UNIVERSITY OF
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Photonics Laboratory Report: Spectrophotometer Measurements

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Photonics for Security, Reliability, and Safety (PSRS)

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Contents

1 Abstract

This report discusses the applications of spectrophotometry in optical analyses, and through experiments conducted using a spectrophotometer and various samples, we will investigate this technique's capabilities in diverse scenarios. Initially, we will determine the concentration of a chemical in liquid samples, employing a calibration curve relating absorbance to concentration. After that we will focus on identifying materials suitable for UV protection by analyzing their transmittance properties using spectrophotometric techniques. Furthermore, we will examine materials that block visible light while transmitting infrared radiation. Through spectral analysis of various plastics, distinctive absorption wavelengths will be identified for material identification. Lastly, we will evaluate the effectiveness of laser safety glasses in filtering specific wavelengths of laser radiation to ensure eye protection. The results will help us understand spectrophotometry better and see how it can be useful in different scientific and industrial situations, especially for security and understanding materials.

2 Theory

Spectrophotometry is a quantitative measurement technique fundamental to the fields of chemistry, physics, biology, and engineering. It involves the measurement of reflectance or transmittance of a sample material across a specific wavelength range. For the purposes of this experiment, we focused on the transmittance properties of various solids and absorbance properties of solutions by employing a Perkin-Elmer Lambda 9 spectrophotometer. This instrument is known for its versatility and accuracy, capable of measuring light wavelengths from 170 nm up to 3200 nm, thus covering both ultraviolet (UV) and infrared (IR) spectra [1].

The primary objectives of this laboratory work were multifaceted: to determine the concentration of a chemical in a liquid solution, assess the UV transmittance of transparent materials, explore the IR transmittance of opaque materials, differentiate types of plastics based on their IR spectra, and verify the protective efficacy of laser safety glasses [2].

The key components of a spectrophotometer include a light source, a holder for the sample, a means of selecting wavelengths or bands of light (typically using a diffraction grating), and a detector. The basic principle relies on a beam of light passing through a sample, where the intensity of the transmitted light is measured. This transmitted light's intensity is then compared to the intensity of a reference channel, allowing for the determination of how much of the initial light is transmitted through the sample and how much is absorbed by the sample.

2.1 Beer-Lambert Law

The fundamental law governing spectrophotometry is the Beer-Lambert Law, which states that the absorbance of a light beam by a medium is directly proportional to the concentration of the absorbing material present in the medium and the path length through which the light travels [3]. Mathematically, it is expressed as:

$$A = \epsilon\, c\, l\,,$$

where A is the absorbance, ϵ is the molar absorptivity or extinction coefficient in $L \cdot mol^{-1} \cdot cm^{-1}$, c is the concentration of the compound in the solution given in $mol \cdot L^{-1}$, and l is the path length of the light through the sample in cm.

2.2 Absorption and Transmittance

Absorption refers to the process by which a substance captures electromagnetic radiation and converts the energy of light into internal energy such as thermal energy. In the context of spectrophotometry, the amount of light absorbed by a substance can provide valuable information regarding the substance's properties. The relationship between absorbance and transmittance is given by the logarithmic equation:

$$A = -\log_{10}(T)\,,$$

where transmittance, denoted by T, is a ratio of the intensity of the light passing through the sample (I) to the intensity of the light before it enters the sample (I_0) [4]:

$$T = \frac{I}{I_0}.$$

2.3 Measurement Task

2.3.1 Spectrophotometer Configuration

In this experiment, we utilized the Perkin-Elmer Lambda 9 spectrophotometer, which is shown below in Fig. 1.

