Trace this figure also. The frequency of the electrically maintained tuning fork will be half of the frequency of signal generator.

(4) Again adjust the frequency of the signal generator such that a figure of eight is obtained in horizontal direction ∞. Trace the figure on a tracing paper. The frequency of the tuning fork will be double the frequency of signal generator in this case.

Result :

(1) The waveform of the electrically maintained tuning fork is shown on the attached tracing paper.

(2) The frequency of the electrically maintained tuning fork = ... cycles/sec.

LIGHT

Refraction and Dispersion of Light

EXPERIMENT No. 1

Object : To determine the refractive index of the material of the prism for the given colours (wavelengths) of mercury light with the help of a spectrometer.

Apparatus required : Spectrometer, given prism, mercury source and reading lens.

Formula used :

The refractive index of the material of the prism is given by the following formula

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)},$$

where A = Angle of the prism,

δ_m = Angle of minimum deviation.

Description of the apparatus :

Spectrometer : The spectrometer consists of the following parts :

(i) the Collimator C,

(ii) the prism table P, and

(iii) the Telescope T.

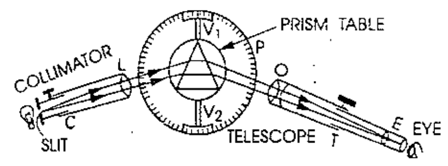


Fig. (1)

(i) The Collimator : The collimator C consists of two hollow concentric metal tubes, one being longer than the other. The longer tube carries an achromatic lens L at one end and the smaller tube on the other end. The smaller tube is provided with a slit at the outer end (width of the slit can be adjusted with the help of a screw attached to it) and can be moved in or out the longer tube with the help of rack and pinion arrangement. The slit is adjusted in the focal plane of the lens L to obtain a pencil of parallel rays from the collimator when light is allowed to be incident upon slit. The collimator is also provided with two screws for adjusting the inclination of the axis of the collimator. This is rigidly fixed to the main part of the apparatus.

(ii) The Prism Table : It is a circular table supported horizontally in the centre of the instrument and the position can be read with the help of two verniers attached to it and moving over a graduated circular scale carried by the telescope. The levelling of the prism table is made with the help of three screws provided at the lower surface. The table can be raised or lowered and clamped in any desired position with the help of a screw. The prism table is also provided with a tangent screw for a slow motion. There are concentric circles and straight lines parallel to the line joining two of the levelling screws on the prism table.

(iii) The Telescope : The telescope consists of similar tubes as in case of collimator carrying achormatic objective lens O at one end and Ramsdon eyepiece E on the another side end. The eyepiece tube can be taken in or out with the help of rack and pinion arrangement. Two crosswires are focussed on the focus of the eyepiece. The telescope can be clamped to the main body of the instrument and can be moved slightly by tangent screw.

The telescope is attached to the main scale and when it rotates, the graduated scale rotates with it. The inclination of telescope is adjusted by two screws provided at the lower surface.

Adjustment :

Before using the spectrometer, the following adjustments must be made.

(a) The axis of the telescope and that of the collimator must intersect the principal vertical axis of rotation of the telescope.

This adjustement is done by the manufacturer and can only be tested in the laboratory. For this purpose a pin is mounted vertically in the centre of prism table and observing its image in the telescope tube without eyepiece and for a wide slit in the collimator. If the image appears in the middle, then the adjustment is perfect otherwise the image is made in the centre by using the screws supporting the telescope and collimator till the pin appears in the middle.

(b) Prism table should be levelled.

(i) The prism table is levelled with the help of three screws supporting the prism table. A spirit level is placed along a line joining the screws and the two screws are moved till the air bubble appears in the middle. Now place the spirit level along a line perpendicular to the previous line and adjust the third screw such that again the air bubble appears in the middle. Here one thing should be remembered that the first two screws should not be touched this time. The prism table is now levelled.

(ii) The second method which is generally used is optical levelling of the prism table. In this method the prism is placed on the prism table with its refracting edge at the centre of the prism table and one of its polished surface perpendicular to the line joining the two levelling screws P and Q as shown in fig. (2)a.

Now rotate the prism table in such a way that refracting edges AB and AC face towards the collimator and light falling on the prism is usually reflected on both the sides as shown in fig. (2) b.

The telescope is moved to one side to receive the light reflected from the face AB and the levelling screws P and Q are adjusted to obtain the image in the centre of the field of view.

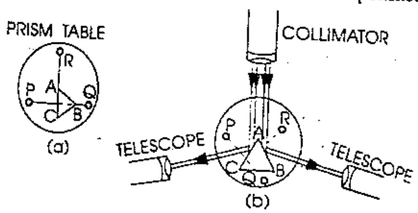


Fig. (2)

Again the telescope is moved to the other side to receive the light reflected from the face AC and the remaining third screw R is adjusted till the image becomes in the central field of view of the telescope.

The procedure is repeated till the two images from both the reflecting faces are seen in the central field of view of the telescope. The prism table is now levelled.

(c) Telescope and collimator are adjusted for parallel light by Schuster's method.

First of all the prism is placed on the prism table and then adjusted approximately for minimum deviation position. The spectrum is now seen through the telescope. The prism table is rotated slightly away from this position towards collimator and the telescope is brought in view. The collimator is well focussed on the spectrum. Again rotate the prism table on the other side of minimum deviation position, *i.e.*, towards telescope and focus the telescope for the best image of the spectrum. The process of focussing the collimator and telescope is continued till the slight rotation of the prism table does not make the image to go out of focus. This means that both collimator and telescope are now individually set for parallel rays.

Procedure :

(A) Measurement of the angle of the prism.

(i) Determine the least count of the spectrometer.

(ii) Place the prism on the prism table with its refracting angle A towards the collimator and with its refracting edge A at the centre as shown in the fig. (3). In this case some of the light falling on each face will be reflected and can be received with the help of the telescope.

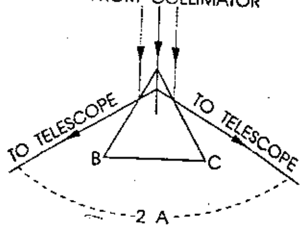


Fig. (3)

(iii) The telescope is moved to one side to receive the light reflected from the face AB and the crosswires are focssed on the image of the slit. The reading of the two verniers are taken.

(iv) The telescope is moved in other side to receive the light reflected from the face AC and again the crosswires are focussed on the image of the slit. The readings of two verniers are noted.

(v) The angle through which the telescope is moved or the difference in the two positions gives twice the refracting angle A of the prism. Therefore, half of this angle gives the refracting angle of the prism.

(B) Measurement of the angle of minimum deviations :

(i) Place the prism so that its centre coincides with the centre of the prism table and light falls on one of the polished faces and emerges out of the other polished face, after refraction. In this position the spectrum of light is obtained.

(ii) The spectrum is seen through the telescope and the telescope is adjusted for minimum deviation position for a particular colour (wavelength) in the following way :

Set up telescope at a particular colour and rotate the prism table in one direction. of course the telescope should be moved in such way to keep the spectral line in view. By doing so a position will come where the spectral line recede in the opposite direction although the rotation of the table is continued in the same direction. The particular position where the spectral line begins to recede in opposite direction is the minimum deviation position for that colour. Note the readings of two verniers.

(iii) Remove the prism table and bring the telescope in the line of the collimator. See the slit directly through telescope and coincide the image of slit with vertical crosswire. Note the readings of two verniers.

(iv) The difference in minimum deviation position and direct position gives the angle of minimum deviation for that colour.

(v) The same procedure is repeated to obtain the angles of minimum deviation for other colours.

Observations :

(i) Value of the one division of the main scale = 0·5 degree
Total number of vernier divisions = 30
Least count of the vernier = 0·5/30 = **1 minute**

(ii) Table for the angle (A) of the prism.

S. No.	Vernier	Telescope reading for reflection from first face			Telescope reading for reflection from second face			Difference a ~ b = 2A	Mean value of 2A	A	Mean A Degrees
		M.S. reading	V.S. reading	Total (a) Degree	M.S. reading	V.S. reading	Total (b) Degree				
1.	V_1	...	...	...	...	...	...	...			
	V_2	...	...	...	...	...	...	...	...	...	
2.	V_1	...	...	...	...	...	...	...			
	V_2	...	...	...	...	...	...	...	...	...	...
3.	V_1	...	...	...	...	...	...	...			
	V_2	...	...	...	...	...	...	...	...	...	

(iii) Table for angle of minimumum deviation (δ_m).

S. No.	Colour	Vernier	Dispersed image. Telescope in minimum deviation position			Telescope reading for Direct image			Difference a ~ b	Mean deviation δ_m degree
			M.S. reading degree	V.S. reading	Total a degree	M.S. reading degree	V.S. reading	Total b degree		
1.	Violet	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
2.	Blue	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
3.	Green	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
4.	Yellow	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	

Calculations :

Angle of minimum deviation for violet = ...

$$\mu \text{ for violet} = \frac{\sin\left(\frac{A+\delta_{m_1}}{2}\right)}{\sin(A/2)}$$

$$= \ldots\ldots$$

Angle of minimum deviation for blue = ...

$$\mu \text{ for blue} = \frac{\sin\left(\frac{A+\delta_{m_2}}{2}\right)}{\sin(A/2)}$$

Similarly find the value of μ for other colours.

Result : Refractive index for the material of the prism :

S. No.	Colour	Calculated μ	Standard μ	% Error
1.	Violet	...	...	...
2.	Blue	...	...	...
3.	...	...	...	...
4.	...	...	...	...
5.	...	...	...	...

Precautions and Sources of Error :

(i) The telescope and collimator should be individually set for parallel rays.

(ii) Slit should be as narrow as possible.

(iii) While taking observations, the telescope and prism table should be clamped with the help of clamping screws.

(iv) Both verniers should be read.

(v) The prism should be properly placed on the prism table for the measurement of angle of the prism as well as for the angle of minimum deviation.

Theroretical Error :

Refractive index of the material of the prism is given by the expression.

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin(A/2)}$$

Taking logarithms of both sides and differentiating

$$\frac{\delta\mu}{\mu} = \frac{\cos\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A+\delta_m}{2}\right)}\frac{\delta(A+\delta m)}{2} + \frac{\cos\left(\frac{A}{2}\right)}{\sin\left(\frac{A}{2}\right)}\frac{\delta(A)}{2}$$

$$\frac{\delta\mu}{\mu} = \cot\left(\frac{A+\delta_m}{2}\right)\frac{\delta(A+\delta_m)}{2} + \cot\left(\frac{A}{2}\right)\delta\left(\frac{A}{2}\right)$$

Now $\left.\begin{array}{l}\delta A = 2' \\ \delta(\delta_m) = 2'\end{array}\right\}$ As the least count of the spectrometer = 1" and there are two verniers.

Hence $\frac{\delta(A+\delta_m)}{2} = 2'$ and $\delta\left(\frac{A}{2}\right) = 1'$

$$\frac{\delta\mu}{\mu} = \cot\left(\frac{A+\delta_m}{2}\right)2' + \cot\left(\frac{A}{2}\right)1'$$

$$= \frac{\pi}{60\times 180}\left\{2\cot\left(\frac{A+\delta_m}{2}\right) + \cot\left(\frac{A}{2}\right)\right\}$$

$$= \ldots\ldots$$

$$= \ldots\ldots\%.$$

ADDITIONAL EXPERIMENTS

EXPERIMENT (1-1)

Object : To study the variation of angle of deviation with the angle of incidence for a prism and to determine the refractive index of the material of the prism using $(i - \delta)$ curve for a given wavelength using prism spectrometer.

Apparatus required : Spectrometer, prism, source of light (mercry or sodium lamp), spirit level and reading lens.

Formula used :

The refractive index of the material of the prism is given by the following formula

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin(A/2)}$$

where δ_m = angle of minimum deviation

A = Angle of prism = $(2i - \delta_m)$, i = angle of incident corresponding to δ_m.

Procedure : (A) Adjustment of spectrometer (see experiment no. 1).

(B) Adjustment of the prism for normal incidence. The following procedure is adopted :

(i) Illuminate the slit of the collimator with the given source of light. Collimator and telescope are arranged in a line and the image of the slit is focussed on the vertical cross wire. The reading of the telescope is noted on the circular scale with the help of one of the verniers attached to it. Let this reading be θ.

(ii) The telescope is now rotated through 90° *i.e.*, the new reading of the telescope is $(\theta + 90)°$. In this position, the telescope and collimator are mutually perpendicular. Now the telescope is clamped.

(iii) Mount the prism on the prism table and rotate the prism table so that the reflected image is seen on the cross wire of the telescope (The tangent screw attached to the prism table may be used for this purpose). The face of the prism now makes an angle 45° with the collimator axis. Note down the position φ of the prism table on the circular scale with the help of one of the verniers attached to prism table.

(iv) Turn the prism table from this position through 45° *i.e.*, its reading is $(\phi + 45°)$. Now the prism face is exactly normal to the direction of incident light. The angle of incidence in this position is zero. Read both the verniers of the prism table.

(C) Observation for obtaining $(i - \delta)$ curve. The following procedure is adopted.

(i) The prism table is turned through 30° (angle of incidence is 30°) and clamped. The reading of both verniers are noted. The telescope is unclamped and rotated to receive the emergent rays from the reflecting surface of the prism. The cross wire is adjusted on the image of the slit. The position of telescope is noted on the circular scale with the help of both verniers attached to it.

(ii) The prism table is rotated through 5° so that the angle of incidence is 35°. The reading of both verniers are noted and prism table is clamped. The telescope is rotated to receive the emergent rays from the reflecting surface of the prism. The cross wire is adjusted on the image of the slit. The position of telescope is noted on the circular scale with the help of both verniers attached to it.

(iii) The experiment is repeated for different angles of incidence.

(iv) The prism is removed from the prism table and the telescope is turned to see the direct image of the slit. The cross wire is adjusted on the image of the slit. The position of telescope is recorded on both the verniers. This gives the direction of the incident beam.

Observations :

Least count of vernier = ...

Table for the setting of the prism :

S. No.	Position of telescope or prism	Angle
1.	Direct position of the telescope on one vernier (θ)	...
2.	Position of the telescope on the same vernier when turned through 90° (θ + 90)°	...
3.	Position of prism table for angle of incidence 45° recorded by one vernier φ°	...
4.	Position of prism table for normal incidence (φ + 45)°	...

Position of the telescope for direct image of the slit

Ist vernier a = ...

IInd vernier b = ...

Table for angle of incidence and deviation.

S. No.	Angle of incidence	Position of telescope for emergent rays		Agle of deviation δ $= \frac{(a'-a)+(b'-b)}{2}$
		Ist vernier a'	IInd vernier b'	
1.	30	...	...	...
2.	35	...	...	...
3.	40	...	...	...
4.	45	...	...	...
5.	50	...	...	...
6.	55	...	...	...
7.	60	...	...	...
8.	65	...	...	...
9.	70	...	...	...
10.	75	...	...	...

Calculations :

(1) Plot a smooth graph between angle of incidence i on X-axis and angle of deviation δ on Y axis. The graph is shown in fig. (4).

(2) From the $(i - \delta)$ graph

Angle of minimum deviation $\delta_m = ...$

Corresponding angle of incidence $i = ...$

∴ Angle of prism $A = 2i - \delta_m$

Now $$\mu = \frac{\sin (A + \delta_m)/2}{\sin A/2} = ...$$

Result : (i) The attached graph represents the variation of angle of deviation with the angle of incidence.

(ii) The refractive index of the material of the prism for λ = ... Å is . . . . . .

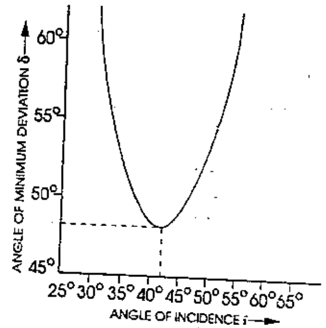


Fig. (4)

EXPERIMENT (1-2)

Object : To study the variation of refractive index of the material of the prism with wavelength and to verify Cauchy's dispersion formula.

Apparatus required : Spectrometer, mercury lamp, prism and reading lens.

Formula used :

Cauchy showed that the variation of refractive index μ with wavelength λ can be represented by the relation

$$\mu = A + \frac{B}{\lambda^2} \quad ...(1)$$

where A and B are two constants whose values are given by

$$B = (\mu_1 - \mu_2) \Big/ \left(\frac{1}{\lambda_1^2} - \frac{1}{\lambda_2^2}\right) \quad ...(2)$$

and

$$A = \mu_1 - B/\lambda_1^2 = \mu_2 - B/\lambda_2^2 \quad ...(3)$$

where μ_1 and μ_2 are the refractive indices for wavelengths λ_1 and λ_2 respectively.

The value of μ at a particular wavelength can be calculated by using the following formula

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin(A/2)} \quad \dots (4)$$

where A = Angle of prism and δ_m = Angle of minimum deviation.

Knowing the values of A and B with the help of eqs. (2) and (3), the value of μ can be calculated at any other wavelength with the help of eq. (1). The calculated value is compared with the help of eq. (1). The calculated value is compared with the experimental value. An agreement between theoretical and experimental value of μ for certain value of λ verifies the Cauchy's dispersion relation.

Procedure :

(1) Adjustment of the spectrometer : see experiment No. 1.

(2) Measurement of δ_m for dfferent wavelength : see exp. No. 1.

(3) Measurement of angle of prism A : see exp. No. 1.

Observations :

(1) Table for the angle (A) of the prism see table on page 3L.

(2) Table for the angle of minimum deviation see table on page 4L.

Calculations :

(1) Using the following formula, calculate μ for each line

$$\mu = \frac{\sin(A+\delta_m)/2}{\sin A/2}$$

Tabulate the result like the following table.

S. No.	Colour of Line	δ_m	μ	λ (Å) From the Table of Constants
1.	Violet II	...	...	4047
2.	Violet I	...	...	4358
3.	Bluish Green	...	...	4916
4.	Green	...	...	5451
5.	Yellow	...	...	5770
6.	Red	...	...	6234

(2) A graph is now plotted between λ (along X axis) and δ (along Y axs). The graph is shown in fig. (5).

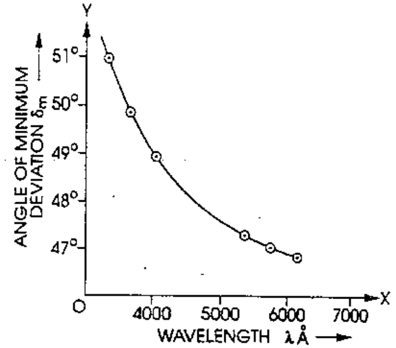


Fig. (5)

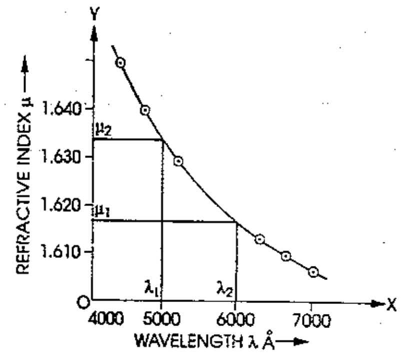


Fig. (6)

(3) Again draw a graph between λ (along the X axis) and μ (along the Y axis). The graph is shown in fig. (6).

From the graph of Fig. (6)

$$\lambda_1 = \dots\dots \text{Å},\ \lambda_2 = \dots\dots \text{Å},\ \mu_1 = \dots\dots \text{ and } \mu_2 = \dots\dots$$

$$\therefore \quad B = \frac{\mu_1 - \mu_2}{\left(\frac{1}{\lambda_2^2} - \frac{1}{\lambda_1^2}\right)} = \dots\dots \text{cm}^2$$

and

$$A = \mu_1 - B/\lambda_1^2 = \mu_2 - \frac{B}{\lambda_2^2} = \dots\dots \text{cm}^2.$$

(4) Using the above derived values of A and B and applying the Cauchy's formula for a particular wavelength (say 5500 Å) we calculate the theoretical value of refractive index μ *i.e.*,

$$\mu = A + \frac{B}{(5500\times10^{-8})^2} = \dots\dots + \frac{\dots\dots}{(5500\times10^{-8})^2} = \dots$$

From the graph of fig. (6), the value of μ = ... for wavelength 5500Å.

Result : (1) Fig. (5) shows the variation of angle of minimum deviation with wavelength.

(2) Fig. (6) shows the variation of refractive index of the material of the prism with wavelength.

(3) The value of μ for a particular wavelength calculated by Cauchy's formula is nearly same as read on (λ – μ) graph for the same wavelength. Hence Cauchy's formula is verified.

EXPERIMENT (1-3)

Object : To verify Hartmann's formula using a prism spectrometer.

Apparatus required : Spectrometer, prism, mercury lamp and reading lens.

Formula used :

According to Hartmann's formula, wavelength λ can be expressed by the relation

$$\lambda = A + \frac{B}{X - C} \quad \dots (1)$$

where A, B and C are constants for the material of given prism and X is the position of the wavelength.

Procedure :

(1) Adjustment of the spectrometer : see experiment No. 1.

(2) Measurement of the positions of various mercury lines : The procedure is as follows :

(i) The spectrum of the mercury source using the given prism is obtained in minimum deviation position in telescope.

(ii) The eyepiece is moved to the red end of the spectrum and the cross wire is fixed on the red line. The micrometer reading is noted.

(iii) The screw is turned in the same direction and the cross wire is fixed on various lines. The corresponding micrometer reading are recorded for each line.

(iv) Various wavelengths of mercury are recorded from the table of constants.

Observations :

Least count of micrometer = ... cm.

S. No.	Colour of the line	Position of spectral line X (cm.)	λ(Å) From the table of constants
1.	Red	X_1 = ...	λ_1 = 6234
2.	Yellow	X_2 = ...	λ_2 = 5770
3.	Green	X_3 = ...	λ_3 = 5441
4.	Bluish Green	X_4 = ...	λ_4 = 4916
5.	Violet I	X_5 = ...	λ_5 = 4358
6.	Violet II	X_6 = ...	λ_6 = 4047

Calculations :

From the table

$$\lambda_1 = 6234 \times 10^{-8}\text{ cm., } X_1 = \ldots\text{ cm.}$$
$$\lambda_2 = 5770 \times 10^{-8}\text{ cm., } X_2 = \ldots\text{ cm.}$$
$$\lambda_3 = 5441 \times 10^{-8}\text{ cm., } X_3 = \ldots\text{ cm.}$$

From Hartmann's formula

$$\lambda_1 = A + \frac{B}{X_1 - C}, \quad \lambda_2 = A + \frac{B}{X_2 - C}$$

and

$$\lambda_3 = A + \frac{B}{X_3 - C}$$

Solving these three equations we get $A = \ldots$ cm., $B = \ldots$ cm. and $C = \ldots$ cm. Now using these values of A, B and C, we calculate λ_4, λ_5, and λ_6 with the help of Hartmann's formula by substituting X_4, X_5 and X_6 from the table.

