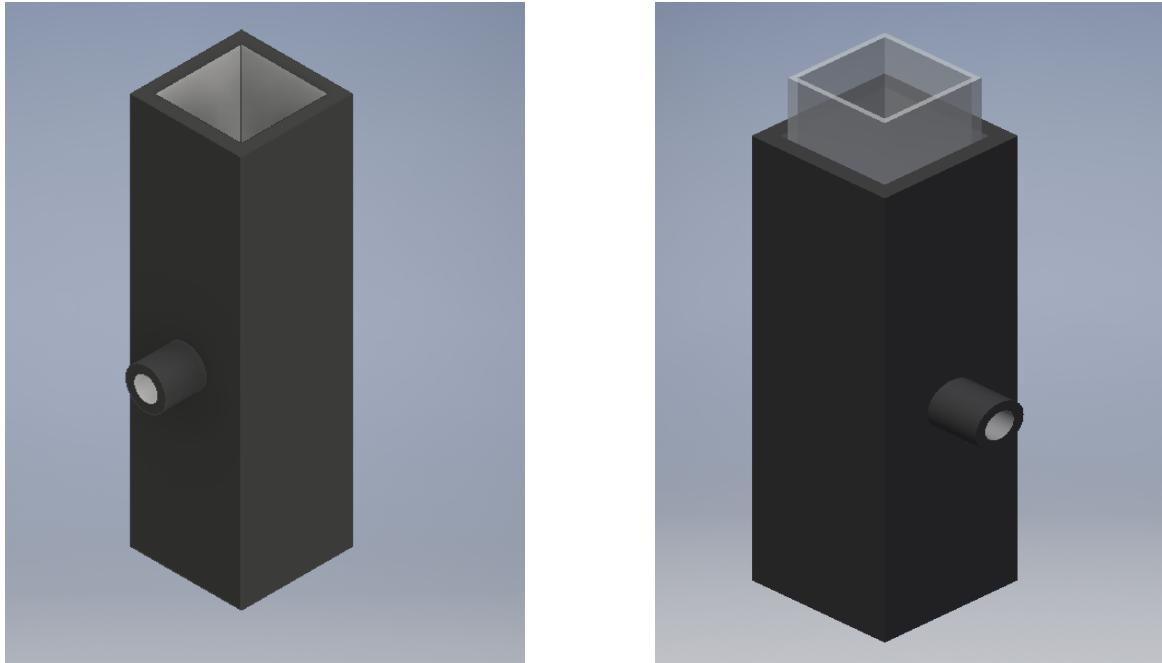


Error Analysis:

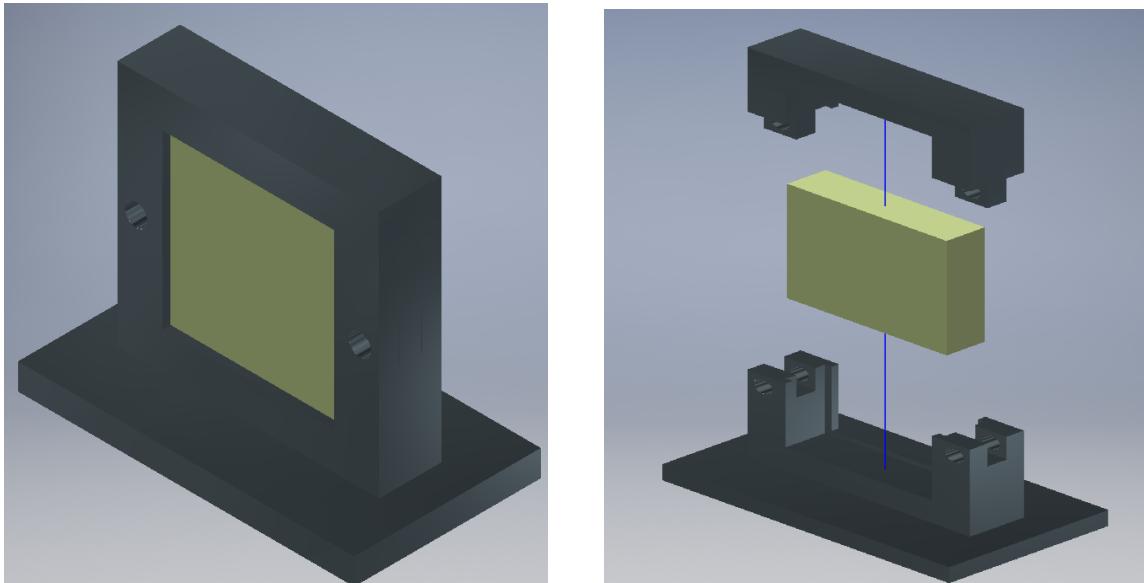
- From the above graph for spectrums of the halogen lamp and Rhodamine 6G sample, we can see that our spectrometer device is giving close results but not correct. There is up to **± 30 nm** error.
- This is because the incident light is not that fixed. Even if we change the angle of incidence by 1 degree, the pixel positions of the spectrum change quantitatively. That's why the wavelength value might increase or decrease for a peak.
- Error sources:
 - Grating might be not straight and fitted inclined by a very less angle.
 - The optical fiber holder is not that effective because optical fiber might be moved by 1 degree and hence pixel position can change.

Appendix

A1 - Cuvette holder design



A2 - Grating Adaptor design



A3 - Slit



A4 - Optical Fiber Holder



References

- <https://www.atascientific.com.au/spectrometry/#:~:text=Spectroscopy%20is%20the%20study%20of,into%20a%20rainbow%20of%20colours>.
- <https://byjus.com/chemistry/principle-of-uv-visible-spectroscopy/>
- <https://www.vedantu.com/physics/spectroscopy>
- <https://pubs.acs.org/doi/10.1021/acs.jchemed.0c01085>
- <https://www.youtube.com/watch?v=6C6H4DkOc04>
- <https://physicsopenlab.org/2015/11/26/webcam-diffraction-grating-spectrometer/>