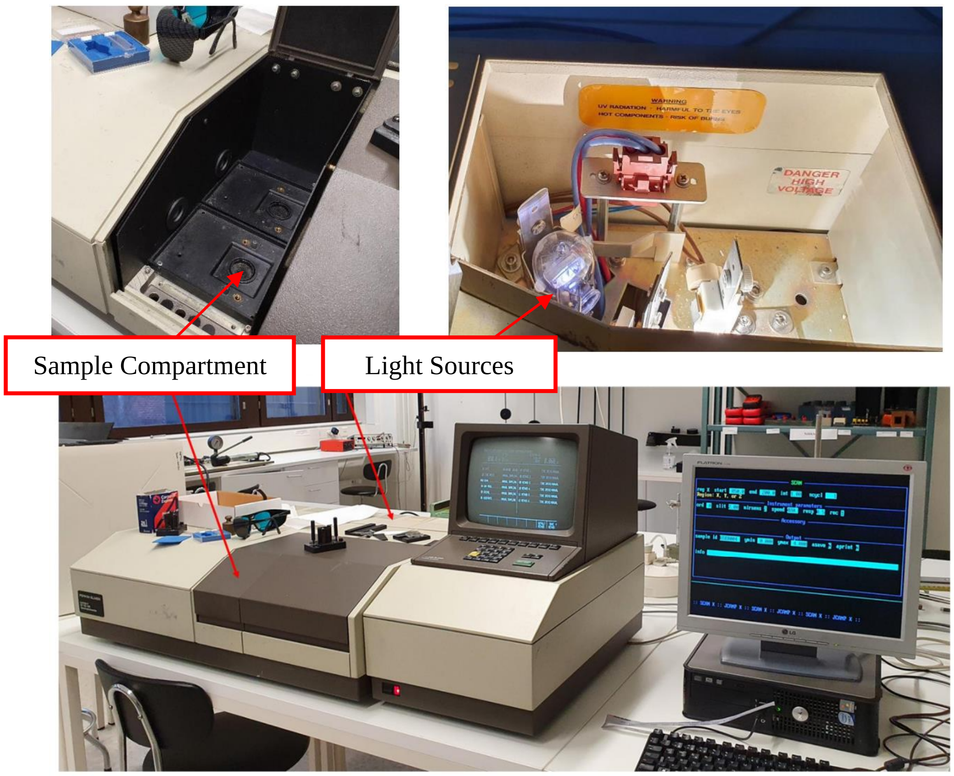


Figure 1: Perkin-Elmer Lambda 9 spectrophotometer: (a) Sample compartment, (b) Light sources of spectrophotometer, (c) The experiment setup including data acquisition station [2].

Light from two sources—a deuterium lamp for ultraviolet light and a halogen lamp for visible and infrared light—is directed toward a diffraction grating, which functions to disperse light into its component wavelengths [1]. The dispersed light is then focused onto the sample. The amount of light absorbed by the sample at each wavelength can be measured, which is critical for determining the characteristics of the sample. A photomultiplier tube for UV and visible wavelengths and a lead sulfide detector for IR wavelengths are used to detect the intensity of the transmitted light, which is then used to calculate the transmittance and absorbance. Despite being old, this device ensures high sensitivity and accuracy across a broad spectral range, from 170 nm to 3200 nm.

2.3.2 Samples and Measurement parameters

We analyzed different samples, starting from chemical solutions to solid materials, across various wavelengths.

The chemical samples tested are shown in Fig. 2. They consisted of water solutions of blue food colorant, a disodium salt of a complex organic compound [5]. The concentration of the dye in these solutions varied, with reference samples prepared at 0%, 0.5%, 1%, 1.5%, and 2% concentrations. Included is a sample with unknown concentration to be determined after establishing a calibration curve linking absorbance to concentration.