$\therefore$

$$(\lambda_4)_{cal.} = A + \frac{B}{(X_4 - C)} = \ldots + \frac{\ldots}{\ldots} = \ldots \text{ Å}$$
$$(\lambda_5)_{cal.} = A + \frac{B}{(X_5 - C)} = \ldots + \frac{\ldots}{\ldots} = \ldots \text{ Å}$$
$$(\lambda_6)_{cal.} = A + \frac{B}{(X_6 - C)} = \ldots + \frac{\ldots}{\ldots} = \ldots \text{ Å}$$

Result : Since the calculated values of wavelengh are nearly equal to the standard values hence Hartmann's formula is verified.

EXPERIMENT (1-4)

Object : To verify Hartmann's formula using a grating.

Apparatus used : Spectrometer, plane transmission grating, mercury lamp, magnifying glass, small mirror and Telescope and scale arrangement.

Formula used :

According to Hartmann's formula, the wavelength λ can be expressed as

$$\lambda = A + \frac{B}{X - C}$$

where A, B and C are constants for the material of the grating and X is the position of wavelength.

Procedure :

Before performing the experiment, the following adjustments are made :

(i) The spectrometer is adjusted.

(ii) The grating is adjusted for normal incidence.

(iii) A small mirror strip M as shown in fig. (7) is placed vertically on the telescope of the spectrometer near the eyepiece with the help of wax.

(iv) At about one metre, set up scale and telescope T_2 arrangement as shown in the figure such that the scale is horizontal. The telescope T_2 is focussed on the image of the scale seen in the mirror M.

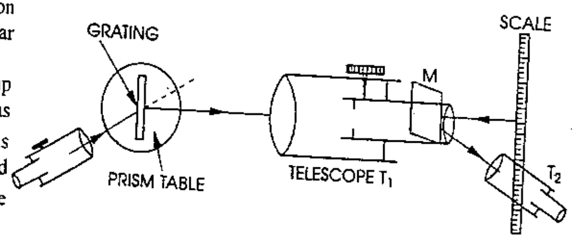


Fig. (7)

Now the following procedure is adopted :

(i) After obtaining the grating spectrum, the cross-wire of the telescope T_1 of spectrometer is adjusted on the violet line.

(ii) Now looking through the telescope T_2, the scale reading that coincide with the vertical cross-wire is noted.

(iii) Similarly, by making the vertical crosswire of the spectrometer telescope coinciding with other spectral lines, the scale readings that coincide with the vertical cross-wire of telescope T_2, are noted.

(iv) Various wavelenths of mercury are recorded from the table of constants.

Observations :

S. No.	Colour of the line	Position of spectral line X (cm.)	λ(Å) From the table of constants
1.	Red	$X_1 = \ldots$	$\lambda_1 = 6234$
2.	Yellow	$X_2 = \ldots$	$\lambda_2 = 5770$
3.	Green	$X_3 = \ldots$	$\lambda_3 = 5441$
4.	Bluish Green	$X_4 = \ldots$	$\lambda_4 = 4916$
5.	Violet I	$X_5 = \ldots$	$\lambda_5 = 4358$
6.	Violet II	$X_6 = \ldots$	$\lambda_6 = 4047$

Calclations :

From the above table

$$\lambda_1 = 6234 \times 10^{-8}\text{ cm., } x_1 = \ldots\text{ cm.}$$
$$\lambda_2 = 5770 \times 10^{-8}\text{ cm., } x_2 = \ldots\text{ cm.}$$
$$\lambda_3 = 5441 \times 10^{-8}\text{ cm., } x_3 = \ldots\text{ cm.}$$

From Hartmann's formula

$$\lambda_1 = A + \frac{B}{X_1 - C}, \quad \lambda_2 = A + \frac{B}{X_2 - C}$$

and

$$\lambda_3 = A + \frac{B}{X_3 - C}$$

Solve these equations to obtain the values of

$$A = \ldots\text{ cm., } B = \ldots\text{ cm. and } C = \ldots\text{ cm.}$$

Using these values of A, B and C, calculate λ_4, λ_5 and λ_6 with the help of Hartmann's formula by substituting x_4, x_5 and x_6 from the table

$$(\lambda_4)_{cal.} = A + \frac{B}{X_4 - C} = \ldots + \frac{\ldots}{\ldots} = \ldots \text{ Å}$$

Similarly, calclate $(\lambda_5)_{cal.}$ and $(\lambda_6)_{cal.}$

Result : Since the calculated values of wavelength are nearly equal to standard values and hence Hartmann's formula is verified.

Sources of errors and Precautions :

(i) All the precautions described in the Expt. 1.

(ii) Telescope and scale arrangement should be horizontal.

(iii) Telescope and scale arrangement must be one meter away from the mirror.

EXPERIMENT (1-5)

Object : To calibrate the drum of a constant deviation spectrometer.

Apparatus required : Constant deviation spectrometer, condensing lens, Mercury lamp, Reading lens and Reading lamp.

Description of apparatus :

The constant deviation spectrometer is shown in fig. (8).

It consists of a cast iron stand with *L*-shaped platform. On this platform, a collimator, prism table, telescope and a wavelength drum are mounted. The collimator and telescope are at right angle to each other. A special prism of quadrilateral section *ABCD* (known as constant deviation prism) with angles *A, B, C, D* of 75°, 90°, 60° and 135° respectively is placed at the centre of prism table. When a ray of polychromatic light falls on the face *BC* of the prism, it is dispersed into its constituent rays. The constituent ray which is parallel to face *CD* of the prism falls at 45° on face *AD* and is reflected parallel to *DB*. The ray emerges from the prism perpendicular to the incident ray. This ray comes in the field of view of the telescope. When the prism is rotated, successive rays (having different wavelengths) fall turn by turn at 45° on *AD* and the corresponding spectral line occupies the centre of the field of view. The wavelength drum is fitted with a rotating screw which rotates the prism table in order to move a particular spectral line across the field of view. The drum is provided with a head and a scale of wavelengths to read off directly the wavelength of spectral line appearing on the cross-wire of the telescope.

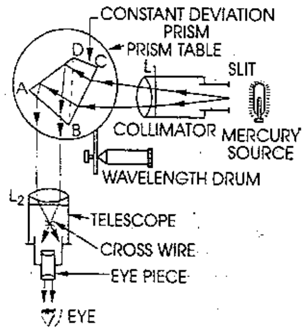


Fig. (8)

Procedure : The following procedure is adopted :

1. The mercury lamp is placed at a distance infront of the slit and switched on. Initially the slit is open wide. The eyepiece is withdrawn from the telescope. We now look through the telescope tube at the face of the prism. The position and height of the mercury lamp is adjusted in such a way that the image appears in the centre of prism face. The slit is then narrowed.
2. A condensing lens is placed between the slit and the lamp such that the image of mercury discharge is projected on the slit. Now on looking through the telescope, the entire surface of the prism appears uniformly bright.
3. The eyepiece is placed in its position in the telescope. By moving it in or out, it is focussed on the cross-wire. The telescope is adjusted by its rack and pinion arrangement until the spectral lines are sharpest.
4. The wavelength drum is rotated slowly so that particular spectral line falls on the cross wire. Its wavelength is read on the drum and noted.
5. The wavelength drum is rotated slowly so that the spectral lines, turn by turn, fall on the cross wires. The corresponding wavelengths are read and noted.

Observations :

S. No.	Spectral line Colour	Wavelength recorded by Drum (A)	Standard wavelength (A)
1.	Violet – 1	...	4046.8
2.	Violet – 2	...	4077.8
3.	Blue	...	4358.5
4.	Blue-green	...	4916.0
5.	Green I	...	4991.5
6	Green II	...	5120.5
7.	Green III	...	5354.0

Result : The table shown above shows the calibration of the drum of the spectrometer.

Sources of errors and Precautions :

(1) The width of the slit should be adjusted at its optimum value.
(2) The slit should be free from dust particles otherwise black horizonal lines will appear across the spectrum.
(3) The Collimator should be adjusted for parallel rays.
(4) The mercury lamp should be placed on the axis of collimator to obtain the best intensity.
(5) The constant deviation prism is so placed that the light from the collimator falls on its longest face and emerges out from the shorter face in a direction at right angles to the direction of incidence.

Viva-Voce

Q. 1. ***What do you mean by refractive index ?***

Ans. The ratio of the sine of angle of incidence to the sine of angle of refraction is constant of any two media, *i.e.*,

$$\frac{\sin i}{\sin r} = \mu$$

a constant known as refractive index.

Q. 2. ***Is it essential in your experiment to place the prism in the minimum deviation position ? If so, why ?***

Ans. Yes, It is essential because we obtain a bright and distinct spectrum and magnification is unity *i.e.*, the distance of the object and image from the prism is same. The rays of different colours after refraction diverge from the same points for various colours.

Q. 3. ***Will the angle of minimum deviation change, if the prism is immersed in water ?***

Ans. Yes. The refractive index of glass in water is less than air hence angle of minimum deviation becomes less.

Q. 4. ***Does the angle of minimum deviation vary with the colour of light ?***

Ans. Yes, it is minimum for red and maximum for violet colour.

Q. 5. ***Does the deviation not depend upon the length of the base of the prism ?***

Ans. No it is independent of the length of the base. By increasing the length of base, resolving power is increased.

Q. 6. ***What do you mean by pure spectrum ?***

Ans. A spectrum in which there is no overlapping of colours is known as pure spectrum. Each colour occupies a separate and distinct position.

Q. 7. ***Can you determine the refractive index of a liquid by this method ?***

Ans. Yes. The experimental liquid is filled in a hollow glass prism.

Q. 8. ***How μ vary with wavelengths ?***

Ans. Higher is the wavelength, smaller is the refractive index.

Q. 9. ***What is the relationship between deviation and wavelength ?***

Ans. Higher is deviation, smaller is wavelength *i.e.* deviation for violet colour is most but wavelength is least.

Q. 10. ***Which source of light are you using ? Is it a monocromatic source of light ?***

Ans. Mercury lamp. It is not a monochromatic source of light. The monochromatic source contains only one wavelength.

Q. 11. ***Can you not use a monochromatic source (sodium lamp) ?***

Ans. Yes, we can use a sodium lamp but it will give only yellow lines and not the full spectrum.

Q. 12. ***What is construction of mercury lamp ?***

Ans. It consists of a long cylindrical tube which contains two electrodes. The tube contains some mercury and argon gas at a pressure of about 10 mm. of mercury. The cylindrical tube is enclosed in a vacuum jacket to reduce the loss of heat from it to surroundings.

Q. 13. ***Why is it that mercury lamp works at high pressure and sodium lamp works at low pressure ?***

Ans. In mercury lamp, the visible light results due to the transition of electron among higher orbits which are promoted at high pressure. In case of sodium, the transitions are due to electron jump from higher orbit to lower orbit which are promoted at low pressure.

Q. 14. ***Can a mercury lamp be run at low pressure ? What will happen in this case ?***

Ans. The mercury lamp can run at low pressure but in this case the light emitted by the lamp will be in ultra-violet region of the spectrum.

Q. 15. ***After switching off mercury lamp, it can not be started again at once, why ?***

Ans. The starting electrode does not function before the vapourised mercury has condensed.

Q. 16. ***What is the working temperature of this lamp ?***

Ans. The working temperature is about 600°C.

Q. 17. ***What is the type of your mercury lamp ?***

Ans. It is hot cathode positive column type.

Q. 18. ***What is an eyepiece ?***

Ans. Eyepiece is a magnifier designed to give more perfect image than obtained by a single lens.

Q. 19. ***Which eyepiece is used in the telescope of a spectrometer ?***

Ans. Ramsden's eyepiece.

Q. 20. ***What is the construction of Ramsden's eyepiece ?***

Ans. It consists of two plano-convex lenses each of focal length f separated by a distance equal to $2f/3$.

Q. 21. ***What is the construction of Huygen's eyepiece ?***

Ans. It consists of two plano-convex lenses one having focal length $3f$ and other with focal length f and separated at distance $2f$.

Q. 22. ***What are chromatic and spherical aberrations ?***

Ans. The image of white object formed by a lens is coloured and blurred. This defect is known as chromatic aberration. The failure or inability of the lens to form a point image of an axial point object is called spherical aberration.

Q. 23. ***How these two defects can be minimised?***

Ans. The chromatic aberration can be minimised by taking the separation betwen two lenses $[d = (f_1 + f_2)/2]$. The spherical aberration can be minimised by taking the separation as the difference of two focal lengths $[d = (f_1 - f_2)]$.

Q. 24. ***What is the main reason for which Ramsden's eyepiece is used with a spectrometer ?***

Ans. In this eyepiece, the cross wire is outside the eyepiece and hence mechanical adjustment and measurements are possible.

Q. 25. ***What is a telescope ? What is its construction ?***

Ans. It is an instrument designed to produce a magnified and distinct image of very distinct object. It consist of a convex lens and eyepiece placed coaxially in a brass tube. The lens towards the object is called objective. This is of wide aperture and long focal-length. Observations are made by eyepiece. This is fitted in a separate tube which can slide in main tube.

Refraction and Dispersion of Light

EXPERIMENT No. 2

Object : To determine the dispersive power of the material of the prism for violet and yellow colours of mercury light with the help of a spectrometer.

Apparatus required : Spectrometer, prism, mercury source and reading lens.

Formula used :

The dispersive power, ω, of the material of the prism is given by the formula

$$\omega = \frac{\mu_v - \mu_y}{\mu - 1}$$

where μ_v = refractive index of the material of the prism for violet colour,

μ_y = refractive index of the material of the prism for yellow colour.

and
$$\mu = \frac{\mu_v + \mu_y}{2}$$

The refractive index of the prism is given by

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

where A = Angle of the prism.

δ_m = Angle of minimum deviation.

Procedure : The procedure is as follows :

(i) Adjustment of the spectrometer.

(ii) Measurement of angle of prism A.

(iii) Measurement of angle of minimum deviation δ_m for violet and yellow colours.

For details see Experiment No. 1.

Observations : Make the tables, similar to those in Experiment No. 1.

Calculations :

Find out the value of μ_v and μ_y using the relation.

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\mu_v = \ldots\ldots$$

$$\mu_y = \ldots\ldots$$

$$\mu = \frac{\mu_v + \mu_y}{2} = \ldots$$

and
$$\omega = \frac{\mu_v - \mu_y}{\mu - 1}$$

Result : The dispersive power of the given prism.
= ......

Precautions and Sources of error :
Same as in the experiment No. 1.

Viva-Voce

Q. 1. ***What do you mean by dispersive power ? Define it.***
Ans. The dispersive power of a material is its ability to disperse the various components of the incident light. For any two colours, it is defined as the ratio of angular dispersion to the mean deviation. *i.e.*

$$\omega = \frac{\delta_v - \delta_r}{\delta_y}$$

Q. 2. ***On what factors, the dispersive power depends ?***
Ans. It depends upon (i) material, and (ii) wavelengths of colours.

Q. 3. ***Out of the prism of flint and crown glasses, which one will you prefer to use ?***
Ans. We shall prefer a prism of flint glass because it gives greater dispersion.

Q. 4. ***What is a normal spectrum ?***
Ans. A spectrum in which angular separation between two wavelengths is directly proportional to difference of the wavelengths is called a normal spectrum.

Q. 5. ***Do you think that a prismatic spectrum a normal one ?***
Ans. No.

Q. 6. ***Can you find out the dispersive power of a prism with sodium light ?***
Ans. No. This is a monochromatic source of light.

Q. 7. ***How many types of spectra you known ?***
Ans. There are two main types of spectra (i) emission spectra and (ii) absorption spectra.

Q. 8. ***What type of spectra do you expect to get from (i) an incandescent filament lamp (ii) sun light (iii) mercury lamp ?***
Ans. (i) continuous spectrum, (ii) band spectrum, and (iii) line spectrum.

Q. 9. ***How do you classify emission spectrum ?***
Ans. (i) Continuous spectrum, given by a candle or electric bulb.
(ii) Band spectrum, given by elements of compound in molecular state.
(iii) Line spectrum, given by sodium or mercury spectrum.

Q. 10. ***What is difference between a telescope and a microscope ?***
Ans. Telescope is used to see the magnified image of a distinct object. Its objective has large aperture and large focal-length. The microscope is used to see the magnified image of very near object. Its objective has small focal-length and aperture.

Q. 11. ***Without touching can you differentiate between microscope and telescope ?***
Ans. The objective of microscope has small aperture while the telescope has a large aperture.

Q. 12. ***What is that which you are adjusting in focussing the collimator and telescope for parallel rays ?***
Ans. In case of collimator, we adjust the distance between collimating lens and slit while in case of telescope the distance between cross wires from the objective lens is adjusted.

Q. 13. ***What are these distances equal to when both the adjustments are complete ?***
Ans. The slit becomes at the focus of collimating lens in collimator and cross wires become at the focus of objective lens in telescope.

Q. 14. ***How can telescope and collimator be adjusted together ?***
Ans. (i) The prism is set in minimum deviation for yellow colour.
(ii) Prism is rotated towards telescope and telescope is adjusted to get a well defined spectrum.
(iii) Now the prism is rotated towards collimator and the collimator is adjusted to get well defined spectrum.
(iv) The process is repeated till the spectrum is well focussed. This is known as Schuster's method.

Refraction and Dispersion of Light

EXPERIMENT No. 3

Object : To determine the angle between crystal surface by spectrometer.
Apparatus required : Spectrometer, crystal and source.
Procedure : When the crystal is of bigger size, *i.e.* of the size of the prism, the angles between the crystal surfaces can be determined with the help of spectrometer. The procedure is as follows :

(i) The spectrometer is adjusted as described in Experiment No. 1.
(ii) The crystal is placed on the prism table with one of the edges facing towards the collimator.
(iii) The light falling on each surface will be reflected and can be received with the help of telescope. The telescope is moved to one side to receive the light reflected from one surface and the cross wires are focussed on the image of the slit. The reading of the two verniers are taken.
(iv) The telescope is moved on other side to receive the light reflected from the other surface and again the cross wires are focussed on the image of the slit. The reading of the two verniers are noted.
(v) The angle through which the telescope is moved or the difference in the two positions gives twice the angle between the crystal surfaces. Half of the angle gives the angle α between the two crystal surfaces.
(vi) Proceed similarly for other pairs of surfaces.

Viva-Voce

See the Viva-Voce of Experment. No. 1 and 2.

Interference

EXPERIMENT No. 5

Object : To determine the wavelength of sodium light (monochromatic source) with the help of a Fresnel's Bi-prism.

Apparats used : Optical bench with uprights, sodium lamp. Biprism, convex lens, slit and micrometer eye piece. Slit and micrometer eye piece are already fitted on the optical bench.

Formula used :

The wavelength λ of the sodium light is given by the formula in the case of Bi-prism experiment.

$$\lambda = \beta \frac{2d}{D}$$

where β = fringe width,
$2d$ = distance between the two virtual sources.
D = distance between the slit and screen (Eye piece upright).

Again $2d = \sqrt{(d_1 d_2)}$

where d_1 = distance between the two images formed by the convex lens in one position.
d_2 = distance between the two images formed by the convex lens in the second position.

Description of the apparatus :

Two coherent sources. from a single source, to produce interference pattern are obtained with the help of a Bi-prism. A Bi-prism may be regarded as made up of two prisms of very small refracting angles placed base to base. In actual practice a single glass plate is suitably grinded and polished to give a single prism of obtuse angle 179° leaving remaining two actue angles of 30′ each.

The optical bench used in the experiment consists of a heavy cast iron base supported on four levelling screws. There is a graduated scale along its one arm. The bench is provided with four uprights which can be clamped anywhere and the position can be read by means of vernier attached to it. Each of the uprights is subjected to the following motions :

(i) motion along bench,
(ii) transverse motion (motion right angle to bench),
(iii) rotation about the axis of the upright,
(iv) with the help of a tangent screw, the slit and Bi-prism can be rotated in thier own vertical planes.

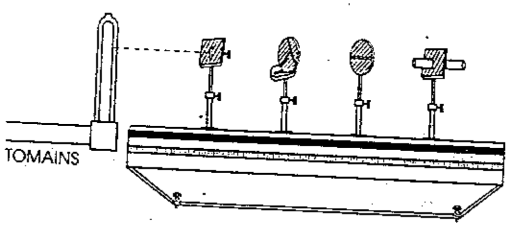


Fig. (1)

The bench arrangement is shown in fig. (1).

Action of Bi-prism :

The action of the Bi-prism is shown in fig. (2).

Monochromatic light from a source S falls on two points of the prism and is bent towards the base. Due to the division of wavefront, the refracted light appears to come from S_1 and S_2. The waves from two sources unite and give interference pattern. The fringes are hyperbolic, but due to high eccentricity they appear to be straight lines in the focal plane of eyepiece.

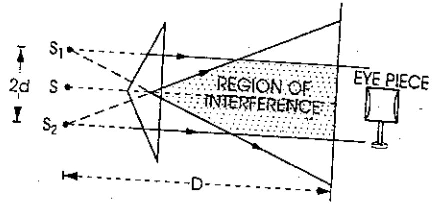


Fig. (2)

Procedure :

Adjustments :

(i) Level the bed of optical bench with the help of spirit level and levelling screws.

(ii) The slit. Bi-prism and eye piece are adjusted at the same height. The slit and the cross wire of eye piece are made vertical.

(iii) The micrometer eye piece is focussed on crosswires.

(iv) With an opening provided to the cover of the monochromatic source, the light is allowed to incident on the slit and the bench is so adjusted that light comes straight along its lengths. This adjustment is made to avoid the loss of light intensity for the interference pattern.

(v) Place the Bi-prism upright near the slit and move the eye piece sideway. See the two images of the slit through Bi-prism; if they are not seen, move the upright of Bi-prism right angle to the bench til they are obtained. Make the two images parallel by rotating Bi-prism in its own plane.

(vi) Bring the eyepiece near to the Bi-prism and give it a rotation at right angle of the bench to obtain a patch of light. As a matter of fact, the interference fringes are obtained in this patch provided that the edge of the prism is parallel to the slit.

(vii) To make the edge of the Bi-prism parallel to the slit, the Bi-prism is rotated with the help of tangent screw till a clear interference pattern is obtained. These fringes can be easily seen even with the naked eye.

(viii) The line joining the cenre of the slit and the edge of the Bi-prism should be parallel to the bed of the bench. If this is not so, there will be a lateral shift and the remlval is most important. This is shown in fig. (3).

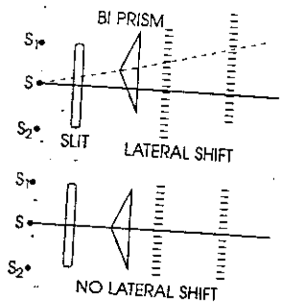


Fig. (3)

(a) In order to adjust the system for no lateral shift, the eyepiece is moved away from Bi-prism. In this case, the fringes will move to the right or left but with the help of base screw provided with Bi-prism. it is moved at right angle to the bench in a direction to bring the fringes back to their original position.

