Prism Spectrometer

Rahmanyaz Annyyev, Hikmat Gulaliyev

02 March 2024

Abstract

In this experiment, we utilize a prism spectrometer—an optical device that separates light into its constituent frequencies—to measure the refractive index of a prism. A collimator with a slit is used to produce a parallel beam of light emitted by a mercury lamp, which is then passed through the prism. The light is then refracted and dispersed into its constituent frequencies. The angle of deviation of the light is measured and used to calculate the refractive index of the prism using a special relation. A graph of the index of refraction versus wavelength is also plotted. The results are compared to the theoretical values and the limitations of the experiment are discussed.

1 Introduction

The visible spectrum is the portion of electromagnetic radiation that is visible to the human eye. It is composed of light with wavelengths between 380 and 780 nm. Each wavelength, or frequency of light is perceived as a different color by the human eye[1]. Spectrum analysis is the study of measure and interpretation of electromagnetic spectra. It is used in various fields such as physics, chemistry, and astronomy. One of the most important tools in spectrum analysis is the prism spectrometer.

A prism spectrometer is an optical device, and it is composed of a collimator, a prism, and a telescope. The collimator is a device that produces a parallel beam of light. It is composed of an adjustable slit on one end and a converging lens on the other. The slit is used to control the width of the entering light, and the lens is used to focus the light into a parallel beam. As the beam exits the collimator, it impinges on the prism. The prism rests on a rotatable table, and it is used to refract and disperse the light into its constituent colors. The telescope is used to observe the dispersed light, and it is composed of a lens and an eyepiece. The set of parallel beams of different wavelengths form images of the slit. The telescope can be rotated with the aid of the reticle to position the images for each spectral line. The instrument that is used throughout the experiment to measure the angles is called a vernier scale. Note that a mercury lamp was used as a source of light.

In this experiment, we use the spectrometer to measure the refractive index of the prism. The refractive index of a prism is a measure of how much the light is bent as it passes through the prism. Examine Figure 1. As you can see, δ is the angle of deviation of the light—the angle between the incident and emergent beams of light, and α is the apex angle of the prism—the angle between two faces of the prism. The deviation angle is dependent on the wavelength of the light. As we vary the incident angle, the deviation angle changes, and we can

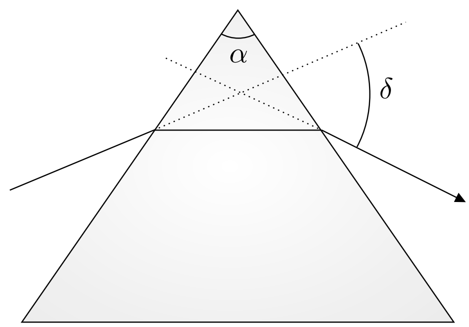

Figure 1: Refraction of light through a prism.

obtain its minimum value. This happens when the angle of incidence is equal to the angle of emergence. Hence, in this case, the refractive index of the prism is given by the relation

$$n = \frac{\sin\left((\delta_{min} + \alpha)/2\right)}{\sin\left(\alpha/2\right)}, \tag{1}$$

which is derived from Snell's law,

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2), \tag{2}$$

where n_1 and n_2 are the refractive indices of the two media, and θ_1 and θ_2 are the angles of incidence and refraction, respectively. Note that the light is refracted twice as it enters and exits the prism.

A dispersion curve is a graph of the refractive index versus wavelength. It can be represented using the Cauchy equation,

$$n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \cdots, \tag{3}$$

where A, B, and C are constant pertaining to a specific material. The dispersion curve is used to determine the refractive index of a material at a specific wavelength.

2 Data & Results

The first part of the experiment involved measuring the angle of the prism, α. The prism was placed on the rotatable table, and the telescope was used to measure the angle. The prism was placed in the center of the table, and the telescope was rotated and used to measure the angle of the prism. The angle is given by the average of the two positions of the telescope:

$$\alpha = \frac{\texttt{Position}_1 + \texttt{Position}_2}{2}. \tag{4}$$

The results are shown in Table 2. The average angle of the prism is given by $\bar{\alpha} = 59.87°$.

Position #1	Position #2	α_i
52°46′	293°01′	59.86°
52°52′	293°05′	59.88°
52°48′	293°03′	59.86°
		$\bar{\alpha} = 59.87°$

Table 1: Data for the prism angle, α.

In the second part of the experiment, we measured the minimum angle of deviation, δ_{min}, for each wavelength. The results are shown in Table 2. The refractive index for each wavelength is calculated using the Equation 1. The results are shown in Table 2.

λ (nm)	Position #1	Position #2	δ_{min}	n
404.6 Violet	351°48′	27°40′	40.19	1.5357
435.8 Blue	351°48′	28°41′	39.18	1.5243
546.1 Green	351°48′	29°28′	38.31	1.5144
579.1 Orange	351°48′	29°49′	38.02	1.5111

Table 2: Data for the refractive index versus wavelength.