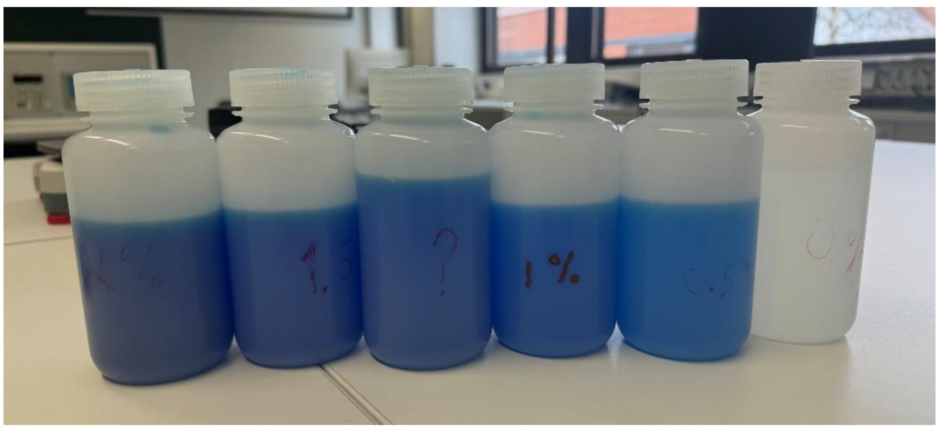
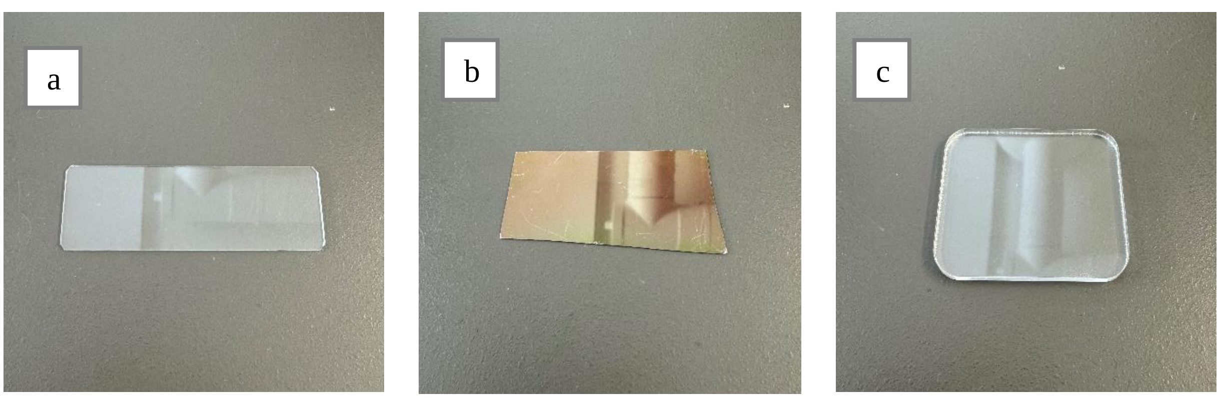


Figure 2: Solutions of a blue dye with concentration (from left to right) 2%, 1.5%, unknown, 1%, 0.5%, and 0% respectively.

Various solid materials were also tested to assess their UV and IR transmittance properties. These materials included the following.



