8 - DISPERSION

OBJECTIVES

- To measure the angle of deviation of light passed through a prism by using a goniometer.
- To study the phenomenon of dispersion by determining the angle of refraction of the prism for different wavelengths.

EQUIPMENTS

- **Goniometer.**
- **He, Ne and H_2 spectral lamps.**

GENERAL INFORMATION

A *goniometer* is an optical instrument that creates and analyzes a spectrum. It is shown schematically in Figure1. It consists of four main parts: collimator, prism table, prism, and telescope.

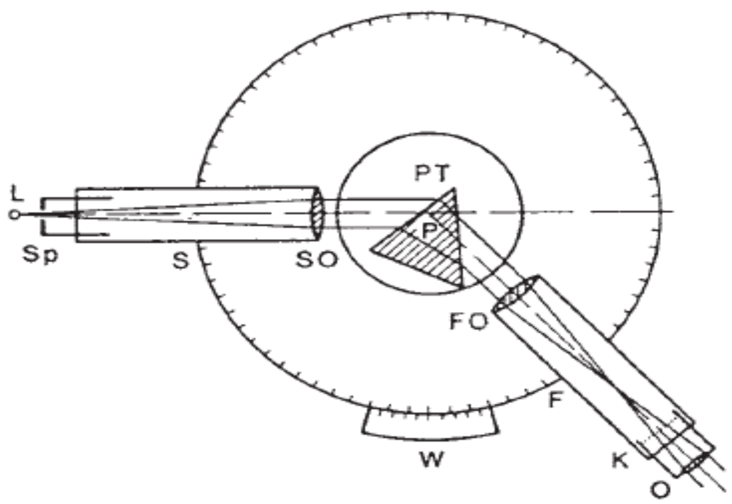

Figure 1: Schematic drawing of a goniometer.

A Goniometer setup consists of four parts:

1 - Collimator: It is a tube with an adjustable slit at one end and a converging lens at the other end. The rays of light coming from the light source enter through the slit and exit parallel to the axis of the collimator.

2 - Prism Table: A small prism stand, used to place the prism, is positioned on the table so that it is coaxial with it. The parallel rays coming from the collimator are directed onto the prism placed on the goniometer table.

3 - Telescope: An instrument that can rotate around the prism axis and is used to examine the light that comes directly or passes through the prism.

4 - Prism: It refracts and disperses the different wavelengths of light from the light source. The set of parallel rays emerging from the prism (one set for each wavelength) enters the telescope, and when viewed through the telescope, distinct lines are observed in the shape of the collimator slit.

In this experiment, the refractive index of the material from which the prism is made will first be determined. Transparent objects with a triangular cross-section are called optical prisms (see Figure 2). The angle between the intersecting planes is called the apex angle (or refracting angle) of the prism. A ray of light that hits one of the lateral surfaces emerges from the other lateral surface in a direction different from it’s initial direction due to refraction. The angle between the direction of incidence of the light on the prism and the direction of its exit is called the angle of deviation, denoted by δ.

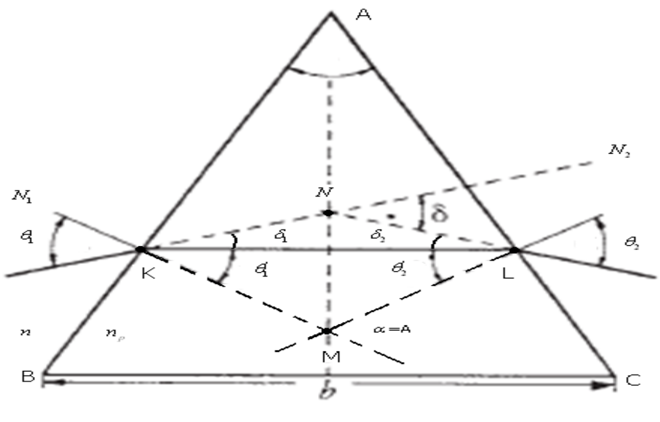

Figure 2: Determination of the deviation angle of the prism.

If we consider that a light ray coming from a medium with a refractive index n enters the prism with a refractive index of n_p at point K and exits the prism at point L, Snell's Law applies to the refractions at points K and L in the following form:

$$n sin\theta_1 = n_p sin\theta_1 \qquad (1)$$

$$n_p sin\theta_2 = n sin\theta_2 \qquad (2)$$

The exterior angle δ of triangle *KLN* is equal to the sum of the two non-adjacent interior angles δ_1 and δ_2.

$$\delta = \delta_1 + \delta_2 \qquad (3)$$

$$\delta = (\theta_1 - \theta_1') + (\theta_2 - \theta_2') \qquad (4)$$

$$\delta = (\theta_1 + \theta_2) - (\theta_1' + \theta_2') \qquad (5)$$

Since the arms of the exterior angle α at vertex *M* of triangle *KLM* are perpendicular to the arms of the refracting angle *A* of the prism, $A = a$. At the same time, in triangle *KLM*, $\alpha = \theta_1' + \theta_2'$, so: $\delta = \theta_1 + \theta_2 - A$

- **Minimum Deviation**

The angle of deviation varies according to the angle at which the light ray strikes the surface of the prism. The smallest value of the angle of deviation is called the minimum deviation. In this case:

$$\theta_1 = \theta_2 , \theta_1' = \theta_2' , A = 2\theta_1' \qquad (6)$$

Hence the angle of minimum deviation is given by:

$$\delta_{min} = 2\theta_1 - A \qquad (7)$$

When the angle of deviation is at it's minimum, the refractive index of the prism can be found using a simple relationship. To derive this relationship, Snell's law is applied at the surface where the light enters the prism. Following figure 2:

$$nsin\theta_1 = n_p sin\theta_1' \qquad (8)$$

can be obtained. In the case of the minimum deviation:

$$\theta_1 = \frac{(\delta_{min} + A)}{2} \text{ and } \theta_1' = \frac{A}{2} \qquad (9)$$