(b) Now move the eyepiece towards the Bi-prism and the same adjustment is made with the help of eyepiece. Now using the process again and again, the lateral shift is removed.

Mesurements :

(A) Measurement of fringe width **(β) :**

(i) Find out the least count of the micrometer screw.

(ii) Place the micrometer screw at such a distance where fringes are distinct, bright and widely spaced. (say 120 cms.)

(iii) The crosswire is moved on one side of the fringes to avoid backlash error. Now the cross wire is fixed at the centre of a bright fringe and its reading is noted on the main scale as well as on micrometer screw.

Formula used :

Thickness of mica sheet t is given by

$$t = \frac{S\lambda}{\beta(\mu - 1)}$$

where S = Shift of the central white fringe.
λ = wavelength of the light employed.
β = fringe width.
μ = refractive index of mica.

Procedure :

(i) Make all the initial adjustments of the Biprism as described in Experiment No. 5.

(ii) Using sodium light, measure the fringe width β as before.

(iii) Without disturbing the adjustments, replace the sodium light source with a white light source.

(iv) Observe the fringes in micrometer eyepiece with a central white fringe. Set up the cross wire on the white fringe and note the reading of micrometer screw.

(v) Introduce a thin mica sheet in one of the interfering beams as shown in fig. (5). Due to the introduction of mica sheet the central fringe is shifted. Again set the crosswire on the white fringe and note the micrometer reading.

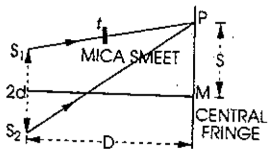


Fig. (5)

(vi) The difference of the two micrometer reading gives the shift S of the central white fringe.

Observatons :

S. No.	Micrometer reading			Mean S
	Position of central fringe without mica sheet	Position of central fringe with mica sheet	Difference	
1.	...	...	...	
2.	...	...	...	
3.	...	...	...	
4.	...	...	...	...

Calculations :

$$t = \frac{S\lambda}{\beta(\mu + 1)}$$

$= \dots$ cm.

Precautions : Same as in previous experiment.

Viva-Voce

Q. 1. ***What do you mean by interference of light ?***

Ans. When the two waves superimpose over each other, resultant intensity is modified. The modification in the distribution of intensity in the region of superposition is called interference.

Q. 2. ***Is there any loss of energy in interference phenomenon ?***

Ans. No. There is only redistribution of energy *i.e.* energy from dark places is shifted to bright places.

Q. 3. ***What are the conditions for obtaining interference of light ?***

Ans. (i) The two sources should be coherent *i.e.* they should vibrate in the same phase or there must be a constant phase difference between them. (ii) The two sources must emit waves of same wavelength and time period. (iii) The sources should be monochromatic. (iv) The amplitudes of the interfering waves should be equal or nearly equal.

Q. 4. ***What are the different types of interference ?***

Ans. (i) Division of wavefront, the incident wavefront is divided into two parts by utilising the phenomenon of reflection, refraction or diffraction. (ii) Division of amplitude, the amplitude of incoming beam is divided into two parts either by partial reflection or refraction.

Q. 5. ***What are interference fringes ?***

Ans. They are alternately bright and dark patches of light obtained in the region of superposition of two wave trains of light.

Q. 6. ***What is a biprism ?***

Ans. A biprism is a combination of two acute prisms placed base to base. This is made from an optically plane glass plate by proper grinding and polishing.

Q. 7. ***Why are the refracting angles of the two prisms made so small ?***

Ans. By doing so $2d$ (distance between two virtual images) will be small and so fringe width will be large.

Q. 8. ***What is the purpose of the biprism ?***

Ans. The purpose of the biprism is to produce two coherent images of a given slit which are separated at a certain distance and behave as two coherent sources.

Q. 9. ***On what factors does the fringe-width depend ?***

Ans. The fringe width β is given by

$$\beta = \frac{\lambda D}{2d}$$

where D = distance between slit and eyepiece. $2d$ = distance between two virtual sources.

Q. 10. ***How does fringe-width depend upon the angle of biprism ?***

Ans. We know that $2d = 2a(\mu - 1)A$, here a is a distance between slit and biprism and A, the angle of biprism. Hence

$$\beta = \frac{\lambda D}{2a(\mu - 1)A}$$

i.e., fringe width is inversely proportional to angle A of biprism.

Q. 11. ***What is the effect of changing the distance between the slit and biprism on the fringe-width ?***

Ans. When a is increased, $2d$ is decreased *i.e.*, fringe width is increased.

Q. 12. ***How do you measure 2d ?***

Ans. We use displacement method. In this method a convex lens is used. We use the formula $2d = \sqrt{(d_1 d_2)}$.

Q. 13. ***What will happen if you replace monochromatic source by white light source ?***

Ans. In case of white light, the interference pattern consists of a central white fringe surrounded by a few coloured fringes.

Q. 14. ***How will you locate zero order fringe in biprism experiment ?***

Ans. First of all the interference fringes are observed with monochromatic source of light. The monochromatic source is replaced by white light source. The cross wire is fixed at white fringe. White light source is replaced by monochromatic source. The fringe on cross wire is zero order fringe.

Q. 15. ***How you can measure the thickness of mica sheet ?***

Ans. Using a white light source, the cross wire is fixed at white fringe. Now a mica sheet is introduced in one of the interfering beams and the shift of white fringe is observed. Then

$$t = \frac{S \times 2d}{D(\mu - 1)}$$

where S is the shift.

Q. 16. ***Are the biprism fringes perfectly straight ?***

Ans. The biprism fringes are not peerfectly straight but they are hyperbolic in nature. The eccentricity of the hyperbola is so large that they appear as straight in the field of view of eyepiece.

Q. 17. ***Why do you get only a limited number of fringes in biprism experiment ?***

Ans. This is due to the inhomogeneity of the light source. The various components produce their own system of fringes of slightly different fringe-width. Due to their overlapping only a limited number of fringes are observed.

Q. 18. ***What is the construction of sodium lamp ?***

Ans. It consists of a U-shaped glass tube with two electrodes of tungston coated with barium oxide. The tube is filled with neon gas at a pressure of 10 mm of mercury and some sodium pieces. This tube is enclosed in a vacuum jacket to avoid heat losses.

Q. 19. ***Why does the sodium lamp give out red light in the beginning ?***

Ans. First of all discharge passes through neon gas.

Q. 20. ***Why is the neon gas filled in it at all ?***

Ans. Initially no discharge passes through sodium as its vapour pressure is low. First, the discharge passes through neon. Now the temperature rises and sodium vaporises. Now sodium gives its own characteristic yellow colour.

Interference

EXPERIMENT No. 6

Object : To determine the wavelength of sodium light using Lloyd's mirror.

Apparatus used : Optical bench with uprights, sodium lamp, Lloyd's mirror. micrometer eye-piece (may be already fitted on the optical bench), slit (may be already fitted with optical bench) and a convex lens of about 20 cms focal length.

Formula used :

The wavelength λ of sodium light using Lloyd's mirror is given by

$$\lambda = \beta \frac{2d}{D}$$

where β = fringe width

$2d$ = distance between two virtual sources

D = Distance between the slit and micrometer eyepiece

Further $2d = \sqrt{d_1 d_2}$

where d_1 = distance between the two images formed by the convex lens in one position

d_2 = distance between the two images formed by the convex lens in the second position.

Description of the apparatus :

The optical bench used in the experiemnt consists of a heavy cast iron base supported on four levelling screws. There is a graduated scale along its one arm. The bench is provided with four uprights which can be clamped anywhere and the position can be read by means of vernier attached to it. Each of the uprights is subjected to the following motions :

(i) motion along bench, (ii) motion right angle to bench (iii) rotation about the axis of the upright, (iv) the slit and Lloyd's mirror can be rotated in their own vertical planes. The bench arrangement is shown in fig. (1).

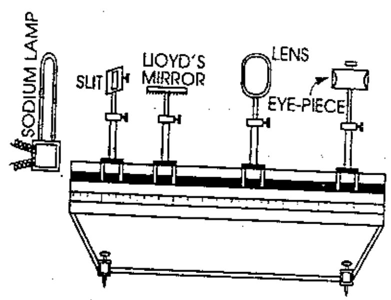


Fig. (1)

The action of Lloyd's mirror is shown in fig. (2). The arrangement consists of a plane mirror AB polished on the front surface and blackened at the back to avoid multiple reflections. Light from a narrow slit S_1 illuminated by a monochromatic source of light is allowed to incident on the mirror almost at grazing angle. The reflected beam appears to diverge from S_2 which is virtual image of S_1. Thus S_2 and S_1 act as two coherent sources. The direct cone of light PS_1Q and reflected cone of light PS_2C superimpose over each other and produce interference fringes in overlapping region PC of the eyepiece.

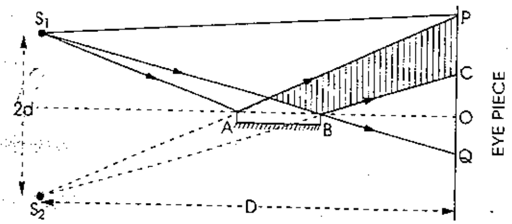


Fig. (2)

Procedure :

Adjustments :

(i) Level the bed of optical bench with the help of spirit level and levelling screws.

(ii) Place slit, Lloyd's mirror and eyepiece at the proper uprights and adjust them at the same height.

(iii) The slit and cross-wire of eyepiece are made vertical.

(iv) The micrometer eyepiece is focussed on cross-wires.

(v) Monochromatic light is allowed to incident on the slit and bench is so adjusted that light comes straight along its length. This adjustment is made to avoid the loss of light intensity for the interference pattern.

(vi) Move the eyepiece at right angle to the optical bench to obtain the region *CP* where interference fringes are obtained. There would be a patch of light where intensity is more in comparison to other places.

(vii) Rotate the Lloyd's mirror in its own plane to obtain the clear interference fringes.

Measurement of fringe-width β **:**

(i) Find the least count of micrometer screw.

(ii) Place the eyepiece at such a distance where fringes are distinct, bright and widely spaced.

(iii) The corss wire is fixed at the centre of a bright fringe and its reading is noted on the main scale as well as on micrometer screw.

(iv) The cross-wire is now moved and fixed at the centre of every bright fringe. The micrometer readings are noted. From these observations β can be calculated.

Measurement of D.

The distance between slit and eyepiece upright is noted. This distance gives *D*.

Measurement of 2d :

The distance $2d$ between two virtual sources can be measured with the help of fig. (3).

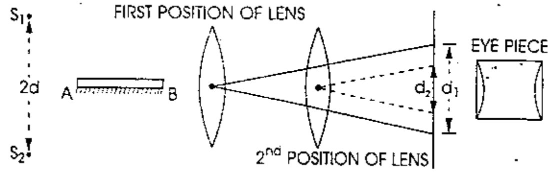


Fig. (3)

(i) To obtain the value of $2d$, the positions of slit and Lloyd's mirror uprights are not disturbed.

(ii) A convex lens is introduced between Lloyd's mirror and eyepiece and moved in between to obtain two sharp and focussed images of source. The position is shown by first position of lens in fig. (3). The distance d_1 between the two images is noted with the help of eyepiece.

(iii) The lens is now moved towards eyepiece to obtain second position where again two sharp and focussed images is again noted with the help of eyepiece.

(iv) Knowing d_1 and d_2, $2d$ can be calculated by using the formula

$$2d = \sqrt{d_1 d_2}$$

Observations :

Pitch of the screw = ... cm.

No. of divisions on micrometer screw = ...

L.C. of micrometer screw = ... cm.

Position of upright carrying the eyepiece = ...cm.

Observed value of D = ... cms.

Position of upright carrying slit = ... cm.

(1) ***Table for fringe width*** β

No. of the fringe	Micrometer reading (a)			No. of the Fringe	Micrometer reading (b)			Diff. of 5 fringes $a \sim b$	Mean for 5 fringes
	M.S. reading cms.	V.S. reading cms.	Total cm.		M.S. reading cms.	V.S. reading cms.	Total cms.		
1	...	...	...	6	...	...	...	...	
2	...	...	...	7	...	...	...	...	
3	...	...	...	8	...	...	...	...	
4	...	...	...	9	...	...	...	...	...
5	...	...	...	10	...	...	...	...	

$$\text{Fringe Width } \beta = \frac{\text{Mean for 5 fringes}}{5} = \ldots\ldots \text{ cm}$$

Measurement of 2d

S. No.	Micrometer reading						$2d = \sqrt{d_1 d_2}$	Mean $2d$
	Ist position of lens			IInd position of lens				
	Ist Image	IInd Image	d_1	Ist Image	IInd Image	d_2		
1	...	...	...	...	...	...	...	
2	...	...	...	...	...	...	...	
3	...	...	...	...	...	...	...	...

Calculations :

$$\lambda = \beta \frac{2d}{D}$$

Result : Wavelength of sodium light λ = ... Å

standard value = 5893 Å

Percentage error = ...%

Precautions and sources of error :

(i) The setting of the uprights at the same level is essential.

(ii) The slit should be vertical and narrow.

(iii) Cross-wire should be fixed at the centre of the fringe while taking observations for fringe-width.

(iv) The fringes should be measured at fairly large distance.

(v) Motion of eyepiece should be perpendicular to the lengths of the bench.

(vi) Convex lens of shorter focal lengths should be used.

(vii) Mirror should be placed close to the slit.

Interference

EXPERIMENT No. 7

Object : To find the thickness of a wire using optical bench.

Apparatus used : Optical bench with uprights, sodium lamp, micrometer eyepiece, slit (may be already fitted with optical bench) and thin wire.

Formula used :

The thickness t of the wire can be found by using the following formula

$$t = \lambda \left[\frac{(D_2 - D_1)}{(\beta_2 - \beta_1)} \right]$$

where λ = wavelength of light used

D_1 = first distance of eyepiece from the wire

D_2 = second distance of eyepiece from the wire

β_1 = average fringe width at a distance D_1

β_2 = average fringe width at a distance D_2

Description of the apparatus :

For the description of optical bench see previous experiment.

The action of the thin wire is shown in fig. (1). When the thin wire is placed in the path of monochromatic light coming from the slit S, the light is reflected. Now the interference of light takes place. The two edges of the wire acts as the two sources. The interference fringes are observed on the screen AB or they can be seen in eyepiece.

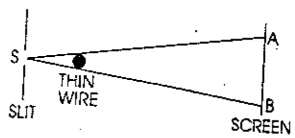


Fig. (1)

Procedure :

Adjustments :

(i) Level the bed of the optical bench with the help of spirit level and levelling screws.

(ii) Place slit, thin wire and eyepiece at the proper uprights and adjust them at the same height (see fig. 2).

(iii) The wire should be adjusted vertical and parallel to the slit at its centre.

(iv) The slit and cross wire of eye-piece are made verticcal.

(v) The micrometer eyepiece is focussed on cross-wires.

(vi) Monochromatic light is allowed to incident on the slit and the bench is so adjusted that light comes straight along its length.

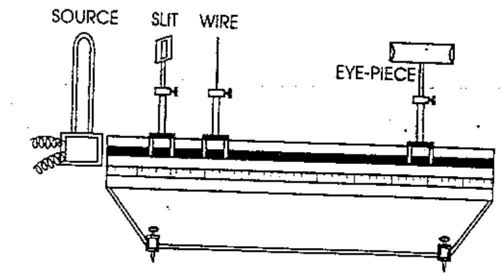


Fig. (2)

(vii) The micrometer eyepiece is moved away from the wire. By moving the eyepiece at right angle to the optical bench, interference fringes are observed.

***Measurement of fringe-width* β :**

(i) Find out the least count of the micrometer screw.

(ii) The micrometer eyepiece is placed in front of the thin wire. This is moved to such a distance where fringes are distinct, bright and widely spaced.

(iii) The vertical cross wire of the eyepiece is fixed at the centre of one of the bright fringes and its reading is noted on the main scale as well as on micrometer screw.

(iv) The cross-wire is moved to different fringes and the corresponding readings are noted. The width of five fringes is found on an average and then fringe width β, is calculated.

(v) The distance D_1 of the eyepiece from thin wire is noted.

(vi) The micrometer eye-piece is moved to another distance D_2 where distinct and bright fringes are observed. Repeat procedure (iv) to obtain the fringe-width β_2 at this distance.

Observations :

Wavelength of light used $\lambda = 5893 \times 10^{-8}$ cm.

First distance of the eyepiece from the wire D_1 = ... cm.

Second distance of the eyepiece from the wire D_2 = ... cm.

Pitch of the screw = ... cm.

No. of divisions on micrometer screw = ...

L.C. of micrometer screw = ... cm.

Table for fringe width β_1 when eyepiece is at a distance D_1 from the wire

No. of fringe	Micrometer reading			No. of fringe	Micrometer reading			Width of 5 fringes	Mean for 5 fringes	Fringe width β_1
	M.S. cm.	V.S. cm.	Total *a* cm.		M.S. cm.	V.S. cm.	Total *b* cm.			
1	...	...	...	6	...	...	...	...		
2	...	...	...	7	...	...	...	...		
3	...	...	...	8	...	...	...	...		
4	...	...	...	9	...	...	...	...	...	...
5	...	...	...	10	...	...	...	...		

Table for fringe width β_2 when eyepiece is at a distance D_2 from the eyepiece

No. of fringe	Micrometer reading			No. of fringe	Micrometer reading			Width of 5 fringes	Mean for 5 fringes	Fringe width β_2
	M.S. cm.	V.S. cm.	Total *a* cm.		M.S. cm.	V.S. cm.	Total *b* cm.			
1	...	...	...	6	...	...	...	...		
2	...	...	...	7	...	...	...	...		
3	...	...	...	8	...	...	...	...		
4	...	...	...	9	...	...	...	...	...	...
5	...	...	...	10	...	...	...	...		

Calculations :

$$t = \lambda \left[\frac{(D_2 - D_1)}{(\beta_2 - \beta_1)} \right]$$

Result : The thickness of the given wire = ... cms.

Precations and sources of error :

(i) The diffraction fringes formed on either side of the interference fringes should be clearly differentiated.

(ii) The wire should be vertical and parallel to the slit at its centre.

(iii) The distance D should be taken as large as possible.

(iv) The setting of uprights should be at the same level.

(v) Cross wire should be fixed at the centre of the fringe while taking obervations for fringe width.

Interference

EXPERIMENT No. 8

Object : To determine the wavelength of sodium light by Newton's ring.

Apparatus required : A plano-convex lens of large radius of curvature, optical arrangement for Newton's rings, plane glass plate, sodium lamp and travelling microscope.

Formula used :

The wavelength λ of light is given by the formula

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4\,p\,R}$$

where D_{n+p} = diameter of $(n+p)$th ring,

D_n = diameter of nth ring.

p = an integer number (of the rings).

R = radius of curvature of the curved face of the plano-convex lens.

Description of apparatus :

The optical arrangement for Newton's ring is shown in fig. (1). Light from a monochromatic source (sodium lamp) is allowed to fall on a convex lens through a broad slit which renders it into a nearly parallel beam. Now it falls on a glass plate inclined at an angle 45° to the vertical, thus the parallel beam is reflected from the lower surface. Due to the air film formed by a glass plate and a plano convex lens of large radius of curvature, interference fringes are formed which are observed directly through a travelling microscope. The rings are concentric circles.

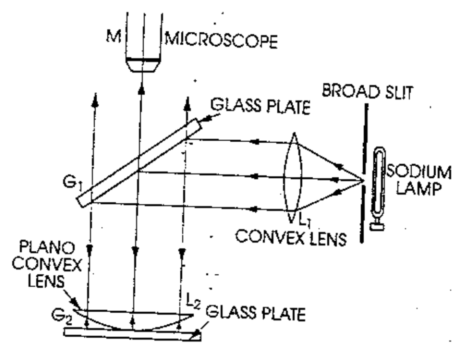


Fig. (1)

Procedure :

(i) If a point source is used only then we require a convex lens otherwise using an extended source, the convex lens L_1 is not required.

(ii) Before starting the experiment, the glass plates G_1 and G_2 and the plano convex lens should be thoroughly cleaned.

(iii) The centre of lens L_2 is well illuminated by adjusting the inclination of glass plate G_1 at 45°.

(iv) Focus the eyepiece on the cross-wire and move the microscope in the vertical plane by means of rack and pinion arrangement till the rings are quite distinct. Clamp the microscope in the vertical side.

(v) According to the theory, the centre of the interference fringes should be dark but sometimes the centre appears white. This is due to the presence of dust particles between glass plate G_2 and plano-convex lens L_2. In this case the lens should be again cleaned.

(vi) Move the microscope in a horizontal direction to one side of the fringes. Fix up the crosswire tangential to the ring and note this reading. Again the microscope is moved in the horizontal plane and the cross wire is fixed tangentially to the successive bright fringes noting the vernier readings till the other side is reached. This is shown in fig. (2).

(vii) The radius of curvature of the plano-convex lens is determined by Boy's method as discussed below :

If an object is placed at the principal focus of convex lens placed over a plane mirror, its image is formed at same point and the distance from the lens is equal to the focal length f of the lens as shown in fig. (3i).

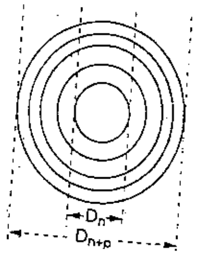


Fig. (2)

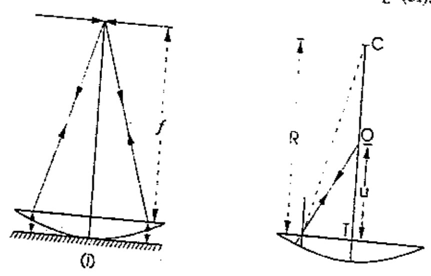


Fig. (3)

If the mirror is removed and the object is moved along the axis, a position will come where the image of the object formed by the lens coincides with object as shown in fig. (3 ii). If the direction of a ray starting from O is such that it is incident normally on the spherical surface, the ray returns to its previous path and forms the image at the same point. Since the refracted ray is normally incident on the surface, it appears to come from the centre of curvature C. Hence in this case $TO = u$ and $TC = v = R$ we have

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\frac{1}{R} - \frac{1}{u} = -\frac{1}{f}$$

or

$$\frac{1}{R} = \frac{1}{u} - \frac{1}{f} = \frac{f-u}{uf}$$

$$\therefore \quad R = \frac{uf}{f-u}$$

Knowing the value of u, the value of R can be calculated because the value of f is already known with the help of fig. (3 i).

The radius of the curvature can also be determined by using a spherometer. In this case

$$R = \frac{l^2}{6h} - \frac{h}{2}$$

where l is the distance between the two legs of the spherometer as shown in fig. (4).

h is the difference of the readings of the spectrometer when it is placed on the lens as well as when placed on plane surface.