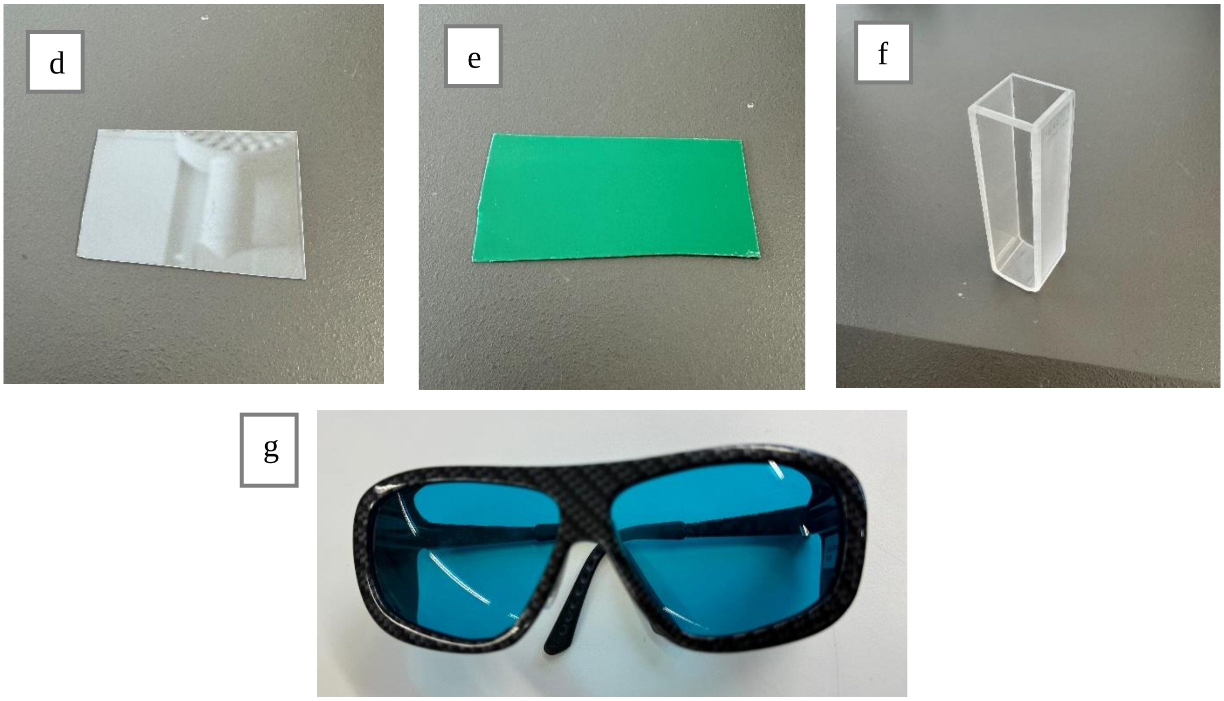


Figure 3: Solid materials: (a) Normal Glass, (b) Polished Silicon Disk, (c) Acrylic PMMA (d) Polycarbonate (e) Green Polypropylene (f) Quartz glass cuvette (g) Laser safety glasses.

Each material was carefully positioned in the spectrophotometer to ensure accurate light beam transmission and stability comparisons against a reference channel. This approach provided precise data on each material's light transmission properties, informing their potential industrial and research applications.

The parameters of the spectrophotometer set for the measurement task of both types of samples are shown in Table 1. Calibration was performed before the measurement of both liquids and solids.

Table 1: Measurement Parameters and Calibration

Sample Type	**Chemical Solutions**	**Solid Materials**
Start Wavelength	800 nm	3200 nm
End Wavelength	200 nm	200 nm
Measurement Mode	Absorbance (A)	Transmittance (T)
Scan Speed	240 nm/min	960 nm/min
Data Points	651 (850 nm to 200 nm at 1 nm intervals)	Broad range from 3200 nm to 200 nm at maximum speed

The autozero calibration ensures that any reading taken accounts for the baseline transmittance or absorbance of the air path alone. It establishes clear reference points for accurate measurements.

3 Results

In this section, we present the results of our experiments and discuss their implications.

3.1 Chemical Concentration of the samples

For the analysis of the blue dye concentration, we utilized the absorbance data captured from the spectrophotometer for each specified concentration of the blueish chemical. After processing the data using MATLAB, we plotted the absorption spectrum of the solution including the unknown one on the same plot on Fig. 4.

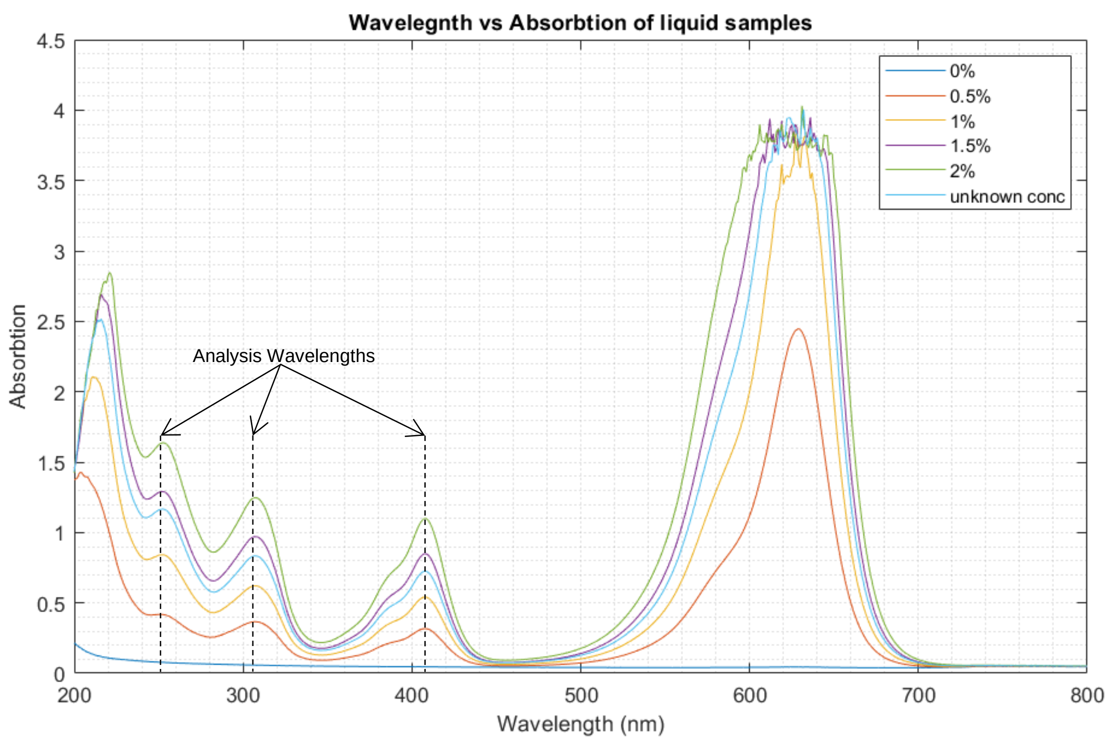


Figure 4: Wavelength vs. Absorbance for Different Concentrations of Brilliant blue FCF water solution.