When these values of θ_1 and θ_1' are placed in the Snell's equation and solved for n_p:

$$n_p = \frac{sin\left(\frac{\delta_{min} + A}{2}\right)}{sin\left(\frac{A}{2}\right)}$$ is obtained (For this experiment, $n = 1$). (10)

The graph of the refractive index as a function of wavelength is called the dispersion curve. The experimentally obtained curve can be analytically expressed using the empirical Cauchy formula in the form:

$$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \ldots \qquad (11)$$

A, B, and C are known as the Cauchy constants. Often, it is sufficient to take only the first two terms.

In this experiment, the refractive index of the material from which the prism is made will be determined for several different wavelengths, and the Cauchy constants will be obtained.

EXPERIMENTAL PROCEDURES

1 - Before the prism is placed on the table, the telescope's focus is adjusted and is not changed until the end of the experiment.

2 - The collimator is adjusted to obtain parallel light. Once adjusted, the collimator's setting is not changed.

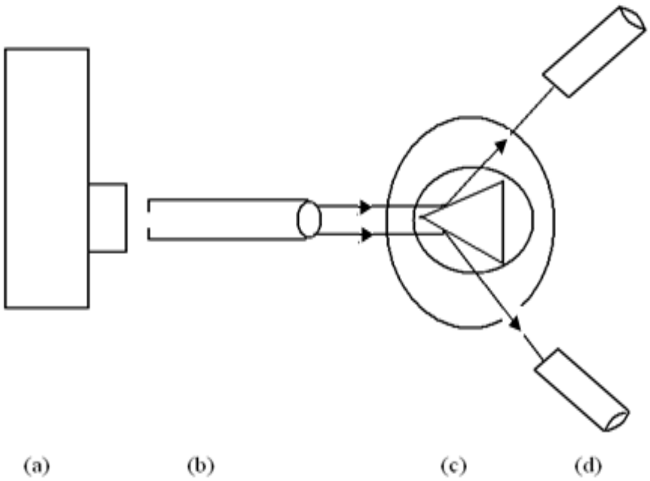

Figure 3: Measuring the apex angle of the prism. (a) Light source. (b) Collimator. (c) Prism and the prism table. (d) Telescope.

3 - The prism is properly placed on the goniometer table as shown in Figure 3.

4 - By moving the telescope, the angular position of the light reflected from one face of the prism is read (telescope position 1).

5 - The obtained value is recorded in its corresponding place in Table 1.

6 - The telescope is rotated to observe the light reflected from the other face of the prism. In this case, the angular position of the telescope is read (telescope position 2), and the obtained value is again recorded in its corresponding place in Table 1.

- ## Measuring the angle of minimum deviation

1 - The prism is removed. Through the telescope, a fine line in the center, called the slit, is observed.

2 - The position of the telescope is read (telescope position 1) and recorded in its corresponding place in Table 2.

3 - The prism is placed as shown in Figure 4. The rays coming from the collimator are refracted and exit through the other face of the prism. The telescope is adjusted to observe this image. Keeping the telescope fixed, the table is slowly moved, and the turning point of the image is found. The angular position of the telescope in this situation is read (telescope position 2) and recorded in its corresponding place in Table 2. This process is repeated several times until the turning point is clearly determined.

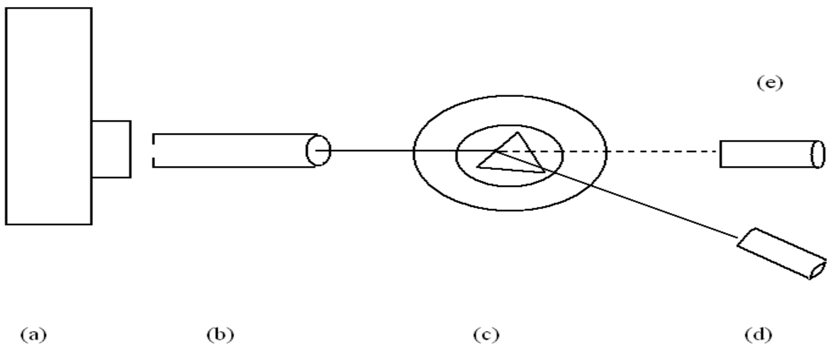

Figure 4: Determining the angle of minimum deviation. (a) Light source. (b) Collimator. (c) Prism and prism table. (d) Telescope at position 1. (e) Telescope at position 2.

This process is repeated for lines of different wavelengths. For each wavelength, the refractive index is calculated using. A graph is then plotted with the refractive index on the vertical axis and the wavelength on the horizontal axis.

Experimental points are plotted on graph paper. Assuming that the relationship between n and λ is given by the Cauchy formula, the least squares line is determined for the expression:

$$n - 1 / \lambda^2$$

The values of the constants *A* and *B* are obtained from this line.

Table 1: Values required for determining the apex angle.

	Case 1	Case 2	*A*
1)			
2)			
3)			

Table 2: Values for refraction index corresponding to the wavelength.

	λ	Case 1	Case 2	δ_{min}	*n*
1)					
2)					
3)					
4)					
5)					
6)					
7)					