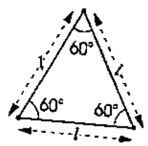


Fig. (4)

Observations : Value of one division of the main scale = … cm.
No. of divisions on the vernier scale = …
Least count of the microscope = …

Table for the determination of $(D^2_{n+p} - D^2_n)$

No. of the rings	Micrometer reading: Left end a cm.	Micrometer reading: Right end b cm.	Diameter D $(a-b)$ cm.	D^2 $(a-b)^2$ cm²	$(D^2_{n+p} - D^2_n)$ cm²	Mean cm²	p
20	…	…	…	…			
19	…	…	…	…			
18	…	…	…	…			
17	…	…	…	…			
16	…	…	…	…			
15	…	…	…	…			
14	…	…	…	…	…		
13	…	…	…	…	…		
12	…	…	…	…	…		
11	…	…	…	…	…	…	8
10	…	…	…	…	…		
9	…	…	…	…	…		
8	…	…	…	…	…		
7	…	…	…	…			
6	…	…	…	…			
5	…	…	…	…			

Table for the deermination of R :

(Either use Boy's method or spherometer method)

Using Boy's method :

S. No.	Position of object	Position of lens placed on plane mirror	f cm.	Position of lens in absence of plane mirror	u	$R = \frac{uf}{f-u}$ cm.
1	…	…	…	…	…	…
2	…	…	…	…	…	…
3	…	…	…	…	…	…

Using spherometer method :

L.C. of spherometer = … cm.

S. No.	Spherometer Reading						$h = (b-a)$ cm.	Mean h cm.
	Zero reading on plane surface			Reading on lens				
	M.S.	V.S.	Total cm.	M.S.	V.S.	Total cm.		
			(a)			(b)		
1	…	…	…	…	…	…	…	
2	…	…	…	…	…	…	…	…
3	…	…	…	…	…	…	…	

Distance between the two legs of spherometer l = … cms.

Calculations :

Using Boy's method

$$R = \frac{uf}{f-u}$$

$$= \ldots \text{ cm.}$$

Using Spherometer method

$$R = \frac{l^2}{h} + \frac{h}{2}$$

$$= \ldots \text{ cm.}$$

The wavelength of sodium light is given by

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}$$

$$= \ldots \text{ A.U.}$$

The value of $(D_{n+p}^2 - D_n^2)$ can also be obtained using a graph as shown in fig. (5). The graph is plotted between the square of diameter of the ring along Y-axis and corresponding number of ring along X-axis.

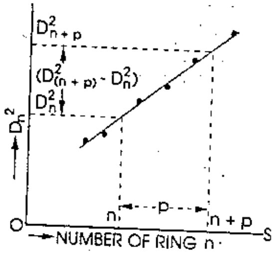


Fig. (5)

Result : The mean wavelength λ of sodium light

$= \ldots$ A.U.

Standard mean wavelength

$\lambda = \ldots$ A.U.

Percentage error

$= \ldots \%$.

Souces of Error and Precautions :

(i) Glass plates and lens should be cleaned thoroughly.
(ii) The lens used should be of large radius of curvature.
(iii) The source of light used should be an extended one.
(iv) Before measuring the diameter of rings, the range of the microscope should be properly adjusted.
(v) Crosswire should be focussed on a bright ring tangentially.
(vi) Radius of curvature should be measured accurately.

Theoretical error :

In our case

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}$$

Taking logarithm of both sides and differentiating

$$\therefore \frac{\delta\lambda}{\lambda} = \frac{\delta(D_{n+p}^2 - D_n^2)}{D_{n+p}^2 - D_n^2} + \frac{\delta R}{R}$$

$$= \frac{2\{D_{n+p}(\delta D_{n+p}) + D_n(\delta D_n)\}}{D_{n+p}^2 - D_n^2} + \frac{\delta R}{R}$$

$$= \ldots\ldots$$

$$= \ldots\ldots \%.$$

ADDITIONAL EXPERIMENTS

EXPERIMENT (8-1)

Object : The determine the refractive index of a liquid by Nerwton's rings.

Apparatus used : Optical arrangement for Newton's rings, plane glass plate, a plano-convex lens of large radius of curvature, experimental liquid, metal container and travelling microscope.

Formula used :

The refractive index μ of the liquid is given by

$$\mu = \frac{D_{n+p}^2 + D_n^2}{D'^2_{n+p} + D'^2_n}$$

where D_{n+p} = diameter of $(n+p)^{th}$ ring in air film between glass plate and plano-convex lens

D_n = diameter of nth ring in air film.

D'_{n+p} = diameter of $(n+p)^{th}$ ring in liquid film between glass plate and plano-convex lens.

D'_n = diameter of nth ring in liquid film.

Description of apparatus :

See Experiment No. (8).

Procedure :

(i) If a point source is used only then we require a convex lens otherwise using an extended source, the convex lens L_1 is not required.

(ii) Before starting the experiment, the glass plates G_1 and G_2 and the plano convex lens should be thoroughly cleaned.

(iii) The centre of lens L_2 is well illuminated by adjusting the inclination of glass plate G_1 at 45°.

(iv) Focus the eyepiece on the cross-wire and move the microscope in the vertical plane by means of rack and pinion arrangement till the rings are quite distinct. Clamp the microscope in the vertical side.

(v) According to the theory, the centre of the interference fringes should be dark but sometimes the centre appears white. This is due to the presence of dust particles between glass plate G_2 and plano-convex lens L_2. In this case the lens should be again cleaned.

(vi) Move the microscope in a horizontal direction to one side of the fringes. Fix up the crosswire tangential to the ring and note this reading. Again the microscope is moved in the horizontal plane and the cross wire is fixed tangentially to the successive bright fringes noting the vernier readings till the other side is reached. This is shown in fig. (2).

(vii) Take the experimental liquid in a metal container and place the plano-convex lens and glass plate system in it such that the air film is replaced by experimental liquid.

(viii) Focus the eyepiece on the cross wire and move the microscope by means of rack and pinion arrangement till the rings are quite distinct. Clamp the microscope in the vertical side.

(ix) Move the microscope in a horizontal direction to one side of the fringes. Fix up the cross-wire tangential to the ring and note this reading. Again the microscope is moved in the horizontal plane and the cross-wire is fixed to the successive bright fringes noting the vernier readings till the other side is reached.

Observations : For air film between glass plate and plano- convex lens

Value of one division of the main scale = ... cm.
No. of divisions on the vernier scale = ...
Least count of the microscope = ...

Table for the determination of $(D^2_{n+p} - D^2_n)$:

No. of the rings	Micrometer reading		Diameter $(a-b)$ cm.	$D^2 = (a-b)^2$ cm^2	$(D^2_{n+p} - D^2_n)$ cm^2	Mean cm^2	p
	Left end a cm.	Right end b cm.					
20	...	...	...	...			
19	...	...	...	...			
18	...	...	...	...			
17	...	...	...	...			
16	...	...	...	...			
15	...	...	...	...			
14	...	...	...	...	...		
13	...	...	...	...	...		
12	...	...	...	...	...	...	7
11	...	...	...	...	...		
10	...	...	...	...	...		
9	...	...	...	...			
8	...	...	...	...			
7	...	...	...	...			
6	...	...	...	...			
5	...	...	...	...			

Table for the determination of $(D'^2_{n+p} - D'^2_n)$:

No. of the rings	Micrometer reading		Diameter $D' = (a-b)$ cm.	$D'^2 = (a-b)^2$ cm^2	$(D'^2_{n+p} - D'^2_n)$ cm^2	Mean cm^2	p
	Left end a cm.	Right end b cm.					
20	...	...	...	...			
19	...	...	...	...			
18	...	...	...	...			
17	...	...	...	...			
16	...	...	...	...			
15	...	...	...	...	...		
14	...	...	...	...	...		
13	...	...	...	...	...		
12	...	...	...	...	...	...	7
11	...	...	...	...	...		
10	...	...	...	...			
9	...	...	...	...	...		
8	...	...	...	...			
7	...	...	...	...			
6	...	...	...	...			
5	...	...	...	...			

Calculations :

$$\mu = \frac{D_{n+p}^2 - D_n^2}{D'^2_{n+p} - D'^2_n}$$

$= \ldots\ldots\ldots\ldots$

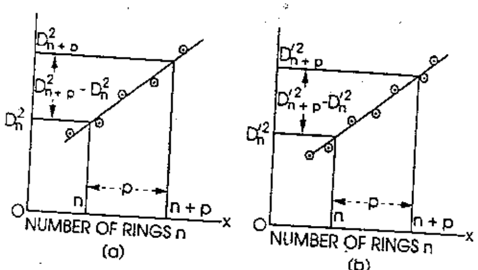


Fig. (6)

The value of $(D_{n+p}^2 - D_n^2)$ or $(D'^2_{n+p} - D'^2_n)$ for the same value of p can be obtained with the help of graphs shown in fig. (6). The graphs are plotted between the square of diameter of ring along Y-axis and correspondng number of rings along X-axis.

Result : The refractive index of the given liquid = ...

Standard result : The refractive index of the liquid = ...

Percentage error = ... %

Sources of error and Precautions :

1. Glass plates and lens should be clean thoroughly.
2. The lens used should be of large radius of curvature.
3. The liquid should be pure.
4. The source of light used should be an extended one.
5. Before measuring the diameters of rings, the range of the microscope should be properly adjusted.
6. The value of p should be taken same in both parts of the experiment.

Theoretical error :

$$\mu = \frac{D^2_{n+p} - D^2_n}{D'^2_{n+p} - D'^2_n}$$

Taking logarithm of both sides and differentiating

$$\frac{d\mu}{\mu} = \frac{\delta(D^2_{n+p} - D^2_n)}{(D^2_{n+p} - D^2_n)} + \frac{\delta(D'^2_{n+p} - D'^2_n)}{(D'^2_{n+p} - D'^2_n)}$$

$$= \frac{2\{D_{n+p}\,(\delta D_{n+p}) + D_n\,(\delta D_n)\}}{D^2_{n+p} - D^2_n} + \frac{\{D'_{n+p}\,(\delta D'_{n+p}) + D'_n\,(\delta D'_n)\}}{D'^2_{n+p} - D'^2_n}$$

= ...... + ... = ... = ... %

EXPERIMENT (8-2)

Object : To determine the radius of curvature of the given concave lens by forming Newton's rings with the combination of convex and concave lenses.

Apparatus usd : Newton's ring arrangement, convex lens, concave lens, Microscope, reading lens and sodium lamp.

Formula used :

The radius of curvature of concave lens R_2 is given by

$$R_2 = \left(\frac{R\,R_1}{R_1 - R}\right) \quad \ldots (1)$$

Where R_1 = radius of curvature of convex lens
and R = Radius of curvature of the combination of concave and convex lens.

The value of R_1 is obtained with the help of formula

$$R_1 = \left[\frac{D_{n+p}^2 - D_n^2}{4p\lambda}\right]$$

where D_{n+p} = diameter of $(n+p)^{th}$ ring
D_n = diameter of n^{th} ring
p = an integer number (of the ring)
λ = wavelength of light used (5893×10^{-8} cm).

Similarly, the radius of curvature R of the lens combination may be obtained using the above formula.

Description of apparatus :

See Experiment No. (8).

Procedure :

(1) ***Formation of Newton's-rigns with convex lens.***

(i) If a point source is used only then we require a convex lens otherwise using an extended source, the convex lens L_1 is not required.

(ii) Before starting the experiment, the glass plates G_1 and G_2 and the plano convex lens should be thoroughly cleaned.

(iii) The centre of lens L_2 is well illuminated by adjusting the inclination of glass plate G_1 at 45°.

(iv) Focus the eyepiece on the cross-wire and move the microscope in the vertical plane by means of rack and pinion arrangement till the rings ae quite distinct. Clamp the microscope in the vertical side.

(v) According to the theory, the centre of the interference fringes should be dark but sometimes the centre appears white. This is due to the presence of dust particles between glass plate G_2 and plano-convex lens L_2. In this case the lens should be again cleaned.

(vi) Move the microscope in a horizontal direction to one side of the fringes. Fix up the cross- wire tangential to the ring and note this reading. Again the microscope is moved in the horizontal plane and the cross wire is fixed tangentially to the successive bright fringes noting the vernier readings till the other side is reached. This is shown in fig. (2).

(vii) A graph is drawn between the number of rings and the square of corresponding diameters as shown in fig. (3). From the graph, the diameters of $(n+1)^{th}$ and n^{th} rings are obtained. The radius of curvature of the convex lens R_1 is calculated by using the formula

$$R_1 = \left(\frac{D_{n+p}^2 - D_n^2}{4p\lambda}\right)$$

(2) ***Formation of Newton's rings with the combination of convex and concave lenses.***

(i) The plane glass plate is replaced by concave lens *i.e.*, the convex lens is placed over the concave lens as shown in fig. (7).

(ii) The procedure mentioned above for the formation of Newton's rings with convex lens is repeated to obtain the radius of curvature R of the combination of lenses.

Thus using the following formula, R is calculated

$$R = \left[\frac{D_{n+p}^2 - D_n^2}{4p\lambda}\right]$$

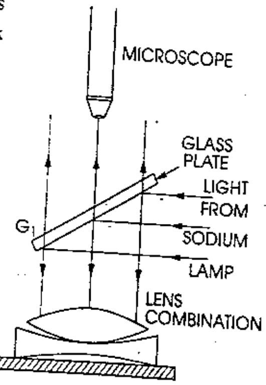


Fig. (7)

Observations :

When convex lens is used

Value of one division of the main scale = ... cm.
No. of divisions on the vernier scale = ...
Least count of the microscope =

Table for the determination of $(D_{n+p}^2 - D_n^2)$:

No. of the rings	Micrometer reading		Diameter D $(a-b)$ cm.	$D^2 = (a-b)^2$ cm^2
	Left end a cm.	Right end b cm.		
20	...	...	...	...
19	...	...	...	...
18	...	...	...	...
17	...	...	...	...
16	...	...	...	...
15	...	...	...	...
14	...	...	...	...
13	...	...	...	...
12	...	...	...	...
11	...	...	...	...
10	...	...	...	...
9	...	...	...	...
8	...	...	...	...
7	...	...	...	...
6	...	...	...	...
5	...	...	...	...

When combination of lenses is used

No. of the rings	Micrometer reading		Diameter D $(a-b)$ cm.	$D^2 = (a-b)^2$ cm^2
	Left end a cm.	Right end b cm.		
20	...	...	...	...
19	...	...	...	...
18	...	...	...	...
17	...	...	...	...
16	...	...	...	...
15	...	...	...	...
14	...	...	...	...
13	...	...	...	...
12	...	...	...	...
11	...	...	...	...
10	...	...	...	...
9	...	...	...	...
8	...	...	...	...
7	...	...	...	...
6	...	...	...	...
5	...	...	...	...

Calculation : R_1 = ... cm and R = ... cm.

$$\therefore \quad R_2 = \left(\frac{R R_1}{R_1 - R}\right)$$

Result : The radius of curvature of the given concave lens = ... cm.

Sources of Error and Precautions :

(i) Glass plates and lens should be cleaned thoroughly.
(ii) The lens used should be of large radius of curvature.
(iii) The source of light used should be an extended one.
(iv) Before measuring the diameters of rings, the range of the microscope should be properly adjusted.
(v) Crosswire should be focussed on a bright ring tangentially.

Viva-Voce

Q. 1. ***What are Newton's ring ?***

Ans. When a plano-convex surface is placed on a glass plate, an air film of gradually increasing thickness is formed between the two. When monochromatic light is allowed to fall normally on film and viewed in reflected light, alternate dark and bright rings are observed. These are known as Newton's ring.

Q. 2. ***Why are these rings circular ?***

Ans. These rings are foci of constant thickness of the air film and these foci being concentric circle hence fringes are circular.

Q. 3. ***Why do you use an extended source of light here ?***

Ans. To view the whole air film, an extended source is necessary.

Q. 4. ***Why do the rings get closer as the order of the rings increases ?***

Ans. This is due to the fact that the radii of dark rings are propotional to square root of natural numbers while those of bright rings are proportional to square root of odd natural numbers.

Q. 5. ***On what factors does the diameter of ring depend ?***

Ans. The diameter depends upon (i) wavelength of light used (ii) refractive index μ of enclosed film (iii) radius of curvature R of convex lens.

Q. 6. ***Do you get rings in the transmitted light ?***

Ans. Yes, in this case the colour of rings is complimentary of the reflected light.

Q. 7. ***Why is the centre of the ring dark ?***

Ans. Although at centre, the thickness of air film is zero but at the point of contact the two interfering rays are opposite in phase and produce zero intensity.

Q. 8. ***Sometimes the centre is bright. Why ?***

Ans. This happens when a dust particle comes between the two surfaces at the point of contact.

Q. 9. ***What will happen when the glass plate is silvered on its front surface ?***

Ans. In this case, the transmitted system of the fringes will be reflected and due to superposition of reflected and transmitted systems there will be uniform illumination.

Q. 10. ***What will happen when sodium lamp is replaced by white light source ?***

Ans. Few coloured fringes will be observed near the centre.

Q. 11. ***What will happen if a few drops of a transparent liquid are introduced between the lens and plate?***

Ans. The diameter of fringes is reduced by a factor of $\sqrt{\mu}$.

Q. 12. ***Why do you make the light fall on the convex lens normally ? What will happen if the light incident obliquely ?***

Ans. The light is allowed to fall normally so that angles of incident and reflection may be zero so that $\cos\theta$ may be taken as unity. In case of oblique incidence, the diameter of rings will increase.

Q. 13. ***How can you determine R ?***

Ans. This can be determined either by spherometer or by Boy's method.

Interference

EXPERIMENT No. 9

Object : To determine (i) λ, the wavelength of sodium yellow light and (ii) $(\lambda_1 - \lambda_2)$, the difference between the wavelengths of two sodium D-lines, with the help of Michelson interferometer.

Apparatus used : Michelson interferometer, sodium lamp, condensing lens and a pin.

Formula used :

(i) The wavelength λ of sodium light is given by

$$\lambda = \frac{2\,(x_2 - x_1)}{N} \qquad \ldots (1)$$

where x_1 = initial position of mirror M_1 of Michelson interferomeer.

x_2 = final position of mirror M_1 of Michelson interferometer

i.e., $(x_2 - x_1)$ = distance moved by mirror M_1.

N = number of fringes appeared at the centre of field corresponding to distance $(x_2 - x_1)$.

(ii) The difference of two wavelenths of sodium lines $(\lambda_2 - \lambda_1)$ is given by

$$(\lambda_2 - \lambda_1) = \frac{\lambda_{av}^2}{2x} \qquad \ldots (2)$$

where $\lambda_{av}^2 = \lambda_1 \lambda_2$ = (mean of λ_1 and $\lambda_2)^2$

x = distance between the two indistinct positions of mirror M_1.

Description of apparatus :

Michelson interferometer is shown in (fig. 1). It consists of two excellent optically plane, highly polished plane mirrors M_1 and M_2 which are right angles to each other. There are two optically flat glass plates G_1 and G_2 of the same thickness and of the same material placed parallel to each other. These plates are also inclined at an angle 45° with mirror M_1 and M_2. The face of G_1 towards G_2 is semisilvered. The mirror M_1 is mounted on a carriage which can be moved forward or backward. The motion is controlled by a very fine micrometer screw (capable of reading upto 10^{-5} cm.). The mirrors M_1 and M_2 are provided with three levelling screws at their backs. With the help of these screws the mirrors can be tilted about horizontal and vertical axes so that they can be made exactly perpendicular to each other. T is a telescope which receives the reflected lights from mirrors M_1 and M_2.

Adjustment of the interferometer : In order to obtain the circular fringes, the following adjustements are made :

(i) The distance $G_1 M_1$ is made nearly equal to $G_2 M_2$ with the help of drum head H_1 *i.e.*, movable mirror M_1 is moved by turning the drum head until the two distances are nearly equal.

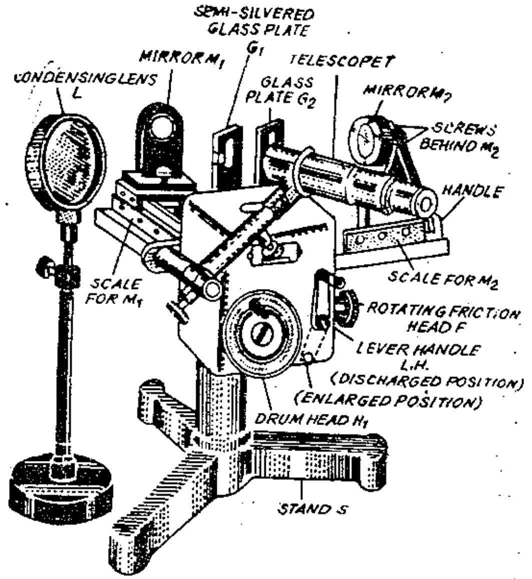


Fig. (1)

(ii) Light coming from sodium lamp is rendered parallel by condensing lens L. Now a pin is introduced between condensing lens L and glass plate G_1. On looking through the telescope (being towards glass plate G_1 for receiving the emergent light from M_1), four images R_1, R_2, R_3 and R_4 are observed as shown in fig. (2). The images R_3 and R_4 are brighter while R_1 and R_2 are fainter. By adjusting the screws behind the mirror M_2, the brighter images R_3 and R_4 are made coincided.

(iii) The pin is now removed. Usually localised firnges appear in the field of view. To obtain the cicular fringes, the mirror M_2 is further tilted with the help of screws attached behind it in such a way that the spacing between the fringes increases. After a slight adjustment circular fringes appear in the centre of the field of view. If the centre of the fringes is not at the centre of field of view, then it is also adjusted by screws.

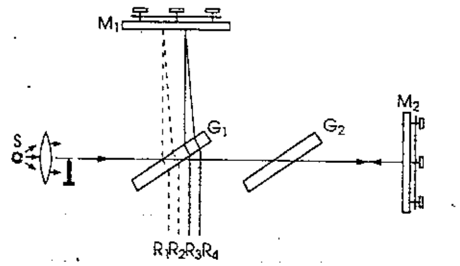


Fig. (2)

(iv) By moving the eye in linear or lateral direction, the fringes should not converge or diverge. If they do so, then again by a final tilt of mirror M_2 the fringes are made sationary.

Procedure : (1) For the wavelength of monochromatic light :

(i) The position of mirror M_1 is adjusted by turning drum head H_1 so that a bright spot of circular fringes appears at the centre of field of view. The micrometer reading is noted.

(ii) The mirror M_1 is moved away so that a god number of fringes (say 25) appear at the centre of the field. The micrometer screw reading is again noted.

(iii) The procedure is repeated to take 20 readings.

(2) For difference of wavelengths :

(i) The interferometer is adjusted for circular fringes. The mirror M_1 is moved till there is maximum indistinctness of the fringe pattern. The micrometer screw reading is noted.