Due to the maximum limit set by the spectrophotometer, absorbance readings in the range of 500 nm to 700 nm exceeded the maximum measurable absorbance, 4.

To determine the concentration of the unknown sample, we selected three wavelengths for analysis: 252 nm, 307 nm, and 410 nm. For each wavelength, we performed curve fitting using the known concentrations and their corresponding absorption values. Finally, we calculated the average concentration based on the results from these three wavelengths.

Table 2: Absorption values at selected wavelengths for known concentrations and the unknown sample

Wavelength, nm	Absorption at the following concentration					
	0 %	0.5 %	1 %	1.5 %	2 %	Unknown conc.
272	0.0785	0.4178	0.8417	1.2904	1.6368	1.1667
307	0.0586	0.3668	0.6214	0.9708	1.2474	0.8345
410	0.0463	0.3118	0.5320	0.8352	1.0807	0.7130

Using this information, we implemented linear fitting for each wavelength to establish the relationship between concentration and absorption. We then used these relationships to determine the concentration at each wavelength for the unknown sample. The final concentration of the unknown sample was obtained by averaging the concentrations derived from each wavelength.

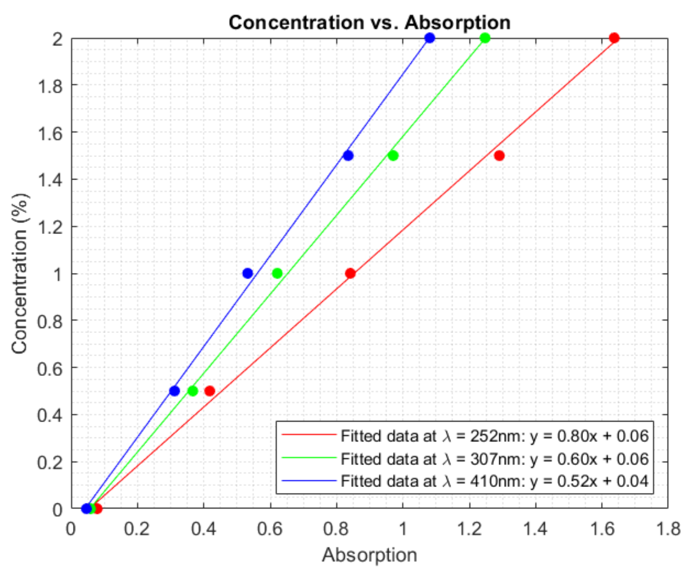


Figure 5: Measured data points and Fitted line of the Concentration vs. Absorption relation at selected wavelengths.

We obtained the absorption values for the unknown concentration at three wavelengths using the fitted line equations. The respective absorption values were 1.3931, 1.3044, and 1.2928. By averaging these values, we determined the concentration of the unknown sample to be **1.3301**.

3.2 Material for UV-Protection

Next, we identified the most suitable materials for constructing a protective enclosure capable of blocking UV radiation, particularly at wavelengths of 254 nm and 365 nm emitted by mercury discharge lamps. The materials tested included Normal glass, Quartz glass, Acrylic (PMMA), and Polycarbonate (PC). Transmission properties of each material were measured across the UV spectrum. The transmission data was plotted in Fig. 6.

Further analysis on the transmission at 254 nm and 365 nm shed some insight on the properties of the materials.

- **Polycarbonate (PC)** exhibited the lowest transmission at 254 nm, close to zero. This shows its excellent potential for blocking UV radiation that is most harmful to human skin and eyes. However, it showed a higher transmission at 365 nm, indicating reduced effectiveness at this wavelength.
- **Acrylic (PMMA)**, on the other hand, demonstrated the lowest transmission at 365 nm (0.0171), making it highly effective at blocking less harmful UV radiation, while also providing substantial protection at 254 nm.