The minimum deviation angle, δ_{min}, was calculated using the formula

$$\delta_{min} = 360° - \texttt{Position}_1 + \texttt{Position}_2. \tag{5}$$

And the refractive index is given by

$$n = \frac{\sin\left(\frac{\delta_{min}+\alpha}{2}\right)}{\sin\left(\frac{\alpha}{2}\right)}, \tag{6}$$

where α is the angle of the prism. Hence, the refractive index for each wavelength is given by

$$n_{\text{Violet}} = \frac{\sin\left(\frac{38.02^\circ + 59.87^\circ}{2}\right)}{\sin\left(\frac{59.87^\circ}{2}\right)} = 1.77 \tag{7}$$

$$n_{\text{Blue}} = \frac{\sin\left(\frac{38.31^\circ + 59.87^\circ}{2}\right)}{\sin\left(\frac{59.87^\circ}{2}\right)} = 1.78 \tag{8}$$

$$n_{\text{Green}} = \frac{\sin\left(\frac{40.19^\circ + 59.87^\circ}{2}\right)}{\sin\left(\frac{59.87^\circ}{2}\right)} = 1.79 \tag{9}$$

$$n_{\text{Orange}} = \frac{\sin\left(\frac{39.18^\circ + 59.87^\circ}{2}\right)}{\sin\left(\frac{59.87^\circ}{2}\right)} = 1.78 \tag{10}$$

After obtaining the refractive index for each wavelength, we can plot two graphs, showing relationship between refractive index and wavelength.

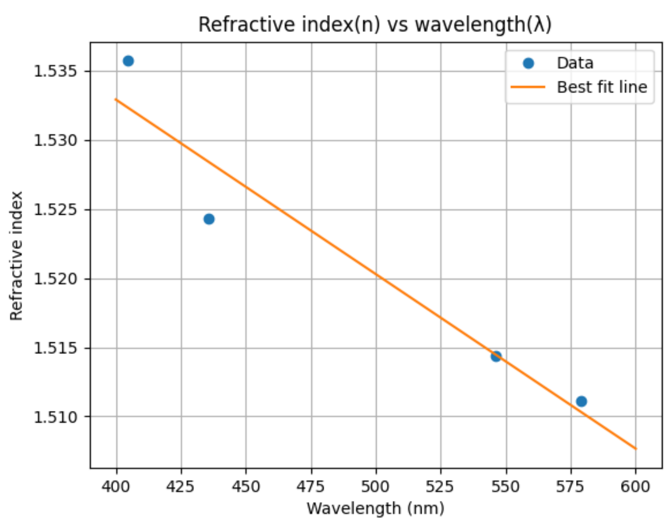

Figure 2: Refraction index versus wavelength.

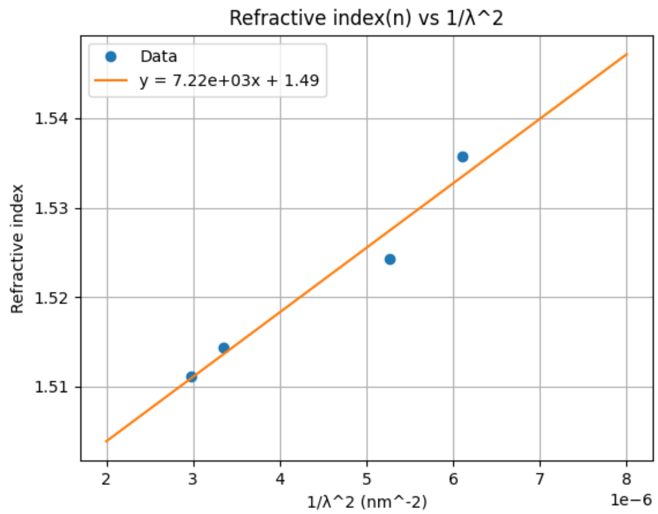

Figure 3: Refraction index versus inverse square of wavelength.

3 Discussion & Conclusion

Due to analog nature of this experiment, human error is inevitable. Especially manually reading the angles using an vernier scale, introduces some error. Also maving to manually adjust the telescope to find the minimum deviation angle is another source of error. Before and during the experiment some assumptions were made, such as the light source is monochromatic, the prism is perfectly shaped and uniform, Airs refractive index is 1, and the telescope is perfectly calibrated. These assumptions might not hold in real life, and they might introduce some error to the results. Despite these experiment is in-line with the theoretical values. Everything was in line with the theory but the number of spectral lines. It might be explained by the fact that some of these lines are too close to each other to be seen by the human eye. In general, the experiment was successful and the results were in line with the theoretical values. Optoelectronics might be introduced to the further studies to reduce the human error and increase the accuracy of the results.

References

[1] Robert T. Marcus. *The Measurement of Color*. Vol. 1. AZimuth. North-Holland, 1998, pp. 31–96. ISBN: 978-0-444-82825-6. DOI: `https://doi.org/10.1016/S1387-6783(98)80005-6`.