(ii) By further movement of mirror M_1, the fringe pattern becomes clear. Again the mirror is moved until the next position of maximum indistinctness is obtained. The micrometer reading is noted.

(iii) The procedure is repeated for a number of consecutive positions of maximum indistinctness.

Observations : (1) Table for wavelength of monochromatic light.

Leastcount of rough micrometer screw = 0· 001 cm.

Leastcount of fine micrometer screw = 10^{-5} cm.

S. No.	No. of fringes appeared	Position of mirror M_1				Difference x for 200 fringes (cm.) (200 x)	Mean difference x (cm.)
		Main scale reading (cm.)	R.M.S. reading (cm.)	F.M.S. reading (cm.)	Total (cm.)		
1	0	...	...	...	...	...	
2	25	...	...	...	...	...	
3	50	...	...	...	...	...	
4	75	...	...	...	...	...	...
:	...	...	...	...	...	...	
:	...	...	...	...	...	...	
20	400	...	...	...	...	...	

(2) Table for difference of wavelengths ($\lambda_1 - \lambda_2$).

S. No.	Position of mirror M_1 for maximum indistinctness				Difference between 5 consecutive positions 5 (x) (cm.)	Mean 5x (cm.)	Mean x (cm.)
	Main scale reading (cm.)	R.M.S. reading (cm.)	F.M.S. reading (cm.)	Total (cm.)			
1	...	...	...	...	...		
2	...	...	...	...	...		
3	...	...	...	...	...		
4	...	...	...	...	...	...	...
:	:	:	:	:	:		
:	:	:	:	:	:		
:	:	:	:	:	:		
:	:	:	:	:	:		
10	...	...	...	...	...		

Calculations :

(1)
$$\lambda = \frac{2x}{N} = \frac{2(\ldots)}{200} = \ldots \text{ cm.}$$

(2)
$$\lambda_1 - \lambda_2 = \frac{\lambda_{av}^2}{2x} = \frac{(5893 \times 10^{-8})^2}{2(\ldots)} = \ldots\text{cm.}$$

where $\lambda_{av} = 5893 \times 10^{-8}$ cm.

Result : (1) The wavelength of sodium light = ... Å

(2) The difference of wavelengths = ... Å

Precautions and Sources of Error :

(1) Glass plate G_1, G_2 and mirrors M_1, M_2 should not be touched or cleaned.
(2) The micrometer screw should be handled carefully.
(3) The screws behind mirror M_2 should be rotatd through a very small angle.
(4) There should not be linear or lateral displacement of circular fringes when viewed by eye.
(5) In the position of maximum indistinctness, the fringes should almost disappear.
(6) There should be no disturbance near the experiment.

Viva-Voce

Q. 1. ***What do you mean by interferometer ?***

Ans. Interferometer is a device used to determine the wavelength of light utilising the phenomenon of interference.

Q. 2. ***Are two mirrors simply plane mirrors ?***

Ans. They are excellently optically plane and highly silver polished plane mirrors.

Q. 3. ***What type of glass plates are G_1 and G_2 and how are they mounted ?***

Ans. The two plates are optically flat glass plates of same thickness and of the same material. They are parallel to each other and inclined at an angle 45° with the two mirrors. G_1 is semisilvered at the face towards G_1 and G_2. is known as compensating plate.

Q. 4. ***What shapes of fringes do you get ?***

Ans. The fringes may be straight, circular, parabolic etc. depending upon the path difference between the two rays and angle between the two mirrors.

Q. 5. ***How do you get circular fringes ?***

Ans. The circular fringes are obtained when the two mirrors are exactly perpendicular to each other (or they encloses an air film of uniform thickness). The screws provided at the back of mirror M_2 are adjusted for this purpose.

Q. 6. ***Where the circular frnges are formed ?***

Ans. They are formed at infinity and that is why a telescope is used to receive them.

Q. 7. ***What will you observe with white light source ?***

Ans. With white light source, we observe a central white fringe and some coloured fringes placed symmetrical on both sides of central fringe.

Q. 8. ***What are localised fringes ?***

Ans. When the two mirrors are not exactly perpendicular to each other then either straight or parabolic fringes are observed. These are known as localised fringes ?

Q. 9. ***When the mirrror is moved through a distance λ/2, how many fringes appear or disappear ?***

Ans. One.

Q. 10. ***Can you measure the difference of two wavelengths with Michelson's interferometer ?***

Ans. Yes. By moving the mirror M_1, the positions of two consecutive maxmum indistinctness are observed. If x be the distance between them, then

$$\lambda_1 - \lambda_2 = \lambda_{av}^2/2x.$$

Interference

EXPERIMENT No. 10

Object : To determine the separation between the plates of a Fabry Perot Etalon.

Apparatus required : Fabry-Perot Etalon spectrometer, condensing lens, reading lamp, sodium lamp.

Formula used :

The condition of maxima in Fabry-Perot Etalon is given by

$$2d \cos \theta_n = n\lambda$$

or

$$d = \frac{n}{\cos \theta_n} \frac{\lambda}{2}$$

where
d = separation between the plates
n = order of interference
θ = angle of incidence
λ = wavelength of light used (5890 Å).

Experimental arrangement and adjustment : The experimental arrangement is shown in fig. (1). In figure, S is a broad source of monochromatic light and S is an adjustable slit. Etalon E_1, E_2 is placed on the turn table of an ordinary spectrometer. The collimator, collimates the beam which side suffers multiple reflections in the air film of Etalon. The transmitted light is collected by telescope. When viewed through the telescope, circular fringes are observed. Sometimes the fringes are not very clear. To obtain a clear fringe pattern, the following adjustment is made : The spectrometer is turned in such a way that light directly from the source falls on the etalon *i.e.* collimator removed from the light path. An oily paper with a fine pin hole is placed in front of the source. Now circular fringes are clearly observed through telescope.

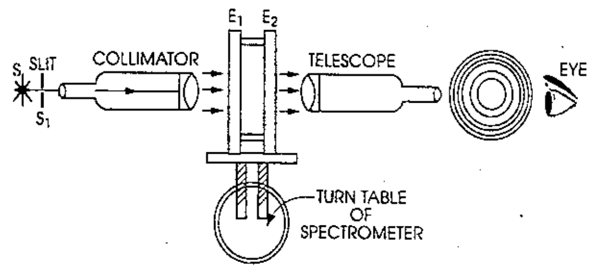


Fig. (1)

Procedure :

(1) The fringe pattern is brought at the centre of the field of view by adjusting the levelling screws provided at the base of the etalon.

(2) The turn table is fixed and the telescope is moved towards right of the fringe pattern. The cross wire of the telescope is made tangential to the first dark ring and the turn table reading is noted. By moving the telescope, the procedure is repeated for successive dark fringes till the clearly visible fringe is reached.

(3) Procedure no. 2 is repeated towards the left side of fringe pattern.

(4) The angular diameter $2\theta_n$ of the rings are measured as shown in the table below.

Observations :

Leat count of spectrometer = ...

Table for plotting $\cos\theta_n$ against *n*.

Ring Number	Angular diameter $2\theta_n$				Difference		Mean $2\theta_n$	θ_n	$\cos\theta_n$
	Reading on left		Reading on right						
	1st scale (a)	2nd scale (b)	1st scale (c)	2nd scale (d)	$\frac{c-a}{2\theta_n}$	$\frac{d-b}{2\theta_n}$			
1	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...
:	...	...	...	...	...	...	...	...	...
:	...	...	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...	...	...

Calculations : A graph is plotted between $\cos\theta_n$ as a function of *n*. The graph is shown in fig. (2).

From graph

$$\frac{n}{\cos\theta_n} = \frac{BC}{AB}$$

$$\therefore \quad d = \frac{BC}{AB} \times \frac{\lambda}{2}$$

Here

$$\lambda = 5893 \times 10^{-8} \text{ cm.}$$

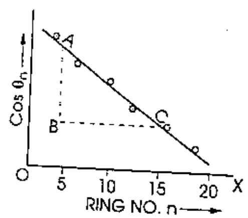


Fig. (2)

Hence the value of *d* can be calculated.

Result : The thickness of the etalon = ... cm.

Precautions and sources of error :

(i) The centre of the fringe pattern should be made at the centre of field of view.

(ii) While taking readings, the turn table should be fixed.

(iii) Before measuring the diameters of the rings, the telescope should be properly adjusted.

(iv) Cross wire should be focussed tangentially.

Viva-Voce

Q. 1. ***What is a Fabry-Perot etalon ?***

Ans. This is a multiple beam high resolution interferometer designed by Fabry and Perot.

Q. 2. ***What is its construction ?***

Ans. This consists of two semi-silvered (inner side) optically plane and parallel glass plates which are separated at a fixed distance.

Q. 3. ***What is the shape of fringes ?***

Ans. The fringes are circular which are widely separated at the centre while crowded for longer radii.

Q. 4. ***What is the difference between these fringes and those obtained in Michelson's interferometer ?***

Ans. These fringes are much narrower, sharper and brighter than those of Micheloson's interferometer.

Q. 5. ***Where are these fringes formed ?***

Ans. They are formed at infinity.

Q. 6. ***What do you mean by sharpness of fringes ?***

Ans. The sharpness of frnges defines that how rapidly the intensity diminishes on either side of maximum.

Q. 7. ***What is half width of a ring ?***

Ans. This is the total width of a fringe at those points where the intensity has fallen to half the maximum intensity.

Q. 8. ***On what factors the sharpness of maxima depend ?***

Ans. The sharpness depends upon half fringe width, smaller is the half fringe width, sharper is the maxima. Moreover half fringe width decreases as reflection coefficient increases.

Q. 9. ***Instead of spectrometer, can you use a Michelson's interferometer arrangement of Fabry Perot Etalon ?***

Ans. Yes. In this case, mirror M_1 of Michelson's interferometer is removed and Fabry Perot Etalon is mounted on the carriage so that required separation between the two plates may be adjusted.

Q. 10. ***Can you measure the difference of two wavelengths with the help of above arrangement ?***

Ans. Yes. As in case of Michelsons interferometer.

Interference

EXPERIMENT No. 11

Object : To determine the thickness of the given wire by wedge method.

Apparatus used : Two optically glass plates of same size, black paper, sodium lamp, microscope, wooden frame and one glass plate.

Formula used :

The diameter (thickness) of the wire can be calculated with the help of following formula

$$d = \left(\frac{\lambda x}{2\beta}\right)$$

where λ = wavelength of light used $= 5893 \times 10^{-8}$ cm.

x = distance between the point of contact of two glass plates and the axis of wire fixed between them

β = fringe-width

Description of apparatus :

The experimental arrangement is shown in fig. (1). Two optically plane glass plates (well cleand) are taken. The given wire is fixed between them such that the two glass plates touch at one end and are separated at the other end. In this way a wedge shaped film is formed. This set is placed on a wooden frame covered at lower surface with a black paper. Another glass plate is fitted to the wooden frame at about 45° to the horizontal. The light falling on this plate is reflected down to fall on the wedge shaped film. For this purpose sodium light from extended source is used. The interference fringe are observed with the help of microscope.

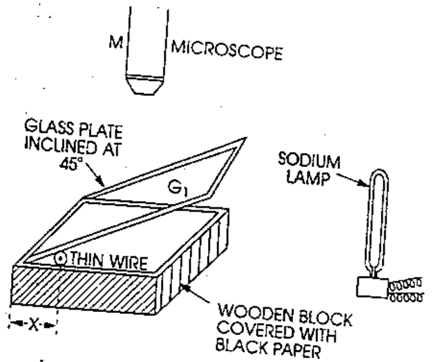


Fig. (1)

Procedure : (i) The wedge shaped film is well illuminated by sodium light by switching on the sodium lamp.

(ii) Focus the eyepiece on the cross wire and move the microscope in the vertical plane by means of rack and pinion arrangement till the fringes are quite distinct. Clamp the microscope in the vertical side.

(iii) The cross-wire is now moved and fixed at the centre of a bright fringe. The reading of microscope is noted.

(iv) The cross-wire is now moved and fixed at the centre of every bright fringe. The corresponding microscope readings are noted. From these observations β can be calculated.

Observations :

(1) Value of one division of the main scale = ... cm.
No. of divisions on the vernier scale = ...
Least count of the microscope = ... cm.

(2) The distance of the wire from the point of contact of the two plates x = ... cm. See table on below :

No. of fringe	Microscope reading			No. of fringe	Microscope reading			Width of 5 fringes $a-b$	Mean Width of frnges	β
	M.S. reading	V.S. reading	Total a cm.		M.S. reading	V.S. reading	Total b cm.			
1	...	...	...	6	...	...	...	...		
2	...	...	...	7	...	...	...	...		
3	...	...	...	8	...	...	...	...		
4	...	...	...	9	...	...	...	...	...	...
5	...	...	...	10	...	...	...	...		

Calculation :

$$d = \left(\frac{\lambda x}{2\beta}\right)$$

$= \ldots$ cm.

Result : The thickness of the given wire = ... cm.

Sources of error and Precautions :

(1) The wire used should be thin.
(2) The glass plates should be very clean and thin.
(3) The source of light used should be an extended one.
(4) Crosswire should be focussed on a bright ring.
(5) The microscope should be moved in the same direction while taking the observations for fringes.

Interference

EXPERIMENT No. 12

Object : To determine the value of Young's modulus Y for the material of a rod by Searle's optical interference method.

Apparatus used : Searle's apparatus, convex lens of large focal length, 50 gm weights, vernier-callipers, screw gauge, sodium lamp.

Formula used :

The Young's modulus Y of the material of the experimental rod is given by

$$Y = \frac{2\,W\,l\,(4\,D\,d - a^2)}{\lambda\,n\,\pi\,a^4}$$

where W = weight loaded on the road
l = perpendicular distance between two plates attached to the experimental rod.
D = perpendicular distance of the weight W from the axis of experimental rod
d = distance between the axis of experimental rod and the centre of the ring system.
a = radius of experimental rod
λ = wavelength of monochromatic light used
n = number of fringes appearing or disappearing for weight W.

Description of apparatus :

The different parts of the Searle's apparatus are shown in fig. (1). As shown in fig. (1b), AB is the experimental circular rod held vertically and fixed to a firm base. The upper portion of the rod AB is connected to another horizontal rod AC by means of screw S_1. With the help of hook H, desired weight W can be suspended. Two metallic plates P_1 and P_2 are attached to rod AB by means of screws S_1 and S_2. A pillar is attached to plate P_1 which passes through the hole of plate P_2. The upper surface of the pillar is spherical so that a convex lens L may rest on it. The upper plate P_2 carries three levelling screws along with springs. A circular plate P is placed on the springs. With the help of springs, a fine contact between lens and glass plate P can be made. A glass plate G, which can be adjusted to an inclined position, is also attached to the experimental rod by means of screw S_3. This helps the monochromatic light to incident normally on the lens system. The fringes are observed with the help of microscope.

Procedure : The following procedure is adopted.

(1) The convex lens is placed on the pillar attached to plate P_1. Now the pillar is moved upward so that the lens just touches the circular glass plate P. The fine adjustment is done with the help of screws attached to plate P_2. In this way an air film is enclosed between the lens and plate P.

(2) The extended monochromatic source of light is switched on. The inclination of glass plate is adjusted so that the light is incident normally on lens system. Newtons rings are now formed. The eye-piece of the microscope M is focussed on the fringe-system.

(3) The most important adjustment is the free movement of the fringe-system This is tested by applying a little pressure by means of finger tip on the unloaded rod AC. This causes the movement of fringe system. If there is no free movement of the fringe-system, the screws of the plate P_2 should be worked out. When this is adjusted, the lens touches the glass plate at a single point.

(4) The weights of different masses say 0·05 0·1 0·15 0·2 kg . . . . . . etc. are hanged in succession at the hook H. For each weight, the number of fringes n which disappear at the centre are counted.

(5) The constants a, d, l and D are measured with the help of screw gauge and vernier-callipers. Here a should be determined very accurately as it occurs in fourth power.

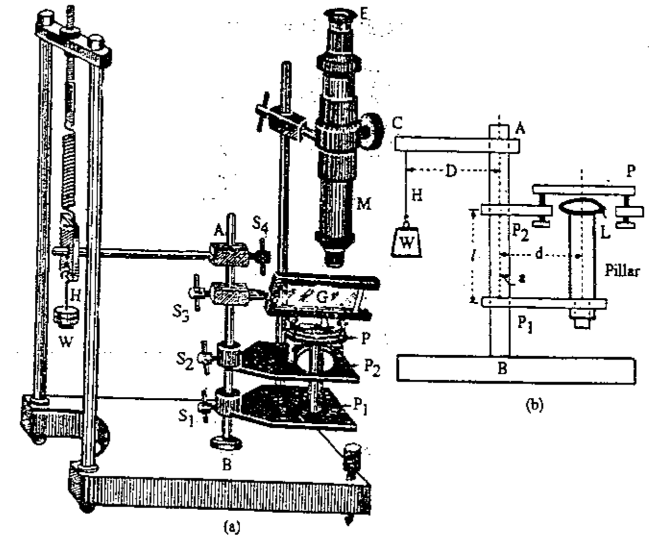


Fig. (1)

Observations :

1. **For number of fringes n disappeared**

S. No.	Weight applied $W = mg$ Newton	Fringes disappeared
1	...	...
2	...	...
3	...	...
4	...	...
5	...	...

2. **Determination of radius a of the rod AB**

Least count of screw gauge = ... cm.

S. No.	Diameter along one direction cm.	Diameter along perpendicular direction cm.	Mean diameter cm.	Meand radius a cm.	Mean a cm.
1	...	...	...	...	
2	...	...	...	...	...
3	...	...	...	...	

Mean a = ... meter

3. **Length l between plates P_1 and P_2**

Least count of vernier callipers = ... cm.

S. No.	Distance between outer surface of plates P_1 and P_2 l_1 cm.	Distance between inner surface of plates P_1 and P_2 l_2 cm.	$l = \frac{l_1 + l_2}{2}$ cm.	Mean l cm.
1	...	...	...	
2	...	...	...	...
3	...	...	...	

l = ... meter

4. **Length d between the point of contact of lens L and the axis of the rod**

Least count of vernier callipers = ... cm.

S. No.	Outer distance between pillar and rod AB d_1 cm.	Inner distance between pillar and rod AB d_2 cm.	$d = \frac{d_1 + d_2}{2}$ cm.	Mean d cm.
1	...	...	...	
2	...	...	...	...
3	...	...	...	

d = ... meter

5. **Distance D between axis of rod AB and the line of acton of load**

D = distance between hook and rod AB + radius a of the rod

= . . . . + ... = ... meter

Calculations :

$$Y = \frac{2\,W\,l\,(4\,D\,d - a^2)}{\lambda\,n\,\pi\,a^4}$$

When $W = 50$ gm, then n = ...

$$Y = \text{......} \times 10^{11}\ \text{Newton/m}^2$$

Calculate Y for different values of W and then take the mean value of Y.

Result : Young's modulus of the material of the rod

$$Y = \text{......} \times 10^{11}\ \text{Newton/m}^2$$

Standard value : Y for . . . . = ... $\times 10^{11}$ Newton/m^2

Precautions and sources of error :

(1) The plates P_1 and P_2 should be adjusted near the end B of the rod AB.

(2) With the help of screws, the fringe system is adjusted for free movement.

(3) By applying the different weights, the centre of the fringe pattern should not be shifted.

(4) The focussing should be accurate.

(5) The radius a of the rod should be measured very accurately as it occurs in fourth power in the formula.

Interference

EXPERIMENT No. 13

Object : To determine the Young's modulus Y of glass by Carnu's method.

Apparatus used : Wooden frame to carry the experimental glass beam, a small rectangular glass plate, glass plate fitted in a stand and inclined at an angle of 45°, sodium lamp, hangers, weights, travelling microscope, screw gauge and vernier callipers.

Formula used : The Young's modulus Y of glass is given by

$$Y = \frac{12\,(W - W')\,d}{b\,t^3 \left(\frac{1}{R_l} - \frac{1}{R_l'}\right)}$$

where
- W and W' = different weights applied on glass beam
- d = distance of the hanger from knife edge
- b = breadth of te beam
- t = thickness of the beam
- R_l = longitudinal radius of curvature of the beam due to weight W
- R_l' = longitudinal radius of curvature of the beam due to weight W'.

The longitudinal radius of curvature of the beam due to weight W is given by

$$R_l = \frac{(X_n^2 - X_1^2)}{4\,\lambda\,(n-1)}$$

- X_n = distance between the n^{th} pair of fringes in longitudinal direction.
- X_1 = distance between first pair of frnges in the longitudinal direcion.

Similarly.

$$R_l' = \frac{X_n'^2 - X_1'^2}{4\,\lambda\,(n-1)}$$

where X_n' and X_1' are the above mentioned distances corresponding to weight W'.

Description of apparatus :

The experimental arrangement is shown in fig. (1). The experimental glass beam AB (about 50 cm. long, 3 cm. in breadth and 1·5 mm in thickness) is supported on two knife edges K_1 and K_2 formed in a wooden frame. By means of thread loops, two hangers are suspended symmetrically near the ends of experimental rod. A square glass plate P (side 2 cm and thickness 2 mm) is placed at the middle of beam AB. Light from the sodium lamp is allowed to incident on plate P by means of glass plate G inclined at an angle of 45° with the horizontal. The interference hyperbolic fringes

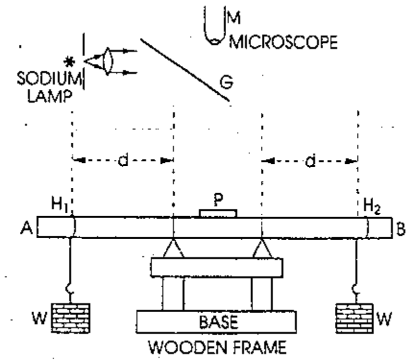


Fig. (1)

formed between the lower face of the plate P and upper curved surface of the beam are vewed with the help of travelling microscope.

Procedure : (1) Weights of certain masses say 200 gms are placed on each hanger at both the ends of the experimental beam and plate P is illuminated by sodium light.

(2) The travelling microscope is focussed on the hyperbolic fringes (fig. 2).

(3) The distance between the first pair of fringes and n^{th} (say 5^{th}) pair of fringes is determined in the longitudinal direction by means of microscope. These readings give X_1 and X_n respectively.

(4) Different sets of readings (X_n and X_1) are taken for different weights.

(5) Remove all the weights from experimental rod.

(6) The broadth b of the experimental beam AB is measured with the help of vernier callipers.

(7) The thickness t of the experimental beam AB is measured with the help of screw gauge.

(8) The distances of the knife edges K_1 and K_2 from their respective hangers are measured. The average of two gives the distance d.