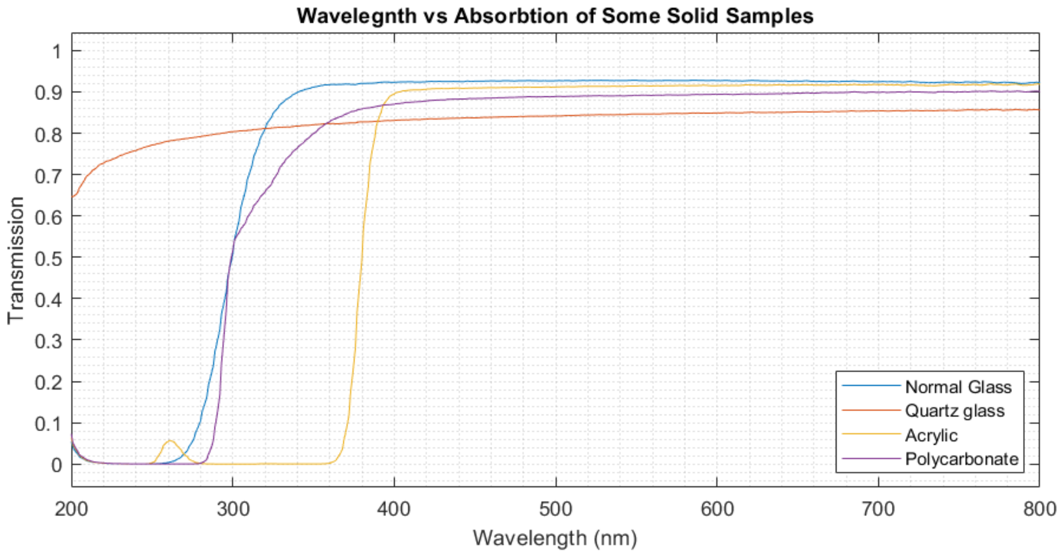


Figure 6: Wavelength vs. Transmission of Some Solid Samples

Considering these results, several material configurations are proposed:

- **Dual-Layer Protection**: An inner box made of Polycarbonate coupled with an outer layer of Acrylic offers a comprehensive protection strategy. It effectively blocks both the most and less harmful wavelengths of UV radiation.
- **Combined Single Enclosure**: A single enclosure that incorporates both Polycarbonate and Acrylic could serve as a cost-effective alternative by providing balanced protection across the critical wavelengths.

3.3 Selecting Materials for IR Transmission and Visible Light Blocking

The task is to identify the optimal material for applications requiring the blocking of visible light while allowing infrared light transmission. We evaluated two materials: Polished silicon disc and green polypropylene (PP).

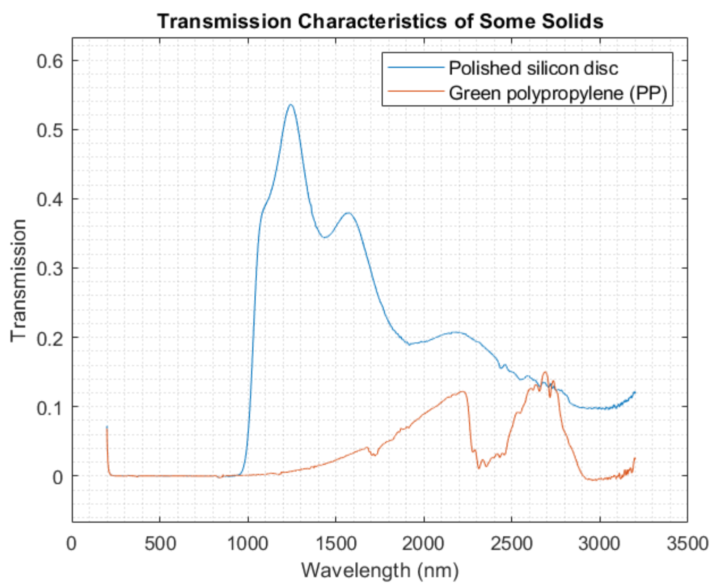


Figure 7: Wavelength vs. Transmission of Polished silicon disc and green polypropylene plastic.

For closer analysis we focused on assessing the transmission at 1450 nm and 1950 nm, because water exhibits significant absorption at 1450 and 1950 nm wavelengths, which make these wavelengths useful for assessing moisture levels in materials. For instance, one can illuminate the target material with infrared light at two wavelengths: 1750 nm and 1950 nm. The reflectance is then measured at these two wavelengths. Since water absorbs infrared light more effectively at 1950 nm than at 1750 nm, the difference in reflectance between these two measurements can be used to infer the moisture content.

