EXPERIMENT 5:Determination of the refractive index (μ) of the material of a prism using sprectometer

Debangshu Mukherjee
B.Sc Physics,1st year
Chennai Mathematical Institute

17.10.2008

1 Aim of Experiment

We try to calculate the Refrative Index of the Prism for various wavelengths of the Mercury Spectrum and then plot a Dispersion and Calibration Curves using a Prism Spectrometer.

2 Apparatus required

a)Mercury lamp(as source of white light)
b)Sprectometer
c)Prism
d)Spirit level

3 Theory of experiment

The spectrometer is an instrument for analyzing the spectra of radiations. The glass-prism spectrometer is suitable for measuring ray deviations and refractive indices. Sometimes a diffraction grating is used in place of the prism for studying optical spectra. A prism refracts the light into a single spectrum, whereas the diffraction grating divides the available light into several spectra. Because of this, slit images formed using a prism are generally brighter than those formed using a grating. Spectral lines that are too dim to be seen with a grating can often be seen using a prism. Unfortunately, the increased brightness of the spectral lines is offset by a decreased resolution, since the prism doesn't separate the different lines as effectively as the grating. However, the brighter lines allow a narrow slit width to be used, which partially compensates for the reduced resolution.

With a prism, the angle of refraction is not directly proportional to the wavelength of the light. Therefore, to measure wavelengths using a prism, a calibration graph of the angle of deviation versus wavelength must be constructed using a light source with a known spectrum. The wavelength of unknown spectral lines can then be interpolated from the graph. Once a calibration graph is created for the prism, future wavelength determinations are valid only if they are made with the prism aligned precisely as it was when the graph was produced. To ensure that this alignment can be reproduced, all measurements are made with the prism aligned so that the light is refracted at the angle of minimum deviation.

The light to be examined is rendered parallel by a collimator consisting of a tube with a slit of adjustable width at one end and a convex lens at the other. The collimator has to be focused by adjusting the position of the slit until it is at the focal point of the lens. The parallel beam of light from the collimator passes through a glass prism standing on a prism-table which can be rotated, raised or lowered, and levelled. The prism deviates the component colors of the emitted light by different amounts and the spectrum so produced is examined by means of a telescope, which is mounted on a rotating arm and moves over a divided angular scale.

The theory of the prism spectrometer indicates that a spectrum of maximum definition is obtained when the angular deviation of a light ray passing through the prism is a minimum. Under such conditions it can be shown that the ray passes through the prism symmetrically. For a given wavelength of light traversing a given prism, there is a characteristic angle of incidence for which the angle of deviation is a minimum. This angle depends only on the index of refraction of the prism and the angle between the two sides of the prism traversed by the light. The relationship between these variables is given by the equation:

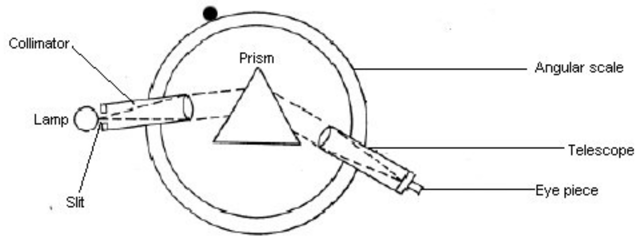
$$n = \frac{sin(\frac{A+\delta_m}{2})}{sin\frac{A}{2}} \tag{1}$$

where n is the index of refraction of the prism and δ_m is the angle between the sides of the prism traversed by the light and is the angle of minimum deviation. Since n varies with wavelength, the angle of minimum deviation also varies, but it is constant for any particular wavelength.

The telescope can also be locked or moved very slowly by a fine adjustment screw and the instrument is provided with a heavy base for stability. To obtain sharp spectral lines the slit width should be quite small, about 0.1-0.3 mm.

The amount by which the visible spectrum spreads out into its constituent colors depends on how rapidly the refractive index of the prism material varies with the wavelength of the radiation, i.e.$\frac{dn}{d\lambda}$. This quantity is called the dispersion and is of prime importance in spectroscopy, since if the dispersion is small, radiation of slightly differing wavelengths cannot be resolved into separate and distinct spectral lines.

4 Procedure



Prism Spectrometer

• First the telescope has to be focussed distant objects i.e infinity and this has to be maintained until the experiment is over, so as not to refocus again. Then, the cross-wires should be focussed by moving the eye-piece of the telescope.
• Adjust the Collimater such that the image seen in the telescope is sharp of the slit without the prism.
• **Measuring the Angle of PrismA:**Place the prism on the Prism Table and lock the prism table in the position so the the incident beam falls on one of the edges of the prism. Now, move the telescope and locate the images of the slit and note down the angles. The difference beteen both the angles is $2A$. Hence, half of the diffece will give us A.
• Now, choose an angle of incidence other than the preious chosen one and with eye locate aprroximately the angle at which the spectrum starts to move in the opposite direction as the prism table is rotated, and lock the prism table. Now, using the telescope, fix the telescope on one of the sprectrum lines, and then use the fine adjustment for the movement of prism tabe to move the table so that we get the precise location of the angle where the line starts to move in the opposite direction, and note the angle for this.
• Without disturbing anything, remove the prism and get the measure of the angle of the direct image of the slit in the telescope. The difference between these two angles is the Angle of Minimum Deviation δ_m for this spectral line λ. Repeat the same for all the spectral lines that are given by the mercury lamp.
• From above data we can calculate the refractive index n of the prism for various wavelengths. For the *Calibration Curve*, plot a graph of δ_m versus λ. For the *Dispersion Curve*, plot a graph of n versus λ.
• We can also calculate the Cauchy's constants A and B by doing a least squares fit of the data to the Cauchy Formula $n = A + \frac{B}{\lambda^2}$. We can also