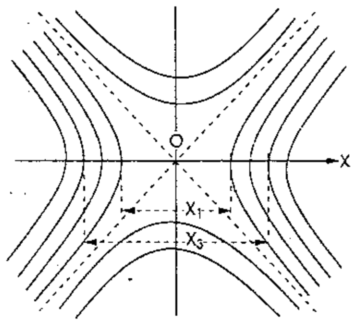


Fig. (2)

Observations :

(1) Distances X_n and X_1 measured in longitudinal direction

Least count of travelling microscope = ... cm.

Set No.	Weight Mirror	No. of Fringe	Distance (Diameter)			Distance X^2 cm^2	Distance X^2 m^2
			Left end cm.	Right end cm.	Difference X cm.		
1st	$W = 0.2$ kg	1 n (say 5)	... ...	... ...	$X_1 = ...$ $X_n = ...$	$(X_1)^2 = ...$ $(X_n)^2 = ...$	... ...
2nd	$W = 0.25$ kg	1 n (say 5)	... ...	... ...	$X_1' = ...$ $X_n' = ...$	$(X_1')^2 = ...$ $(X_n')^2 = ...$	... ...
3rd	$W = 0.3$ kg	1 n (say 5)	... ...	... ...	$X_1'' = ...$ $X_n'' = ...$	$(X_1'')^2 = ...$ $(X_n'')^2 = ...$	... ...
4th	$W = 0.3$ kg	1 n (say 5)	... ...	... ...	$X_1''' = ...$ $X_n'' = ...$	$(X_1''')^2 = ...$ $(X_n''')^2 = ...$	... ...

(2) Breadth b of the beam (for weight zero)

Least count of Vernier callipers = ... cm.

S. No.	Main scale reading cm.	Vernier scale reading cm.	Total reading cm.	Mean b cm.	b meter
1	...	...	...		
2	...	...	...	...	...
3	...	...	...		

(3) Thickness t of the beam (for weight zero)

Least count of screw guage = ... cm.

S. No.	Main scale reading cm.	Circular scale reading cm.	Total reading cm.	Mean t cm.	t meter
1	...	...	...		
2	...	...	...	...	...
3	...	...	...		

(4) Distance d between knife edge and hanger (for $W = 0$)

L.C. of Vernier Callipers = ...

S. No.	Distance K_1H_1 cm.	Distance K_2H_2 cm.	$d = \frac{K_1H_1 + K_2H_2}{2}$	Mean d cm.	d meter
1	...	...	...		
2	...	...	...	...	...
3	...	...	...		

Calculations :

$$\frac{1}{R_l} = \frac{4\lambda(n-1)}{(X_n^2 - X_1^2)} = ... \text{ cm}^{-1} \text{ for } 0.2 \text{ kg}$$

Similarly

$$\frac{1}{R_l'} = \frac{4\lambda(n-1)}{\{(X_n')^2 - (X_1')^2\}} = ... \text{ cm}^{-1} \text{ for } 0.25 \text{ kg}$$

$$\frac{1}{R_l''} = \frac{4\lambda(n-1)}{\{(X_n'')^2 - (X_1'')^2\}} = ... \text{ cm}^{-1} \text{ for } 0.3 \text{ kg}$$

$$\frac{1}{R_l'''} = \frac{4\lambda(n-1)}{\{(X_n''')^2 - (X_1''')^2\}} = ... \text{ cm}^{-1} \text{ for } 0.35 \text{ kg}$$

Now

$$Y = \frac{12(W - W')d}{bt^3\left(\frac{1}{R_l} - \frac{1}{R_l'}\right)}$$

$= ..... \times 10^{11}$ Newton/meter^2

(For $W = 0.2$ kg and $W' = 0.25$ kg)

And

$$Y = \frac{12(W'' - W''')d}{bt^3\left(\frac{1}{R_l''} - \frac{1}{R_l'''}\right)}$$

$= ..... \times 10^{11}$ Newton/meter^2

(For $W'' = 0.3$ kg and $W''' = 0.35$ kg)

Mean value of $Y = ... \times 10^{11}$ Newton/meter^2

Resul : Young's modulus Y for glass = ... $\times 10^{11}$ Newton/meter^2

Standard result : Young's modulus Y for glass = ... $\times 10^{11}$ Newton/meter^2.

Sources of error and Precautions : (1) The beam should be placed symmetrically on two knife edges.

(2) The glass plates should be optically plane and clean.

(3) Constants of the apparatus should be determined only when the beam is unloaded.

(4) The experimental beam should not touch the wooden stand.

Diffraction of Light

EXPERIMENT No. 14

Object : To determine the wavelength of prominent lines of mercury by plane diffraction grating.

Apparatus required : A diffraction grating, spectrometer, mercury lamp, prism, reading lens.

Formula used :

The wavelength λ of any spectral lines can be calcualted by the formula

$$(a+b)\sin\theta = n\lambda$$

or

$$\lambda = \frac{(a+b)\sin\theta}{n}$$

where $(a+b)$ = grating element.
θ = angle of diffraction.
n = order of the spectrum.

Adjustments :

(A) **Before using the spectrometer, the following adjustments are made :**

(i) The axis of the telescope and that of the collimator must intersect the principal vertical axis of rotation of telescope.

(ii) Prism table should be levelled.

(iii) Telescope and collimator are adjusted for parallel light by Schuster's method.

For the details of these points, see the experiment of refraction and dispersion of light.

(B) **Grating should be normal to the axis of collimator :**

This adjustment is shown in fig. (1).

(i) Collimator and telescope are arranged in a line and the image of the slit is focussed on the vertical cross wire. The reading is noted on both the verniers.

(ii) The telescope is now rotated through 90°.

(iii) Mount the grating on the prism table and rotate the prism table so that the reflected image is seen on the vertical cross wire. Take the reading of the verniers.

(iv) Turn the prism table from this position through 45° or 135°. In this position the grating is normal to the incident beam.

(C) **The slit should be adjusted parallel to the lines of the grating :**

For this setting, the slit is rotated in its own plane till the spectral lines become very sharp and bright.

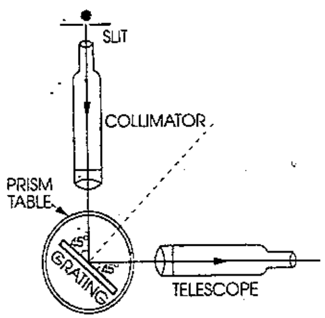


Fig. (1)

Procedure for the determination of angles of diffraction :

The spectrum obtained in a grating is shown in fig. (2).

(i) Rotate the telescope to the left side of direct image and adjust the different spectral lines (violet, green and red) turn by turn on the vertical cross wire for 1st order. Note down the reading of both the verniers in each setting.

(ii) Rotate the telescope further to obtain the second order spectrum and again the spectral lines on the vertical cross wire and note the readings.

(iii) Now rotate the telescope to the right of the direct image and repeat the above procedure for first order as well as for second order.

(iv) Find out the difference of the same kind of verneirs (V_1 and V_1 and V_2 from V_2) for each spectral line in the first order and then in the second order. The angle is the twice the angle of diffraction for that particular colour. Half of it will be angle of diffraction.

(v) Find out the angles of diffraction for other colours in first and second orders.

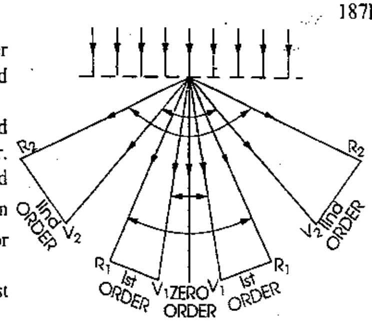


Fig. (2)

Observations :

No. of rulings per inch on the grating, N = ...
Least count of spectrometer = ... cm.
Reading of telescope for direct image = ...
Reading of telescope after rotating it through 90° = ...
Reading of circular scale when reflected image is obtained on the cross wire = ...
Reading after rotating the prism table through 45° or 135° = ...

Determination of angles of diffraction :

Order of Spectrum	Colour of light	Kinds of vernier	Spectrum on left side Reading of Telescope			Spectrum on right side Reading of Telescope			$2\theta = a - b$	Mean θ Degrees
			M.S. reading	V.S. reading	Total (a) Degrees	M.S. reding	V.S. reading	Total (b) Degrees		
First	Violet	V_1 V_2	... ...	... ...	... ...	... ...	... ...	... ...	... ...	...
	Green	V_1 V_2	... ...	... ...	... ...	... ...	... ...	... ...	... ...	...
	Red	V_1 V_2	... ...	... ...	... ...	... ...	... ...	... ...	... ...	...
Second	Violet	V_1 V_2	... ...	... ...	... ...	... ...	... ...	... ...	... ...	...
	Green	V_1 V_2	... ...	... ...	... ...	... ...	... ...	... ...	... ...	...
	Red	V_1 V_2	... ...	... ...	... ...	... ...	... ...	... ...	... ...	...

Calculations : Grating element $(a+b) = 2{\cdot}54/N = \ldots$ per cm.
where N = number of rulings per inch on the grating.

The wavelength of various spectral lines in the first order ($n = 1$) can be calculated by

$$\lambda = \frac{(a+b)\sin\theta}{1} = (a+b)\sin\theta$$

λ violet = ... A.U.

Calculate λ for other spectral lines.

Wavelength in scond order is given by

$$\lambda = \frac{(a+b)\sin\theta}{2}$$

λ violet = ... A.U.

Calculate λ for other spectral lines.

Mean value of λ violet = ... A.U.

Result : The wavelength are given in the table.

Colour of Spectral line	λ Observed A.U.	λ Standard A.U.	% Error
Violet I	...	...	...
Violet II	...	...	...
Blue	...	...	...
Blue green	...	...	...
Green	...	...	...
Yellow I	...	...	...
Yellow II	...	...	...
Red	...	...	...

Sources of error and Precautions :

(i) Before performing the experiment, the spectrometer should be adjusted.

(ii) Grating should be set normal to the incident light.

(iii) Grating should not be touched by fingers.

(iv) While taking observations, telescope and prism table should be kept fixed.

Theoretical error :

$$\lambda = \frac{(a+b)\sin\theta}{n}$$

Taking logarithm and differentiating

$$\frac{\delta\lambda}{\lambda} = \frac{\cos\theta\,\delta\theta}{\sin\theta} = \cot\theta\,\delta\theta$$

$$= \cos\theta\,\delta\theta\left(\frac{3\cdot14}{180}\right) \quad (180° = \pi \text{ radian})\ \delta\theta = 2'$$

$$= \cos\theta\left(\frac{2}{60}\right)\left(\frac{3\cdot14}{180}\right) \quad \text{Least count of spectrometer} = 1'$$

$= \ldots\ldots \%$.

ADDITIONAL EXPERIMENT

EXPERIMENT No. (14-1)

Object : To determine the dispersive power of a plane transmission diffraction grating.

Apparatus required : Spectrometer, sodium lamp, grating and reading lens.

Formula used : The dispersive power of a grating $d\theta/d\lambda$ is given by

$$\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta}$$

where $(a+b)$ = grating element

n = number of spectrum

θ = angle of diffraction.

Adjustments :

(A) Adjustment of the spectrometer : As described in experiment No. 1.

(B) Grating is adjusted normal to the axis of collimator : See experiment No. 14.

(C) The slit is adjusted parallel to the lines of grating : See experiment No. 14.

Procedure : For the determination of angles of diffraction, the following procedure is adopted :

(i) Rotate the telescope to the left side of direct image and adjust the specral lines D_1 and D_2 one by one on the cross wire in first order. Note down the readings of both verniers for D_1 and D_2.

(ii) Rotate the telescope further to obtain the second order spectrum. Adjust the cross wire on the spectral lines D_1 and D_2 one by one in second order. Note down the readings of both verniers for D_1 and D_2.

(iii) Now rotate the telescope to the right of direct image and repeat the above procedure for first order as well as for second order.

(iv) Find the difference of same kind of verniers for the spectral lines in first order and then in the second order. The angle is twice the angle of diffraction. Half of this angle will be the angle of diffraction. In this way the angles of diffraction for D_1 and D_2 in first order and in second order are known.

Observation : No. of rulings per inch on the grating, N = ...

Least count of the spectrometer = ... cm.

Reading of telescope for direct image = ...

Reading of circular scale when reflected image is obtained on the cross wire = ...

Reading after rotating the prism table through 45° = ...

Table for determination of angle of diffraction.

Order of Spectrum	Kinds of Vernier	Specification of the line	Spectrum on left side Reading of Telescope: M.S. reading	V.S. reading	Total a Degrees	Spectrum on right side Reading of Telescope: M.S. reading	V.S. reading	Total b Degrees	$2\theta = a \sim b$	Mean θ	$d\theta$	cos θ
First	V_1	D_1	...	...	...	...	...	...	...	...	...	...
	V_2		...	...	...	...	...	...	...			
	V_1	D_2	...	...	...	...	...	...	...	...	...	...
	V_2		...	...	...	...	...	...	...			
Second	V_1	D_3	...	...	...	...	...	...	...	...	...	...
	V_2		...	...	...	...	...	...	...			
	V_1	D_4	...	...	...	...	...	...	...			
	V_2		...	...	...	...	...	...	...			

Calculations : Grating element

$$(a+b) = \frac{2\cdot54}{N} = \ldots\ldots \text{ per cm.}$$

For Ist order.
$$\frac{d\theta}{d\lambda} = \frac{1}{(a+b)\cos\theta} = \ldots\ldots$$

Also
$$\frac{d\theta}{d\lambda} = \frac{\theta_2 - \theta_1}{\lambda_2 - \lambda_1} = \ldots\ldots$$

For second order
$$\frac{d\theta}{d\lambda} = \frac{2}{(a+b)\cos\theta} = \ldots\ldots$$

Also
$$\frac{d\theta}{d\lambda} = \frac{\theta_2 - \theta_1}{\lambda_2 - \lambda_1} = \ldots\ldots$$

Result : The dispersive power of grating in first order = ... and the second order = ...
The theoretical and experimental values are approximately equal.

Viva-Voce

Q. 1. ***What do you mean by diffraction of light ?***

Ans. When light falls on obstacle or small aperature whose size is comparable with the wavelength of light, there is a departure from straight line propagation, the light bends round the corners of obstacles or apertures. The bending of light is called diffraction.

Q. 2. ***What is difference between interference and diffraction ?***

Ans. Interference of light takes place due to the superposition of two waves coming from two different coherent sources while diffraction is due to the mutal interference of secondary wavelets originating from the various points of the wavefront which are not blocked off by the obstacle.

Q. 3. ***What is a diffraction grating ?***

Ans. An arrangement consisting of a large number of parallel slits of same width and separated by equal opaque spaces is known as diffraction grating.

Q. 4. ***What are the requisites of a good grating ?***

Ans. The lines should be exactly parallel, uniform, equidistant and of equal width.

Q. 5. ***What is grating element ?***

Ans. The distance between the centres of two successive slit is called grating element. This is denoted by $(a+b)$ where a is width of transparent part and b is width of opaque part.

Q. 6. ***How many orders do you get here ? Why ?***

Ans. We know that $(n)_{max} = \frac{a+b}{\lambda}$. The grating which we are using have 15.000 lines per inch. Hence

$$(a+b) = \frac{2 \cdot 54}{15.000} \cdot \lambda = 5893 \times 10^{-8}$$

$$\therefore \quad (n)_{max} = \frac{2 \cdot 54}{15{,}000 \times 5893 \times 10^{-8}} = 2 \cdot 875 < 3$$

Thus we get only two orders.

Q. 7. ***What is main difference between a prism spectrum and a grating spectrum ?***

Ans. In grating spectrum red colour is deviated most and violet least while this order is reversed in prism spectrum.

Q. 8. ***Why is the prism spectrum more intense than the grating spectrum ?***

Ans. In case of a prism, the light is concentrated in one spectrum while in case of grating, the incident light is diffracted into spectra of various orders moreover most of the light is concentrated in direct image where no spectrum is formed.

Q. 9. ***What is dispersive power of grating ?***

Ans. The rate of change of angle of diffraction with wavelength is defined as the dispersive power of grating. This is expressed as

$$\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta}$$

Dispersive power is more for higher orders.

Q. 10. ***On what factors does the dispersive power of a grating depend ?***

Ans. The dispersive power depends upon (i) grating element, (ii) angle of diffraction and (iii) order of spectrum.

Q. 11. ***What will happen if the width of clear space and ruled space is made equal ?***

Ans. Even order spectra (2, 4, 6, 8 . . . . . etc.) will be absent.

Diffraction of Light

EXPERIMENT No. 15

Object : To determine the diameter of lycopodium particles by forming diffraction fringes.

Apparatus used : Optical bench, glass plate, lycopodium powder, sodium lamp and a metal plate having a small hole at centre and provided with pin holes along two perpendicualr lines passing through the centre of hole.

Formula used :

The diameter of the lycopodium powder d can be calculated by the formula

$$d = \frac{1 \cdot 22\, \lambda D}{r}$$

where λ = wavelength of light used = 5893 Å

D = distance of glass plate from the metal plate

r = distance of the first set of pin holes from the central hole.

Procedure :

(i) Mount the metal plate on the upright of an optical bench.

(ii) The glass plate is dusted with lycopodium powder. The dusted plate is mounted on the upright of the optical bench at a certain distance from metal plate as shown in fig. (1).

(iii) The metal plate is illuminated with sodium light. Viewing through the dusted glass plate, a series of circular fringes of yellow colour are observed.

(iv) The dusted glass plate is moved in such a way that the first ring of diffraction pattern coincides with the first set of pin holes. The Distance D of glass plate from metal plate is noted.

(v) The experiment is repeated for other sets of equidistant pin holes.

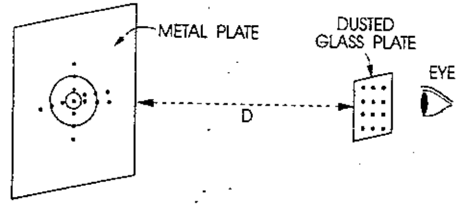


Fig. (1)

Observations :

Wavelength of sodium light $\lambda = 5893 \times 10^{-8}$ cm.

Table for the determine of *d*

S. No.	*D* cm	*r* cm	$d = \frac{1 \cdot 22\, \lambda D}{r}$ cm	Mean *d* cm
1	...	...	...	
2	...	...	...	
3	...	...	...	
4	...	...	...	...
5	...	...	...	

Calculations : The diameter d is given by

$$d = \frac{1.22\,\lambda D}{r}$$

$(d)_{\text{For first set of pin holes}} = \ldots\ldots$

Calculate d for other sets of pin holes.

Result : The mean diameter of lycopodium powder = ... cm.

Precautions :

(1) The optical bench should be levelled.
(2) The glass plate and metal plate should be adjusted at the same level.
(3) The glass plate should be parallel to metal plate.
(4) r should be measured accurately.
(5) The central hole of metal plate and eye should be at the same level.

Diffraction of Light

EXPERIMENT No. 16

Object : To determine the wave-length of monochromatic light by diffraction at a straight edge.

Apparatus required : Optical bench, a straight edge (say a razor blade) slit, stand and travelling microscope.

Description of apparatus and theory :

The experimental arrangement is shown in fig. (1).

The optical bench used in the experiment consists of a heavy iron base supported on four levelling screws. There is a graduated scale along one of its arms. The bench is provided with three uprighs which can be clamped any where and the position can be read by means of vernier attached to it. Each of the uprights is subjected to the following motions :

(i) motion along bench.
(ii) transverse motion.
(iii) rotation about the axis of upright.

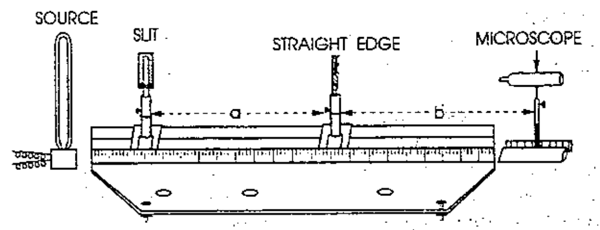


Fig. (1)

The straight edge is set up in one of stands on optical bench, parallel to the length of the slit which is illuminated by monochromatic light. The fringes are observed with the help of travelling microscope.

For first maximum,

$$x_1 = \sqrt{\left\{\frac{b(a+b)\lambda}{a}\right\}}$$

and for nth maximum,

$$x_n = \sqrt{\left\{\frac{b(a+b)(2n-1)\lambda}{a}\right\}}$$

Subtracting, we get

$$x_n - x_1 = \sqrt{\left\{\frac{b(a+b)\lambda}{a}\right\}}\,[\sqrt{(2n-1)} - 1]$$

or

$$(x_n - x_1)^2 = \frac{b(a+b)\lambda}{a}\,[\sqrt{(2n-1)} - 1]^2$$

or

$$\lambda = \frac{(x_n - x_1)^2 a}{(a+b)\,[\sqrt{(2n-1)} - 1]^2}$$

Using the above formula λ can be calculated.

Procedure :

The experiment is divided into the following two parts :

(i) Obtaining perfect fringes,

(ii) Measurement of $(x_n - x_1)$.

(i) Adjustment for getting perfect fringes :

In order to secure well defined fringes in the field of view of eyepiece, the following adjustments are made :

(a) the optical bench should be levelled,

(b) the eyepiece should be focussed on the cross wires,

(c) axis of the slit should be made vertical,

(d) slit, straight edge and micrometer eyepiece should be adjusted to the same height.

(e) the edge of the razor blade and the slit are made parallel, and

(f) the lateral shift is removed.

Procedure for the various adjustments :

(a) Level the bed of the optical bench with the help of spirit level and levelling screws.

(b) Point the micrometer eyepiece towards a white wall. By moving the tube containing the eye lens in or out focus the eyepiece on the cross-wire till they are distinctly visible. Set one of them vertical by rotating the eyepiece as a whole.

(c) Illuminate the slit with the help of sodium lamp. Now see the slit in the micrometer eyepiece and rotate the slit in its own plane with the help of tangent screw, till it becomes vertical.

(d) The upright carrying the staight edge is placed as close to the slit as possible. The edge of the razor blade is made vertical approximately with the help of tangent screw attached with it. See the diffracted images of the slit and adjust the height of slit and razor blade so to obtain the maximum length of the images of the slit. Adjust the height of the micrometer eyepiece such images of the slit are visible in the centre of the field of view of the eyepiece.

(e) Put the upright carrying the micrometer eyepiece near the straight edge. Fringes will be visible in the field of view. They are made clear by gradually narrowing the slit.

In case the fringes are not sharp, rotate the edge of the razor blade in its own plane with the help of tangent screw till the fringes are sharp. In this case slit and the edge of razor blade will be parallel to each other.

(f) The lateral shift will exist so long as the line joining the slit and the edge of the razor blade is not parallel to the bed of the bench.

In order to adjust the system for no lateral shift, the eyepiece is moved away from the straight edge. In this case the fringes will move to the right or left, but with the help of the base screw provided with straight edge it is moved at right angle to the bench in a direction to bring the fringes back to their original position.

Now move the eyepiece towards the straight edge and same adjustment is made with the help of eyepiece.