According to our analysis, the polished silicon disc emerged as the superior option over green polypropylene. Demonstrating higher transmission at key IR wavelengths of 1450 nm and 1950 nm, the polished silicon disc effectively supports precise moisture measurements in devices, making it the recommended material for applications demanding high accuracy and efficiency in diverse lighting conditions [2].

3.4 Identifying Plastic Types Through IR Transmittance

To distinguish between different types of plastics based on their IR transmittance properties, we analyzed the previously measured spectra of three polymers: acrylic (PMMA), polycarbonate (PC), and polypropylene (PP).

We select the characteristic absorption peaks that do not overlap between the three materials we have. For PMMA, 1171 nm or 1361 nm can be used, as these peaks are not found in the PC or PP spectrums. For PC, the wavelengths 2206 nm or 2456 nm are suitable, as they do not overlap with PP or PMMA peaks. For PP, the peak at 1710 nm is unique to PP and are not found in PMMA or PC spectrums, which make it a suitable identifier.

The result of this task proved that the absorption spectra enable to effectively identify the types of plastics from their IR transmittance spectra.

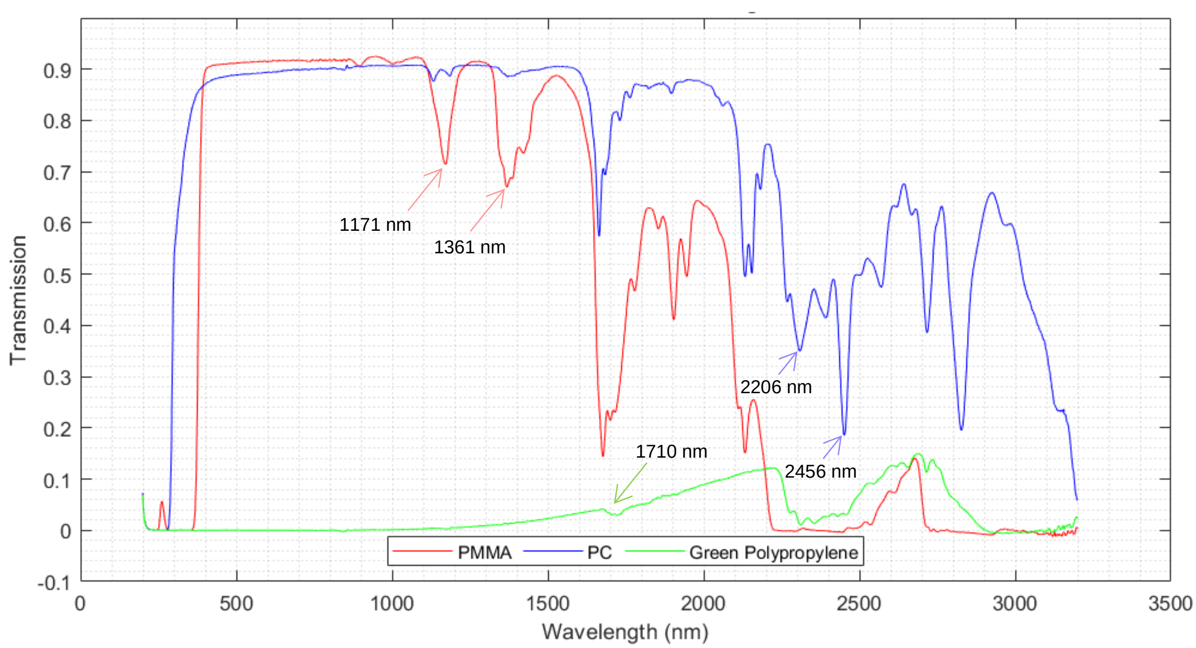


Figure 8: Transmittance and absorbance profiles of three different polymers.

3.5 Efficacy of Laser Safety Glasses

Laser safety glasses are essential protective gear used to shield our eyes from harmful laser exposure during operations involving laser equipment. We evaluated the transmittance properties of the safety glasses on Fig. 3(g). This information is crucial as it indicates the effectiveness of the glasses in protecting against specific lasers.

