Dispersion of light by a prism

Aim: (i) To calculate refractive index μ of a prism for various wavelengths (λ) of Hg and to find dispersive power of the material of the prism.

(ii) To plot μ-1/λ^2 curve and hence determine Cauchy's constants for the prism material.

Apparatus: Spectrometer, prism, Hg lamp and spirit level

Theoretical background

When a ray of light is refracted by a prism, the angle between the incident and refracted ray is called the *angle of deviation δ.* For a given prism angle A and wavelength λ, δ depends on the angles of incidence *i* and emergence *r* (See Fig. 1). The angle of deviation is minimum when the angles of incidence *i* and emergence *r* make equal angles with prism surfaces, i.e. *i*= *r*. We denote this angle of minimum deviation as δ_m which depends on the wavelength of the light used. Refractive index of the prism for a given wavelength of light λ is related to the corresponding δ_m by,

$$\mu(\lambda) = \frac{sin\left(\frac{A+\delta m}{2}\right)}{\sin\left(\frac{A}{2}\right)} \qquad (1)$$

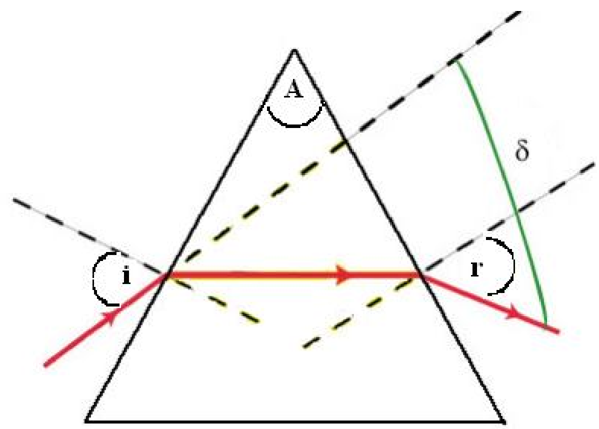

Fig. 1

If μ_1 and μ_2 are refractive indices of the material of the prism for wavelengths λ_1 and λ_2, and μ is the refractive index of λ, which is the mean of λ_1 and λ_2, then dispersive power is defined as

$$\omega = \frac{\mu_2 - \mu_1}{\mu - 1} \qquad (2)$$

Using Eq.(1), μ(λ) of the prism can be obtained experimentally by determining δ_m for the corresponding λ. Thus a calibration curve of μ-λ can be drawn for the prism from which the refractive index can be determined for a given wavelength or vice-versa. The experimental μ-λ curve can be described with a fair degree of accuracy by the empirical Cauchy's equation,

$$\mu(\lambda) \approx C + \frac{D}{\lambda^2}, \qquad (3)$$

where C and D are Cauchy's constants for the prism material. The plot μ versus 1/λ^2 is a straight line from which C and D values can be determined by fitting the data with Cauchy's relation.

The dispersion of the material of the prism is defined as $d\mu/d\lambda$, which can be obtained from the Cauchy's formula in eqn. (2),

$$\frac{d\mu}{d\lambda} = \frac{-2D}{\lambda^3}, \qquad (4)$$

Experimental set up:

In this experiment, we will use a prism spectrometer to measure the deviations of light for various wavelengths. The detail description of the spectrometer is already provided as a separate note. Before starting the experiment please identify all parts of the spectrometer. Familiarize yourself with the focusing adjustments and also coarse and fine movement of different parts.

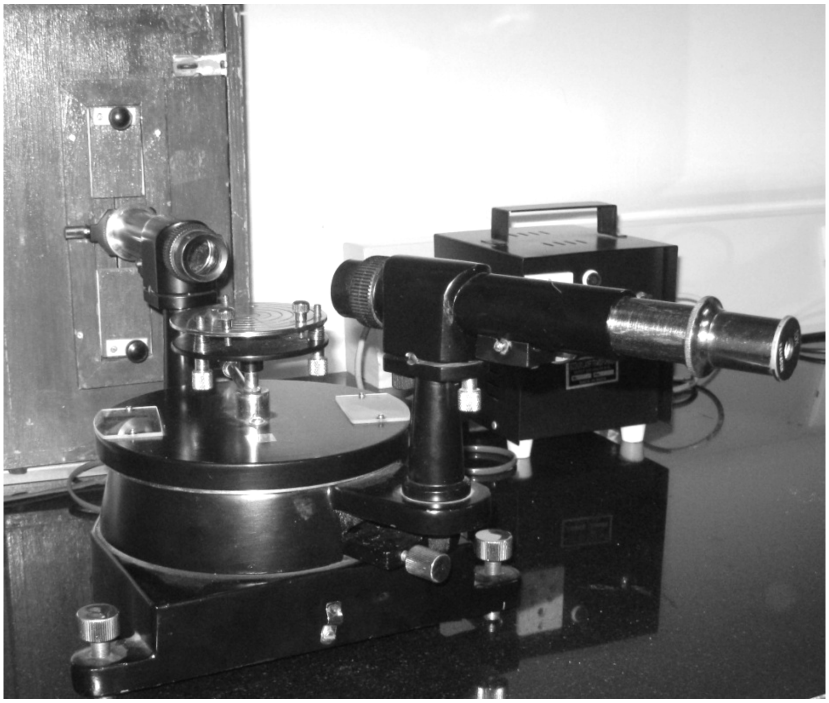

Fig. 2: Experimental set up

Procedure:

1. DO NOT PLACE THE PRISM ON THE SPECTROMETER YET.
2. First check leveling of the spectrometer base, prism table, collimator and telescope. If needed, level them using the adjustment screws and a spirit level.
3. The collimator is adjusted for parallel beam of light and the telescope for focusing the parallel beam by Schuster's method (details of which is given in another experiment). But the present set up may not require it.
4. **Adjusting the telescope:** While looking through the telescope, slide the eyepiece in and out until the crosswire comes into sharp focus. Point the telescope at some distant object and view it through the telescope. Turn the focus knob of telescope until the image is sharp. The telescope is now focused for parallel light rays. DO NOT change the focus of the telescope henceforth.
5. Ensure the Hg lamp is fully illuminated and placed close to the slit of the collimator. Check that the slit is partially open.
6. **Adjusting the collimator:** Align the telescope directly opposite the collimator and look through the telescope, to see a focused image of the slit. If necessary, adjust the slit width

until the image of the slit as seen through the telescope is sharply focused on the crosswire. The collimator is then set to produce parallel light from the slit.

7. Determine the vernier constant of the spectrometer. Report all the angles in degree unit. Details about reading angles in spectrometer are given in the manual for finding angle of minimum deviation.
8. **Angle of prism:** (Refer Fig. 2)

- Place the prism such that its vertex is at the center of the prism table, directly in line with the illuminated slit.
- The opaque face (AC) should face towards you so that light from the collimator is reflected at the two faces AB and AC.
- Rotate and adjust the telescope to position I where the image of the slit reflected at AB is centered on the crosswire. Record the angular positions on each vernier.
- Now, turn the telescope to position II for the image reflected at AC and record again the angular positions on each vernier.
- Take three independent sets of readings for telescope position I and II on each vernier. Let the mean of these three sets of readings of the two verniers V_1 and V_2 are respectively,
  telescope position I: α_1 , α_2
  telescope position II: β_1 , β_2
- Then the mean angle of the prism A is obtained using $\mathbf{2A = (A_1 + A_2)/2}$, where $A_1 = \alpha_1 \sim \beta_1$ and $A_2 = \alpha_2 \sim \beta_2$.

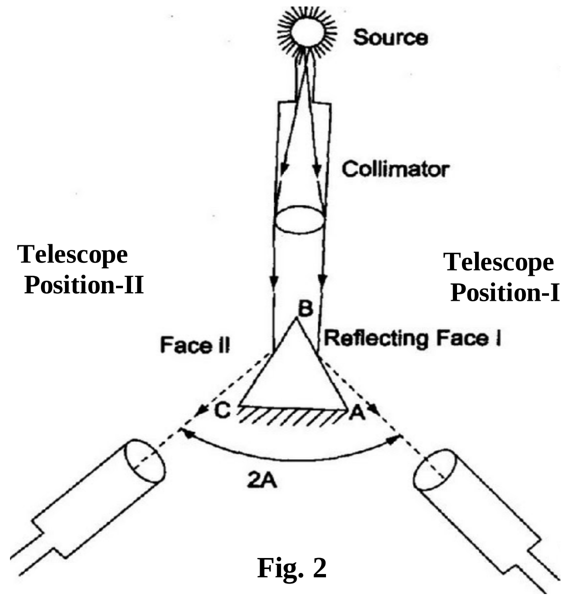

Fig. 2

9. **Direct ray reading:** Remove the prism from the spectrometer and align the telescope so that the direct image of the slit is seen through the telescope centered on the crosswire. Record the angular position of the telescope on the two verniers as D_1 and D_2. This will be the reference angular position for any measurements later.
10. **Angle of minimum deviation:** (Refer Fig. 3)

- Replace the prism on the spectrometer table so that it is oriented as shown in Fig. 3.
- Locate the image of the spectrum with naked eye. Then rotate the telescope to bring the spectrum in the field of view.
- Gently turn the prism table back and forth. As you do so, the spectrum should appear to migrate in one direction until a point at which it reverses its direction.
- Lock the prism table. Now, using fine adjustment screw