Using the process again and again, the lateral shift is removed.

(ii) Measurement of $x_n - x_1$:

(i) Find out the least count of the microscope and adjust it on the first maximum. Note down this reading.

(ii) Now adjust the microscope on a clearly visible maximum and again note down its position.

(iii) The distance between slit and straight edge (*a*) is noted.

(iv) The distance between straight edge and microscope (*b*) is also noted.

Observations :

(i) Distance between slit and straight edge (*a*) = ... cms.

Distance between straight edge and microscope (*b*) = ... cms.

(ii) Table for the determination of $(x_n - x_1)$.

Least count of the microscope = ... cms.

S. No.	Microscope reading for x_1			x_1	Microscope reading for x_n			x_n	n	$(x_n - x_1)$
	M.S. readng	V.S reading	Total cms.		M.S. readng	V.S reading	Total cms.			
1	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...

Calculations : The wave-length of monochromatic light is given by

$$\lambda = \frac{(x_n - x_1)^2 a}{(a+b)\,(b)\,[\sqrt{(2n-1)} - 1]^2}$$

Result : The wavelength of the monochromatic light

= ...... A.U.

Standard Result : A.U.

Percentage error : = ... %.

Sources of error and Precautions :

(i) The straight edge should be parallel to the slit.

(ii) Make the slit as narrow as possible until the fringes are most clear.

(iii) The cross wire of the microscope should be well focussed on the fringes.

(iv) Distance (*a*) and (*b*) should be measured accurately.

Viva-Voce

Q. 1. ***What do you use for straight edge ?***

Ans. We use razor blade as straight edge.

Q. 2. ***Where you place the razor blade ?***

Ans. We place the razor blade on the bench of biprism experiment between slit and eyepiece.

Q. 3. ***What are two kinds of diffraction ?***

Ans. (i) Fresnel's diffraction, in this class the source and screen are placed at finite distances from diffracting system.

(ii) Fraunhofer diffraction, in this class the source and screen are placed at infinity or effectively at infinity by using convex lenses.

Q. 4. ***Give example of Fresnel's diffraction and Fraunhofer diffraction.***

Ans. The diffraction at straight edge comes under Fresnel's class while diffraction at grating is the example of Fraunhofer class.

Q. 5. ***What is the nature of fringes observed in this experiment ?***

Ans. Inside the geometrical shadow, the intensity of light falls off rapidly without any maxima and minima while outside the geometrical shadow there are diffraction bands of diminishing intensity.

Q. 6. ***What type of a soruce are you using in this experiment ?***

Ans. Monochromatic source of light.

Q. 7. ***What will happen if the source is not monochromatic ?***

Ans. The bands will be coloured where blue bands appearing near the edge.

Q. 8. ***What is the importance of this experiment with regards to the wave theory of light ?***

Ans. As the shadow cast by straight edge is not sharp, so the propagation is not rectilinear.

Resolving Power of A Telescope

EXPERIMENT No. 17

Object : To determine the resolving power of a telescope.

Apparatus required : Telescope with a rectangular adjustable slit, a black cardboard with narrow white strips on it, travelling microscope and metre scale.

Formula used :

The theoretical and practical resolving powers are given by

$$\text{Theoretical resolving power} = \frac{\lambda}{a}$$

and

$$\text{Practical resolving power} = \frac{d}{D}$$

where λ = mean wavelength of light employed,
a = width of the rectangular slit for just resolution of two objects.
d = separation between two objects.
D = distance of the objects from the objective of the telescope.

Hence

$$\frac{\lambda}{a} = \frac{d}{D}$$

Theory of the experiment :

Rayleigh's criterion of resolution : According to Rayleigh's criterion, two equally bright sources can be just resolved by any optical system when their distance apart is such that in the diffraction pattern, the maximum due to one falls on the minimum due to the other.

Resolving power of Telescope : The resolving power of a telescope may be defined as the inverse of the least angle subtended at the objective by two distant point objects which can be just distinguished as separate in its focal plane.

Let a beam of monochromatic light starting from a distant object O (not shown) be incident normally on a rectangular aperture AB fitted infront of the telescope objective. Let AQ represents the incident wavefront which is brought to a focus F and observed magnified by means of eyepiece. The intensity pattern at F is shown by thick curved line.

Consider again an object O' towards the right of O whose pattern is formed towards left of the F. The pattern is formed at F as shown by dotted curve. The wave-front due to the incident light is shown by AN. According to the Rayleigh criterion, the two objects can only be resolved when the maximum due to one falls on the minimum due to the other as shown in figure (1).

As the aperture is rectangular the minimum due to one will fall on the maximum of the other when $QN = \lambda$. The angle between the two wavefronts, is,

$$\theta = \frac{AQ}{AN} = \frac{\lambda}{a}$$

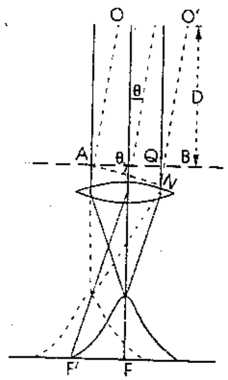


Fig. (1)

where a is the aperture and θ is the angle subtended by two objects OO' at the objective of telescope.

Again

$$\theta = \frac{OO'}{D} = \frac{d}{D} = \frac{\lambda}{a}.$$

where d is the distance between two objects and D is their distance from the objective of telescope.

Procedure :

(i) Mount the telescope on a stand such that its axis lies horizontal and the rectangular lines marked on cardboard or glass on the another stand such that they are vertical. Place the two stands at a suitable distance (say about 5 or 6 ft.) fig. (2).

(ii) Illuminate the object with source of light.

Now open the slit with the help of micrometer screw and move the telescope in the horizontal direction such that the images of two vertical sources are in the field of view of the eyepiece.

(ii) Gradually reduce the width of the slit till the two images just cease to appear as two. Note down the reading of the micrometer. Again close the slit completely and note down the micrometer reading. The difference of the two readings gives the width of the slit (a) just sufficient to resolve the two images.

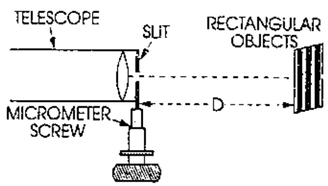


Fig. (2)

Or

If the slit is not provided with micrometer arrangement, the slit is gradually reduced till the two images cease to appear two. Take the slit and measure its width with the help of travelling microscope.

(iv) Measure the width (d) of white or black rectangular strips with the help of travelling microscope.

(v) Measure the distance between the object and the slit which gives D.

(vi) The experiment is repeated for different values of D.

Observations :

(i) Mean value of $\lambda = 5000 \times 10^{-8}$ cms.

(ii) **Table for width (a) of slit when micrometer arrangement is attached.**

L.C. of screw = ... cms.

S. No.	Slit reading						Width of the slit a $= (X \sim Y)$	Theoretical resolving power (λ/a)	Distance D cms.
	Slit when images cease			When slit is closed					
	M.S. reading	V.S. reading	Total X	M.S. reading	V.S. reading	Total Y			
1	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...

When micrometer arrangement is not used.

Table for the width of slit (a).

Least Count of microscope = ... cms.

S. No.	Distance D	Micrometer reading						$a = Y - X$ cms.
		ONE END			OTHER END			
		M.S.	V.S.	Total X	M.S.	V.S.	Total X	
1	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...

(ii) Table for the distance between two Objects (*d*)
Least count of microcope = ... cms.

Micrometer reading						$d = Y - X$ cms.
ONE END			OTHER END			
M.S.	V.S.	Total *X*	M.S.	V.S.	Total *X*	
...	...	...	...	...	...	...
...	...	...	...	...	...	...
...	...	...	...	...	...	...
...	...	...	...	...	...	...

Result : The theoretical and practical resolving powers of the telescope is shown in the table.
Theoretical and Practical Resolving Powers :

Distance	Theoretical (λ/a) resolving power	Practical (d/D) resolving power
...	...	...
...	...	...
...	...	...

Precaution and Sources of error :

(i) The axis of telescope should be horizontal.
(ii) The rectangular object drawn on the card-board should be vertical.
(iii) Backlash error in the micrometer screw should be avoided.
(iv) The plane of the slit should be parallel to the objects.
(v) The width a should be measured carefully.
(vi) The minimum width of slit for resolution should be adjusted very carefully.
(vii) The distance *D* should be measured from the slit of the telescope to the card-board.

Viva-Voce

Q. 1. *What do you mean resolving power of a telescope ?*
Ans. The resolving power of a telescope is defined as the reciprocal of the smallest angle subtended at the objective by two distinct points which can be just seen as separate one through the telescope.

Q. 2. *On what factors does the resolving power depend ?*
Ans. The resolving power of a telescope is given by

$$\frac{1}{d\theta} = \frac{d}{1 \cdot 22\,\lambda}$$

Resolving power is directly proportional to *d i.e.*, a telescope with large diameter of objective has higher resolving power and inversely proportional to λ.

Q. 3. *Define the magnifying power of the telescope.*
Ans. The magnifying power of a telescope is defined as the ratio of angle subtended at the eye by the final image of the angle subtended at the eye by object when viewed at its actual distance.

Q. 4. *What is Rayleigh criterion of resolution ?*
Ans. According to Rayleigh criterion, two point sourcers are resolvable by an optical instrument when the central maximum in the dffraction pattern of one falls over the first minimum in the diffraction pattern of the other and vice versa.

Q. 5. *Why have the objectives of telescopes large aperatures ?*
Ans. The resolving power is increased.

Q. 6. *What is the resolving power of a normal eye ?*
Ans. The resolving power of normal eye is about one minute.

Q. 7. *What does indicate the term 200 inch written on a telescope ?*
Ans. This indicates that the diameter of the objective of a telescope is 200 inches.

Q. 8. *What will be the resolving power of this telescope ?*
Ans. It is about 1/40th of a second for sunlight.

Resolving Power of A Grating

EXPERIMENT No. 18

Object : To determine the resolving power of a grating.

Apparatus used : Plane diffraction grating, spectrometer, mercury lamp, prism, a rectangular aperture of adjustable width, reading lens.

Formula used :

The resolving power $\lambda/d\lambda$ of a plane diffraction grating is given by

$$\frac{\lambda}{d\lambda} = N_0 n.$$

Where $d\lambda$ is the smallest wavelength difference between the two spectral lines, which are just resolved by the grating.

N_0 = Total number of lines in the exposed width of the grating in just resolution position. and

n = order of the spectrum

Procedure :

(1) The spectrometer adjustments are made as described under the spectrometer head in the general section on refraction and dispersion of light.

(2) Procedure (*B*) of expt. no. 9 is then adopted for normal incidence setting of the grating on the prism table.

(3) The slit should be adjusted parallel to the ruling of the grating [procedure (c) of expt. no. 14].

(4) Mount the rectangular aperture of adjustable width on the prism table infront of the grating or on the collimating lens of the collimator such that its axis is parallel to the slit.

(5) Now keep the aperture fully opened and turn the telescope to the left to the direct image of slit till two yellow lines of first order of mercury spectrum are seen in the field of view.

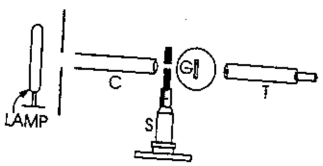


Fig. (1)

(6) Gradually reduce the width of the aperture till the two spectral lines just cease to appear or to separate. Measure this width of the aperture with the help of a travelling microscope.

(7) Again put the aperture in the same position and open it fully. Now turn the telescope to the right of the direct slit image till the two yellow lines of the Ist order of Hg spectrum are seen, and again reduce the width of the aperture till the two lines cease to appear as separate. Again measure this width of aperture by microscope. Take mean of the widths measured this time and that measured in observation 6.

(8) Repeat the same procedure for two yellow lines in the second order.

(9) Note the number of lines ruled per cm. on the grating.

Observations :

(1) No. of lines per cm. of the grating, (grating element) $= \frac{2 \cdot 54}{N} = \ldots$ per cm.

where N is the number of rulings per inch on the grating.

(2) **Table for the measurement of rectangular aperture for just resolution :**

S. No.	Side	Microscope reading when its cross wire is set at		Exposed width of the aperture for just resolution $(x - y)$	Mean aperture width $(x - y)$	No. of lines of grating in this width N_0	Order of spectrum n
		One end of the aperture x cms.	Other end of the aperture y cms.				
1	Left Side	...	...	...	...	...	1
2	Right Side	...	...	...			
3	Left Side	...	...	...	...	...	2
4	Right Side	...	...	...			

Calculations :

(1) The difference in wavelengths of the two yellow lines of Hg spectrum,

$= 5790 - 5770$

$= 20$ A.U.

(2) Mean wavelength,

$$\lambda = \frac{\lambda_1 + \lambda_2}{2} = \frac{5770 + 5790}{2}$$

$= 5780$ A.U.

(3) Therefore theoretical resolving power,

$$\frac{\lambda}{d\lambda} = \frac{6780}{20} = 289$$

(4) We have calculated already that the number of lines per cm. of grating = 2· 54/N. Therefore :

Order of spectrum $= n$	No. of lines in mean width $x - y = N_0$	Product $N_0 n$	$\lambda/d\lambda$	Difference
1	$\frac{2 \cdot 54}{N} \times (x - y)$ = ...	...	...	...
2	$\frac{2 \cdot 54}{N} \times (x - y)$ = ...	...	...	...

Result : Comparision of theoretical and practical resolving power is shown in the table.

Sources of error and Precautions :

Same as in experiment No. 14.

Viva-Voce

Q. 1. ***What do you mean by resolving power of grating ?***

Ans. The resolving power of grating is defined as the capacity to form separate diffraction maxima of two wavelengths which are very close to each other.

Q. 2. ***How the resolving power of a grating is measured ?***

Ans. This is measured by $\lambda / d\lambda$. The value is $N_0 n$, where n is order of spectrum and N_0 the number of lines on grating.

Q. 3. ***Upon what factors does the resolving power of a grating depend ?***

Ans. The resolving power depends upon the total number of rulings N in the grating and the order of spectrum.

Q. 4. ***Does the resolving power of a grating depends upon the spacing between the ruling ?***

Ans. No, when the number of lines in a given width increase the order of the spectrum in a given direction decrease such that the product $N_0 n$ remains constant.

Q. 5. ***How the resolving power can be increased ?***

Ans. This can be done by increasing the total number of ruling without decreasing the grating element.

Q. 6. ***If double the number of lines are ruled in the same space in a grating, what will happen to its resolving power ?***

Ans. The resolving power will not change because the grating element will be halved which will make the order of the spectrum half in a particular direction.

Q. 7. ***What is a normal spectrum ?***

Ans. A spectrum for which $d\theta \propto d\lambda$ (spectral lines differ in angle by amounts which are directly proportional to difference in wavelength) is known as normal spectrum.

Q. 8. ***How can you obtain a normal spectrum ?***

Ans. We can obtain a normal spectrum by using a concave grating in Rowland's mounting in which $\theta = 0$ *i.e.* $\cos\theta = 1$.

Polarisation of Light

EXPERIMENT No. 19

Object : To determine the specific rotation of cane sugar solution with the help of polarimeter.

Apparatus used : Polarimeter, a balance, measuring cylinder, beaker and source of light.

If the polarimeter is employing a half shade device, a monochromatic source should be used, and if biquartz device is used then white light can be used.

Formula used :

The specific rotation of the plane of polarisation of sugar dissolved in water can be determined by the following formula,

$$S = \frac{\theta}{l \times c} = \frac{\theta \times V}{l \times m}$$

where θ = rotation produced in degrees.

l = length of the tube in decimeter.

m = mass of sugar in gms. dissolved in water.

V = volume of sugar solution.

Description of apparatus :

The polarimeter is shown in fig. (1).

S is a source of light placed at the focus of convex lens. Thus the beam becomes parallel after passing through lens and then passes through the polariser. The polarised light passes through the half shade and travels the length of the polarimeter tube made of glass. The light is analysed with the help of the analyser which can be rotated about a horizontal axis and its position can be read by a vernier moving over a fixed graduated scale. The light is now viewed with the help of telescope. The analyser and telescope are placed in the same tube. A filter is also used after the source to allow only a particular wavelength to pass through the polarimeter.

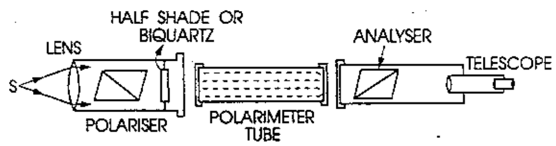


Fig. (1)

Procedure :

(i) If the polarimeter is employing a half shade device, a monochromatic source should be used and if biquartz device is used then white light can be used.

(ii) Take the polarimeter tube and clean well both the sides such that it is free from dust. Now fill the tube with pure water and see that no air bubble is enclosed in it. Place the tube in its position inside the polarimeter.

(iii) Switch on the source of light and look through the eyepiece. Two halves of unequal intensity are observed. Rotate the analyser until two halves of the field appear equally bright. Take the reading of main scale as well as vernier scale and find out the total reading.

(iv) Prepare a sugar solution of known strength. The procedure for preparing it can be seen under the heading observations.

(v) Take the polarimeter tube and remove the pure water. Fill it with the prepared sugar solution and again place it in the polarimeter.

(vi) Rotate the analyser to obtain the equal intensity position, first in clockwise direction and then in anti-clockwise direction.

[When the tube containing sugar solution is placed in the path of the polarised light, the plane of polarisation is rotated which disturbs the previous position (equal illumination)].

Note down the position of the analyser on main and vernier scales in the two directions. Find the mean reading. The difference between this and previous reading gives the specific rotation.

(vii) Repeat the experiment with sugar solutions of different concentrations.

(viii) Measure the length of the tube in centimeters and change it in decimeters.

Observations :

(A) Preparation of sugar solution :

Mass of the watch glass = ... gm. = ... kg.
Watch glass + sugar = ... gm. = ... kg.
∴ Mass of sugar taken m = ... gm. = ... kg.
Volume of the solution V = ... gm. = ... kg.

Concentration of the solution m/V = ... gm./c.c. = ... kg/m^3

(B) Length of the polarimeter tube l = ... decimeter

Room temperatre = ... degree centigrade

(C) Table for the specific rotation :

Value of one division of main scale = ...
No. of division of vernier scale = ...
Least count of vernier = ...

Analyser reading with pure water						Mean	Concentration of solution gm./c.c	Analyser reading with sugar solution						Mean	$\theta = (a-b)$ in degree
Clockwise			Anti-clockwise					Clockwise			Anti-clockwise				
M.S.	V.S.	Total X	M.S.	V.S.	Total Y	$a = \frac{X+Y}{2}$		M.S.	V.S.	Total X'	M.S.	V.S.	Total Y'	$b = \frac{X'+Y'}{2}$	
...	...	...	...	...	...	...	...$\left(\frac{m}{V}\right)$	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...$\left(\frac{m}{2V}\right)$	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...$\left(\frac{m}{3V}\right)$	...	...	...	...	...	...	...	...

Calculation : Draw a graph between θ and concentations. The graph is shown in fig. (2). From graph find out the value of θ for a particular concentration. Then.

$$S = \frac{\theta \cdot V}{l \cdot m}$$

$$= \ldots ^\circ/\text{dm./kg./m.}^3$$

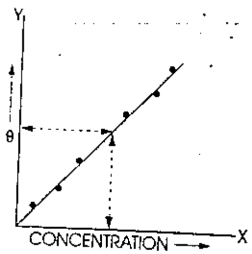


Fig. (2)

Result : The specific rotation for cane sugar at a temperatre ...°C and λ .... Å = ...

Standard value : ...% dm./kg./m^3.

Percentage error : ...%.

Sources of error and Precautions :

(i) The polarimeter tube should be well cleaned.

(ii) Water used should be dust free.

(iii) Whenever a solution is changed, rinse the tube with the new solution under examination.

(iv) There should be no air bubble inside the tube.

(v) The position of analyser should be set accurately.

(vi) The temperature and wave-length of light used should be stated.

(vii) Reading should be taken when halves of the field of view become equaly illuminated.

Theoretical error :

$$S = \frac{\theta \cdot V}{l \cdot m}.$$

Taking log and differentiating, we get

$$\frac{\delta S}{S} = \frac{\delta\theta}{\theta} + \frac{\delta V}{V} + \frac{\delta l}{l} + \frac{\delta m}{m}$$

Here $\delta\theta = 0{\cdot}1^\circ$, $\delta V = 0{\cdot}1$c.c., $\delta m = 0{\cdot}001$ gms. and $\delta l = 0{\cdot}1$ cm., then

$$\frac{\delta S}{S} = \ldots\ldots \%.$$

Maximum theoretical error = ... %

Viva-Voce

Q. 1. ***What do you mean by polarised light ?***

Ans. The light which has acquired the property of one sideness is called a polarised light.

Q. 2. ***How does polarised light differ from ordinary light ?***

Ans. The ordinary light is symmetrical about the direction of propagation while in case of polarised light, there is lack of symmetry about the direction of propagation.

Q. 3. ***What does polarisation of light tell about the nature of light ?***

Ans. Light waves are transverse in nature.

Q. 4. ***Define plane of vibration and plane of polarisation ?***

Ans. The plane containing the direction of vibration as well as the direction of the propagation of light is called plane of vibration. On the other hand, the plane passing through the direction of propagation and containing no vibration is called plane of polarisation.

Q. 5. ***What is phenomenon of double refraction ?***

Ans. When ordinary light is incident on a calcite or quartz crystal, it splits in two refracted rays and this phenomenon is known as double refraction.

Q. 6. ***Define optic axis and principal section.***

Ans. A line passing through any one of the blunt corners and making equal angles with three faces which meet there is the direction of optic axis. A plane containing the optic axis and perpendicular to two opposite faces is called the principal section.

Q. 7. ***What are uniaxial and biaxial crystals ?***

Ans. The crystals having one direction (optic axis) along which the two refracted rays travel with the same velocity are called as uniaxial crystals. In biaxial crystals, there are two optic axes.

Q. 8. ***What do you mean by optical activity, optical rotation and angle of rotation ?***

Ans. The property of rotating the plane of vibration of plane polarised light about its direction of travel by some crystal is known as optical activity. This phenomenon is known as optical rotation and the angle through which the plane of polarisation is rotated is known as angle of rotation.

Q. 9. ***What is specific rotation ?***

Ans. The specific rotation of a substance at a particular temperature and for given wavelength of light may be defined as the rotation produced by one decimeter length of its solution when concentration is 1 gm. per c.c. Thus

$$\text{Specific rotation} = \frac{\theta}{l \times c}$$

where θ is angle of rotation in degrees, l the length of solution in decimeter and c, the concentration of solution in gm. per c.c.

Q. 10. ***What is a polarimeter ?***

Ans. It is an instrument used for measuring the angle of rotation of the plane of polarisation by an optically active substance.