calculate the Resolving Power (R) of the prism using the two yellow lines of the mercury spectrum as $R = \frac{\lambda}{d\lambda}$ where $\lambda = \frac{\lambda_1 + \lambda 2}{2}$ and $d\lambda = \lambda_2 - \lambda_1$

5 Calculations

Colour	λ (nm)
Red	623.437
Yellow	576.959
Green	546.074
Blue	497.325
Violet	404.656

These data are obtained standard values obtained from books and internet.
• R_1-one particular line of the spectrum at the position of minimum deviation
• R_2-the reflected ray coming from the prism
• R_3-the image of the slit without the prism on the prism table
Angle of minimum deviation $D_m = R_1 \sim R_3$
Angle of incidence for minimum deviation $i = 90° - \frac{R_2 \sim R_3}{2} = \frac{A + D_m}{2}$
Angle of prism $A = 2i - D_m$
Refractive index

$$\eta = \frac{sini}{sin\frac{A}{2}} \quad (2)$$

Measurement for RED light

	UPPER SCALE			LOWER SCALE		
	R_1	R_2	R_3	R_1	R_2	R_3
$M.S.R$	329.5°	86.5°	8.5°	149.5°	266°	188°
$V.S.R$	$7'$	$1'$	$3'$	$14'$	$20'$	$12'$
$T.R$	$329°37'$	$86°31'$	$8°33'$	$149°44'$	$266°20'$	$188°42'$

. The μ value = 1.48
Measurement for YELLOW light

	UPPER SCALE			LOWER SCALE		
	R_1	R_2	R_3	R_1	R_2	R_3
$M.S.R$	329°	86.5°	8.5°	149°	266°	188°
$V.S.R$	$27'$	$1'$	$3'$	$36'$	$20'$	$12'$
$T.R$	$329°27'$	$86°31'$	$8°33'$	$149°36'$	$266°20'$	$188°42'$

. the μ value is = 1.49
Measurement of GREEN light

UPPER SCALE				LOWER SCALE		
	R_1	R_2	R_3	R_1	R_2	R_3
$M.S.R$	329°	86.5°	8.5°	149°	266°	188°
$V.S.R$	$5'$	$1'$	$3'$	$2'$	$20'$	$12'$
$T.R$	$329^\circ 5'$	$86^\circ 31'$	$8^\circ 33'$	$149^\circ 2'$	$266^\circ 20'$	$188^\circ 42'$

. The μ value is $= 1.50$

Measurement of BLUE light

UPPER SCALE				LOWER SCALE		
	R_1	R_2	R_3	R_1	R_2	R_3
$M.S.R$	328.5°	86.5°	8.5°	148.5°	266°	188°
$V.S.R$	$5'$	$1'$	$3'$	$12'$	$20'$	$12'$
$T.R$	$328^\circ 35'$	$86^\circ 31'$	$8^\circ 33'$	$149^\circ 42'$	$266^\circ 20'$	$188^\circ 42'$

. The μ value is $= 1.51$

Measurement of VIOLET light

UPPER SCALE				LOWER SCALE		
	R_1	R_2	R_3	R_1	R_2	R_3
$M.S.R$	327°	86.5°	8.5°	147°	266°	188°
$V.S.R$	$5'$	$1'$	$3'$	$24'$	$20'$	$12'$
$T.R$	$327^\circ 5'$	$86^\circ 31'$	$8^\circ 33'$	$147^\circ 24'$	$266^\circ 20'$	$188^\circ 42'$

. The μ value is $= 1.54$

- The behaviour of the Dispersion curve can be seen that the fall is not rapid over these range of wavlengths, hence, it is not a very heavily sloping line which implies that the dispersion of various spectral line donot vary a lot from each other i.e which is manifested by the closeness of the refractive index for the range of wavelengths.It can be observed that the curve is roughly parabolic in nature.The dispersion curve is as follows:

Now, if μ be the refractive index of the medium, then by Cauchy's formula,

$$\mu = a + \frac{b}{\lambda^2}$$

Now, we take two arbitray readings, say for RED and YELLOW light. Then, we put the values of μ and λ and get two simultaneous equation. We solve for a and b. The values are :

$$a = 1.42 \text{ and } b = 23190.125$$

For verification, we substitute this values in the equation again, but using a differrent λ value, say of GREEN light. We get the μ for GREEN light to be 1.50 which is same as the experimental value.

6 Results

Thus, the mean refractive index of the material = 1.504

7 Discussions

•It must be ensured that the light rays coming out of collimator are parallel. Hence, the collimator must be focussed properly before the experiment.
•The plane on which the priam rests must be horizontal
•The slit must be as thin as possible in order to avoid diffraction