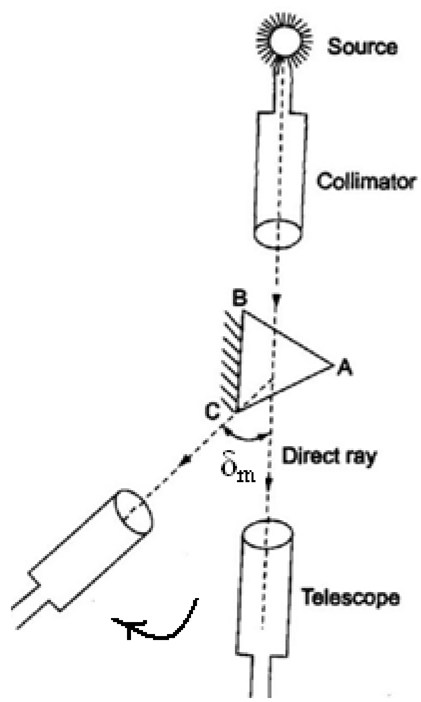

Fig. 3

of the telescope fix the crosswire on one of the spectral lines of wavelength λ_1 at an extreme end.

- Then move the prism table using fine adjustment screw so that the angle where the line starts reversing its direction is precisely located. Take three such independent readings. Let the mean of these readings on the two verniers V_1 and V_2 for λ_1 are θ_1 and θ'_1. Calculate the mean value of $\delta_m(\lambda_1)$ as follows:

$$\delta m(\lambda_1) = \frac{1}{2}[(\theta_1 \sim D_1) + (\theta'_1 \sim D_2)]$$

- Similarly, note down the angles of minimum deviation for all the spectral lines, whose wavelengths and colors are given in the chart. (see last page)

11. Calculate the refractive index for each wavelength using Eq.1 and then determine the dispersive power using Eq. 2.
12. Plot $\mu \sim (1/\lambda^2)$ and determine Cauchy's constants by least square fitting.

OBSERVATIONS

Table 1: Determination of vernier constant (VC) of the spectrometer

Value of 1 small main scale division (MSD) = ………

……. vernier scale divisions = ….. main scale divisions

Hence, 1 vernier scale division = ………… main scale division (VSD)

Vernier Constant (VC) = (1 – VSD) x MSD = ………

Table-2. Determination of the angle of the prism

Vernier	obs	Reflection image1				Reflection image 2				2A (degree)	Mean 2A (degree)	A (degree)
		Main scale (M)	Vernier (V)	T = M + VC x V	Mean T (degree)	Main scale (M)	Vernier (V)	T = M + (VC x V)	Mean T (degree)			
V_1	1											
	2				$\alpha_1 =$				$\beta_1 =$	$A_1 = \alpha_1 \sim \beta_1$	$2A = (A_1 + A_2)/2$	
	3											
V_2	1											
	2				$\alpha_2 =$				$\beta_2 =$	$A_2 = \alpha_2 \sim \beta_2$		
	3											

Table-2. Direct ray reading

Vernier	Obs.	Main scale (M)	Vernier (V)	T = M + (VC x V)	Mean (degree)
V_1	1 2 3				D_1
V_2	1 2 3				D_2

Table-3. Angle of minimum deviation for various λ

Color / λ(nm)	Vernier	Obs	Main Scale(M)	Vernier (V)	T = M + (VC x V)	Mean (degree)	$\delta_m(\lambda_n)$ (degree)	Mean $\delta_m(\lambda_n)$ (degree)
Color λ_1	V_1	1 2 3				θ_1	$\theta_1 \sim D_1$	$\delta_m(\lambda_1) =$ …………….
	V_2	1 2 3				θ'_1	$\theta'_1 \sim D_2$	
. . .	. . .	. . .						. . .
Color λ_N	V_1	1 2 3				θ_n	$\theta_n \sim D_1$	$\delta_m(\lambda_N) =$ ……………
	V_2	1 2 3				θ'_n	$\theta'_n \sim D_2$	

Table-4. Determination of refractive indices $\mu(\lambda)$ and data for $\mu - 1/\lambda^2$ plot

angle of the prism, A = ….

Color	λ(nm)	$1/\lambda^2$ (nm^{-2})	$\delta_m(\lambda)$	$\mu(\lambda)$
.. ..	……….. ………..	……….. ………..	……….. ………..	……….. ……….. . . .

Calculations:

Dispersive power of prism =

Cauchy's constants: Using least square fitting in $\mu - 1/\lambda^2$ plot

C = ….. **D = ……**

Precautions:

1. Do not touch the refracting surfaces by hand. Place the prism on the prism table or remove it from the prism table by holding it with fingers at the top and bottom faces. The reflecting surfaces of the prism should be cleaned with a piece of cloth soaked in alcohol.
2. Rotate the adjustment screws slowly. Do not force any movement. If something is not moving check the clamping screw. Use fine adjustment screw after locking the clamping screw.

Questions: 1) What is normal and anomalous dispersion? Where do you get anomalous dispersion?

2) What are the factors on which the dispersive power of a prism depends?

Additional Reading:

1. **Feynman lectures on physics**, volume 1. Narosa Publishing House, Delhi
2. **Practical Physics**, R.K. Shukla and A. Srivastava, New Age International (P) Ltd.