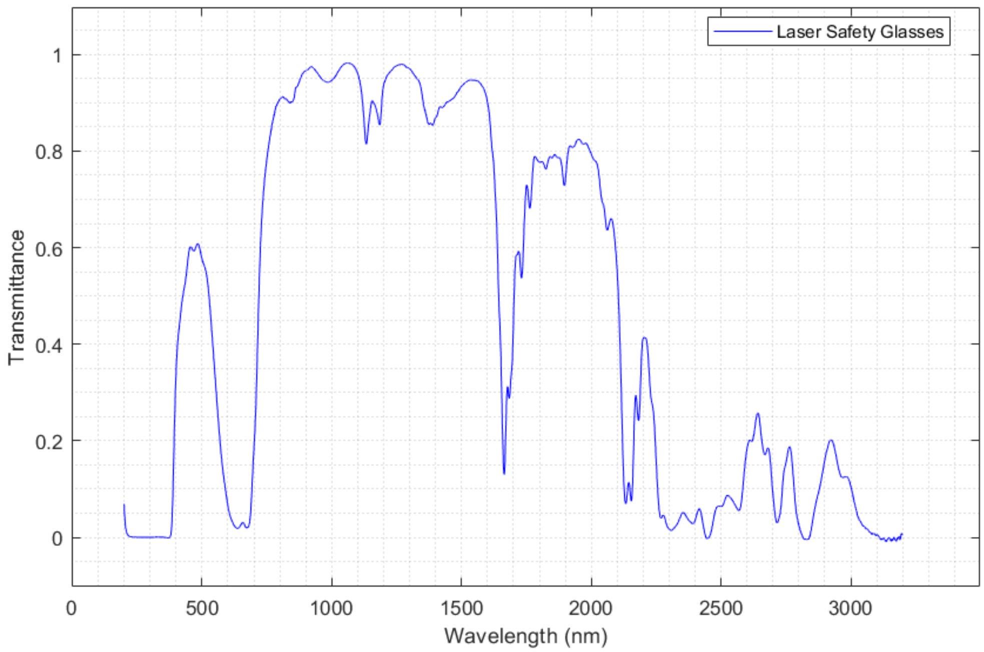


Figure 9: Transmittance Curve of Laser Safety Glasses

Following is a table that summarizes the transmittance levels and protective effectiveness of the laser safety glasses for some lasers.

Table 3: Effectiveness of the Laser Safety Glasses Across Different Laser Wavelengths [6]

Laser Type	**Wavelengths (nm)**	**Transmittance**	**Effectiveness**
Xenon Chloride Laser	308, 459	0	Highly Effective
Argon Laser	488, 514	0.6	Moderately Effective
Helium-Neon Laser	633	0.02	Highly Effective
Ruby Laser	694	0.12	Moderately Effective
Nd:YAG Laser	1064	0.98	Ineffective
Er:YAG Laser	2940	0.17	Moderately Effective

The tested laser safety glasses are particularly effective for Xenon chloride and Helium-neon lasers, as indicated by their low transmittance at the corresponding wavelengths. While they also provide substantial protection against the Ruby laser, caution should be exercised due to the slight transmission observed.

While transmission spectra are valuable for initial evaluation, their effectiveness for high-power laser applications has limitations, and many factors should be taken into consideration including optical density which is the logarithmic measure of the light attenuation, damage threshold which represent the maximum power density the glasses can resist before getting damaged, and heat resistance testing assessments.

4 Conclusion

Through our investigation into the various applications of spectrophotometry and across various analyses, we reached important findings. We determined the concentration of the blue fluid, with the unknown sample measured at approximately 1.29 percent concentration. Moreover, polycarbonate exhibited minimal transmission at 254 nm indicating its effectiveness in blocking harmful UV radiation, while acrylic demonstrated notable blocking capabilities at 365 nm. Furthermore, we found that the Polished silicon works better than the green plastic at letting infrared light pass through, especially at certain wavelengths like 1450 nm and 1950 nm. Additionally, our spectroscopic analysis of plastics showed distinct absorption peaks for different types. For example, PMMA, PC, and PP exhibited unique absorption spectra, enabling their differentiation based on IR absorption characteristics. Lastly, our evaluation of laser safety glasses demonstrated their efficacy in filtering specific laser wavelengths, particularly for Xenon chloride and Helium-neon lasers. Overall, these results emphasize the practical implications of spectrophotometry in various applications including security measures, material characterization, and occupational safety.

References

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Appendix

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