Q. 11. ***What is a saccharimeter ?***

Ans. A polarimeter used in case of sugar analysis is called saccharimeter.

Q. 12. ***What do you mean by dextro and laevo-rotatory substances ?***

Ans. When the optically active substance rotates the plane of polarisation of light towards right, it is called as right handed or dextro-rotatory. If the substance rotates the plane of polarisation towards left. it is called as left handed or laevorotatory.

Q. 13. ***What is half shade or a Laurent's plate ?***

Ans. The Laurent's half shade plate consists of a semicircular half wave plate of quarz cut parallel to optic axis so that it introduces a phase change of π between extra ordinary and ordinary rays passing through it and semi-circular glass plate with thickness such that it absorbs the same amount of light as quartz plate. Both are cemented along diameter. It is prepared to suit for one particular wavelength.

Q. 14. ***Explain the working of a half shade.***

Ans. See any optics book.

Q. 15. ***Where is the half-shade plate fitted in the polarimeter ?***

Ans. This is fitted betwen the polarising Nicol and the polarimeter tube containing the solution.

Q. 16. ***Is there any arrangement which can work with white light ?***

Ans. Yes, bi-quartz arrangement.

Q. 17. ***What is bi-quartz plate ?***

Ans. A bi-quartz plate consists of two semi-circular plates of quartz (one left handed and other right handed). Both are cut perpendicular to optic axis and joined together along diameter.

Q. 18. ***Can you find from your experiment, the direction of rotation of polarisation ?***

Ans. No.

Q. 19. ***How can you modify your present experiment to find the direction of rotation ?***

Ans. The apparatus is modified in such a way that we can study the rotation produced by two different lengths of the solution. When θ is larger for longer lengths, then the direction of rotation gives the direction of the plane of polarisation.

Q. 20. ***What will be the resultant if plane polarised light is passed through a number of optically active solution ?***

Ans. The resultant rotation will be algebraic sum of individual rotations produced by each solution separately.

*Students are advised to study the action of biquartz plate and Nicol's prism (Construction, Polariser and Analyser).

Polarisation of Light

EXPERIMENT No. 20

Object : To study the polarisation of light by simple reflection.

Apparatus required : A simple glass plate, photo voltaic cell. 60 watt incandescent lamp. micrometer, polaroid, convex lens.

Theory and Formula used :

It was discovered that when a beam of ordinary light is incident at particular angle, about 57°, on a glass plate, the reflected light is plane polarised. Plane polarsed light means that the light vector in the reflected light is vibrating transversely to the direction of transmission, in a fixed plane through this direction. At angles other than 57°, the reflected beam is not completely plane polarised. It will consist vibrations parallel to the plane of incidence as well as those perpendicular to the plane of incidence. The percentage reflection for the parallel vibrations actually decreases with increasing the angle of incidence and falls to zero at an angle θ_p (polarising angle, about 57°). Therefore at θ_p only perpendicular vibrations remain and the reflected light is completely plane polarised. Intensity variation of parallel and perpendicualr vibrations with angle of incidence is shown in graph–1. This intensity measurement is done with the help of polaroid and photo voltaic cell. From these observations, one can calculate the degree of polarisation p given by

$$p = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

at different values of θ. A graph between p and θ can then be plotted (See graph 2). The value of θ which corresponds to the maximum of the curve gives Brewster's angle.

As another part of the experiment, we keep $\theta = \theta_p$ and rotated the polaroid in its own plane. The intensity variation follows the cosine law (Graph 3).

Procedure :

Set the lamp, lens, photo voltaic cell and glass plate as shown in fig. (1). The position of polaroid and photo voltaic cell are adjusted so as to receive the full beam of reflected light.

(2) Now we rotate polaroid in its own plane and note I_{max} and I_{min} as given by microammeter. Repeat this observation by increasing each time the angle of incidence by say 10° (by setting the plate at different angles).

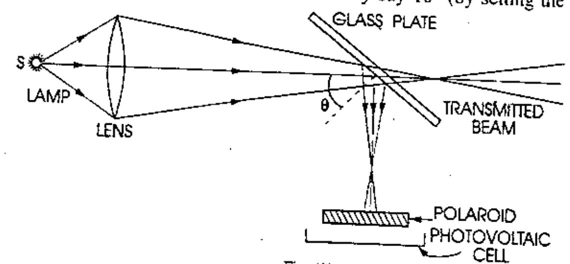


Fig. (1)

I_{max} corresponds to perpendicular vibrations and I_{min} corresponds to parallel vibrations and thus we plot the graph 1, and get θ_p.

(3) From the above observations, calculate the value of p at different θ and plot the graph no. 2, and also find θ_p.

(4) Now keeping $\theta = \theta_p$, rotate the polaroid in its own plane, angle β being measured now and intensity I is observed at each setting of β. A plot of I against β is sketched and at the maximum we set $\beta = 0$, marking other angles relative to this. Thus new angles β are obtained (See Table-2). Then we calculate $I_{max} \cos^2 \beta'$ and check these values against, observed I values.

Observations :

Table 1 : Reading of I_{max} ($\perp'$ vib) and I_{min} ($\parallel^1$ vib) with θ :

Angle of Incidence θ in degrees	Photo electric current		$p = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$
	I_{max} or $R \perp r$	I_{min} or $R \parallel l$	
...	...	...	...
...	...	...	...
...	...	...	...

Table 2 : Variation of transmitted intensity through polaroid with angle of rotation in its own plane.

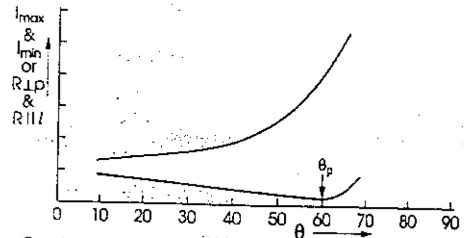
Agular positions β, of polaroid (degree)	I (obs) in terms of current (in μA)	Angle for $I_{max} = 170°$ (from graph) (degrees) Therefore $\beta' = \beta - 170°$	$\cos^2 \beta'$	$I_{max} \cos^2 \beta'$
110	6	– 60	0·248	5
120	9	– 50	0·413	7
130	12	– 40	0·587	11
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...

Calculation : (1) In order to find p, make calculation using

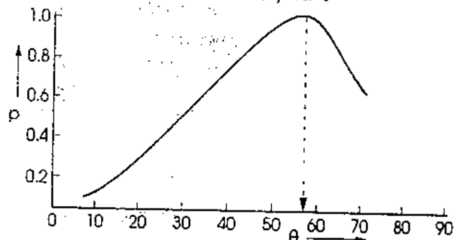
$$p = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

(2) Find $\beta' = \beta - 170°$ and calculate I_{max}, $\cos^2 \beta'$ and compare this product with I (observed) values.

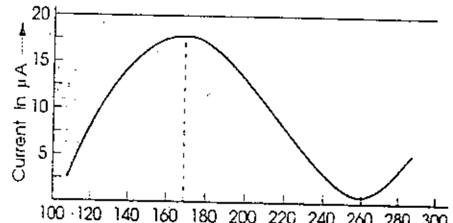
Result : Graphs 1, 2, 3 are plotted as shown in fig. (2).



Graph no. 1. Reflected intensity vs. θ



Graph no. 2. Degree of polarisation vs. θ.



Graph no. 3. Variation of the cosine square law.

Fig. (2)

Some points to note :

(1) Before starting the experiment with glass plate, one can make the following observations :

Light from lamp is made to fall directly on polaroid and through it to photo voltaic cell. Then by rotating the polaroid in its own plane we check that there is no variation of the reading in micrometer connected with the photovoltaic cell *i.e.* the beam is unpolarised.

(2) While working with glass plate in position, distances of polaroid and photovoltaic cell do not matter so long as full width of the beam is covered by them.

(3) In procedure at no. 2 it may be noted that I_{max} and I_{min} are observed for angular rotations of the polaroid 90° apart, and always in same positions.

ADDITIONAL EXPERIMENT

EXPERIMENT (20-1)

Object : To determine Brewster's angle for a glass surface and hence to determine refractive index of glass.

Apparatus required : Spectrometer, monochromatic source of light, glass prism and polaroid attachment to telescope objective.

Formula used :

According to Brewster's law

$$\mu = \tan p$$

where μ = refractive index of the material of prism

p = angle of polarisation.

Procedure :

(1) First of all the mechanical and optical adjustments of the spectrometer are made as usual by removing the polaroid attachment from the telescope.

(2) Place the prism on prism table and mount the polaroid attachment on the telescope objective. Turn the telescope in such a way that the light reflected from one of the polished face of the prism is received in the telescope as shown in fig. (3).

(3) The telescope is adjusted to obtain the reflected light on the cross wire. The polaroid is slowly rotated through one complete cycle and variation in the intensity of reflected light is observed. The intensity may or may not be zero in a particular position of polaroid. Let the intensity is not zero in one complete rotation of polaroid.

(4) Procedure (3) is repeated a number of times by increasing the angle of incidence till reflected light, on being examined by rotating polaroid shows the zero intensity (*i.e.*, complete darkness in the field of view of telescope).

(5) The readings of two verniers are noted to record the position of telescope.

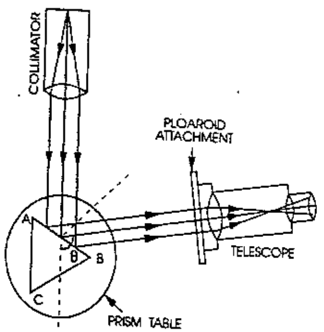


Fig. (3)

(6) The prism is removed from the prism table and the telescope is turned to receive the direct image of the slit. The image of the slit is adjusted on the cross wire of the telescope and the readings of the two verniers are noted.

(7) The difference of the positions of telescope gives the angle θ. The angle of polarisation p is given by

$$p = (90 - \theta/2).$$

(8) The experiment is repeated a number of times and mean θ is obtained.

Observations :

Least count of vernier = ... sec.

Table for Polarising angle

S. No.	Vernier	Telescope reading for complete extinction of reflected image			Telescope reading for direct image			Difference $a - b$	Mean	Mean θ
		M.S. reading	V.S reading	Total a (degrees)	M.S. reading	V.S. reading	Total b (degrees)			
1	V_1	...	...	...	...	...	...	...	...	...
	V_2	...	...	...	...	...	...	...		
2	V_1	...	...	...	...	...	...	...	...	
	V_2	...	...	...	...	...	...	...		
3	V_1	...	...	...	...	...	...	...	...	
	V_2	...	...	...	...	...	...	...		

Calculations :

Polarising angle $p = (90 - \theta/2)$

Again $\mu = \tan p = \tan \ldots = \ldots$

Result : Polarising angle $p = \ldots$

Refractive index for the material of the prism $\mu = \ldots$

Precautions and Sources of error :

(i) See the precuations of experiment 1.

(ii) Prism surface must be very clean.

(iii) Near polarising angle, the angle of incidence should vary slowly and carefully.

(iv) The test for the complete extinction of reflected light should be done carefuly.

Viva-Voce

Q. 1. ***What was the discovery of Brewster ?***

Ans. For a particular angle of incidence, known as angle of polarisation, the reflected light is completely plane polarised.

Q. 2. ***Define Brewster's law.***

Ans. The tangent of the angle of polarisation (p) is numerically equal to the refractive index of the medium, *i.e.*,

$$\mu = \tan p.$$

this is known as Brewster's law.

Q. 3. ***What is a polaroid ?***

Ans. This is device to produce plane polarised light. It consists of ultra-microscopic crystals of quinine iodo-sulphate which are embedded in nitro-cellulose films in such a way that their optic axes are parallel to each other.

Q. 4. ***What is the characteristic of a polaroid ?***

Ans. It absorbs the ordinary ray while allows the extraordinary rays pass through them.

Q. 5. ***What do you mean by optic axis of a crystal ?***

Ans. It is a direction parallel to the line drawn through any one of the blunt corners and making equal angles with the three edges meeting there.

Q. 6. ***What do you mean by principal section of a crystal ?***

Ans. A plane containing the optic axis and perpendicular to the opposite faces of the crystal, is called its principal section.

Q. 7. ***How can you produce plane polarised light ?***

Ans. The plane polarised light can be produced by the following methods :

(i) By reflection—when the light is reflected at the plane surface it is partly polarised. If the angle of incidence is equal to Brewster angle then reflected light is perfectly plane polarised light.

(ii) By double refraction—when ordinary light is passed through doubly refracting crystals it is broken into ordinary and extra ordinary rays and each of them is plane polarised in planes perpendicular to each other.

Polarisation of Light

EXPERIMENT No. 21

Object : To verify the cosine square law (Malus law) for plane polarised light with the help of a photo voltaic cell.

Apparatus required : Photo voltaic cell, moving coil galvanometer, lamp and scale arrangement, source of light, convex lens and two polaroids.

Formula used :

According to Malus law or cosine square law, when a beam of completely plane polarised light is incident on the analyser, then the intensity I of the emergent light is given by

$$I = I_0 \cos^2 \phi$$

where I_0 = intensity of plane polarised light incident on the analyser.

ϕ = angle between planes of transmission of polariser and the analyser.

From this law, when $\phi = 0$, $I = I_0$ maximum intensity

when $\phi = 90°$, $I = 0$ minimum intensity

To verify this law, the light from the analyser is made to enter in a photo voltaic cell. The current output of photo voltaic cell is connected to moving coil galvanometer. The deflection of galvanometer θ is directly proportional to the intensity of light falling on photo voltaic cell. According to cosine law $\theta \propto \cos^2 \phi$. Hence if a graph is plotted between θ and $\cos^2 \phi$, it should be a straight line, thus verifying cosine law.

Description of Apparatus : The experimental arrangement is shown in fig. (1). P is a polariser and A is an analyser. These two are fitted at the ends of a metallic tube. Both are capable of rotation about a common

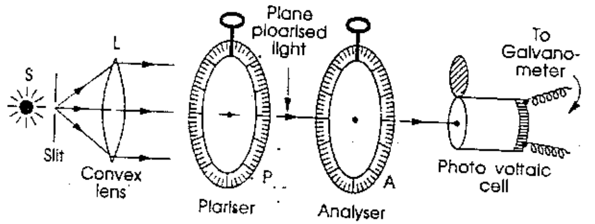


Fig. (1)

axis. The rotation can be read on a circular scale provided with each of them. Light from the source S rendered parallel with the help of convex lens L, is allowed to fall on polariser P. The light after passing through P becomes polarised. The polarised light then passes through analyser A. It is then allowed to fall on a photo voltaic cell connected with a galvanometer. The experiment is performed in a dark room to avoid any external light to enter inside the photo voltaic cell.

Procedure :

(i) The experimental arrangement is made according to fig. (2). In this arrangement, the source S, convex lens, Polariser P, analyser A and the window of photo voltaic cell should be at the same height. Adjust the lamp and scale arrangement in such a way that the spot of light would be at zero of the scale.

(ii) Now open the window of photo voltaic cell. For any orientation of the polariser P, the analyser is rotated till there is a maximum deflection in the galvanometer. The position of analyser is noted on the circular scale. The corresponding galvanometer deflection is also recorded. This position analyser corresponds to $\phi = 0$.

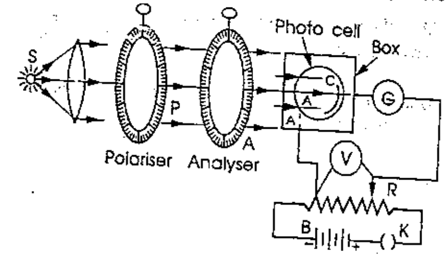


Fig. (2)

(iii) The analyser is rotated through a small angle say 10° and the steady galvanometer deflection is noted.

(iv) The experiment is repeated by rotating the analyser through 10° each time and noting the corresponding galvanometer deflection till it becomes practically zero.

Observations :

S. No.	Angle through which analyser is rotated ϕ	Steady galvanometer deflection θ	$\cos \phi$	$\cos^2 \phi$	$\frac{\theta}{\cos^2 \phi}$
1	0°	...	...	...	...
2	10°	...	...	...	...
3	20°	...	...	...	...
4	30°	...	...	...	...
5	40°	...	...	...	...
6	50°	...	...	...	...
7	60°	...	...	...	...
8	70°	...	...	...	...

Calculations : Find the value of $\theta/\cos^2 \phi$ from each observation. It remain practically constant.

Draw a graph between $\cos^2 \phi$ on X axis and θ on Y axis. The graph comes a straight line as shwon in fig. (3). The graph verify the cosine square law (Malus law).

Sources of error and precautions :

(i) The position of the polariser P should not be disturbed throughout the experiment.

(ii) Source of light, lens, polariser, analyser and window of photo voltaic cell should be adjusted to the same height.

(iii) Galvanometer should be of low resistance.

(iv) The voltage applied to the source of light should be constant throughout the experiment.

(v) The experiment should be performed in a dark room.

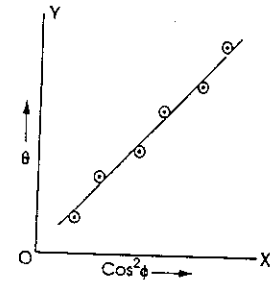


Fig. (3)

Viva-Voce

Q.1. *What do you mean by plane polarised light ?*

Ans. When the vibrations of light are confined in a single plane, then the light is known as plane polarised light.

Q.2. *What do you mean by elliptically and circularly polarised light ?*

Ans. If light vector rotates along ellipse *i.e.* changes in magnitude while rotating the light is elliptically polarised light or elliptically polarised light is the resultant of two waves of unequal amplitudes vibrating at right angles to each other and having a phase difference of $\pi/2$.

If the light vector rotates along a circle *i.e.*, it does not changes magnitude while rotating, the light is circularly polarised light or circularly polarised light is the resultant of two waves of equal amplitudes, vibrating at right angles to each other and having a phase difference of $\pi/2$.

Q.3. *What is Brewster's law ?*

Ans. Brewster discovered that when the light is reflected from a transparent material, then for a particular angle of incidence known as angle of polarisation, the reflected light is completely polarised in the plane of incidence. The tangent of the angle of polarisation (p) is numerically equal to the refractive index (μ) of the medium *i.e.*, $\mu = \tan p$. This known as Brewster's law.

Q.4. *What is the angle between reflected and refracted light ?*

Ans. 90°.

Q.5. *What is Malus law ?*

Ans. According to Malus law, when a completely plane polarised light is incident on analyser, the intensity of polarised light transmitted through the analyser varies as the square of cosine of the angle between the plane of transmission of the analyser and the plane of polariser.

Q.6. *How do you get a plane polarised light ?*

Ans. A plane polarised light is obtained with the help of polariser (Nicol's prism).

Q.7. *How do you prove Malus law ?*

Ans. The light from analyser is made to enter in photovoltaic cell connected to a galvaonometer. The galvanometer deflection θ is directly proportional to the intensity falling on voltaic cell. We draw a graph between θ and $\cos^2 \phi$ (ϕ is the angle between planes of transmission of polariser and analyser) which comes out to be a straight line, thus verifying cosine law.

Polarisation of Light

EXPERIMENT No. 22

Object : To analyse elliptically-polarised light by means of Babinet's compensator, *i.e.*,

(A) Calibration of micrometer screw

(B) Measurement of phase difference between components of elliptical vibration produced by $\lambda/4$ plate, and

(C) Determination of positions and ratio of the axes of the ellipse.

Apparatus used : Babinet's compensator, sodium lamp (monochromatic source), white light source, quarter wave plate, Nicols or polaroids, eyepiece, reading lens and plumb line.

Experimental arrangement :

The experimental arrangement is shown in fig. (1). In the figure S is a monochromatic source of light *i.e.*, sodium lamp. L_1 is a collimating lens. In front of L_1, polaroid or Nicol N_1 is placed which can be rotated in its own plane. After N_1 a quarter wave plate ($\lambda/4$ plate) placed in a suitable mount is introduced. The $\lambda/4$ plate can

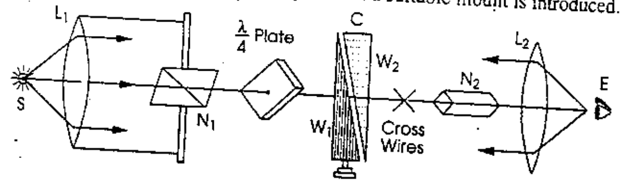


Fig. (1)

be rotated in its own plane and the rotation can be read on the graduated circular scale. Beyond this the Babinet compensator C, analyser Nicol or polaroid N_2, and an eyepiece L_2 are introduced. Actually the Babinet compensator, Nicol and eyepiece are mounted in a single mount, of course, the compensator is removable. The cross wires of the compensator are in a sharp focus of L_2. Moreover, the compensator can be rotated about the optical axis of the instrument and its rotation can be read on the graduated circular scale. The nicol N_2 can also be rotated.

The Babinet compensator C consist of two quartz wedges W_1 and W_2 of equal acute angles. The two are placed in such a way so that they form a small rectangular block. The optic axis in the two wedges are perpendicular to each other as shown by straight lines in W_1 and dots in W_2. The wedge W_2 is fixed while the wedge W_1 can be slided in its own plane by means of a micrometer screw. Cross wires are placed in front of the fixed wedge W_2.

Procedure :

(A) Calibration of micrometer screw :

(i) The Nicols N_1 and N_2 ae adjusted in the crossed position by the following procedure :

First of all the Babinet compensator C, polariser N_1 and $\lambda/4$ plate are removed from their mounts. The light from sodium lamp is collimated on the analyser N_2. The analyser is rotated so that the minimum intensity is observed. Now the polariser N_1 is placed in its mount and it is rotated in such a way that after looking through the eyepiece the minimum intensity is observed. The two Nicols are then in a crossed positions.

(ii) The compensator C is now introduced between N_1 and N_2. On looking trough the eyepiece, bright and dark bands are observed. The compensator is now rotated exactly through 45°. The bright and dark bands of maximum contrast are now observed.

(iii) One of the dark bands is taken on the cross wire by moving the wedge W_1 of the compensator by means of micrometer screw. The reading of the screw is noted.

(iv) The successive dark bands are adjusted on cross wire by micrometer screw and the micrometer reading are noted.

(v) The distance between two successive bands is found out. Let it be $2b$. This distance corresponds to a change of 2π in phase difference produced by the compensator. In this way the compensator is calibrated in terms of phase difference.

(B) Measurement of the phase difference :

(i) The monochromatic source of light is replaced by white light source. The micrometer screw is adjusted so that the central band is under the cross wire. In this position the phase difference at the cross wire is zero. The micrometer reading is noted.

(ii) The quarter wave plate with its optic axis making nearly 25° angle with the vertical is introduced between polariser and compensator. The light falling on compensator is ellipticaly polarised. The central dark band now shifts from the cross wire. Here it should be remembered that the intensity (blackness) of the central bands decreases. The blackness is restored by rotating the compensator. The micrometer screw is now rotated such that the central band is again at the cross wire. This reading of micrometer is also noted.

(iii) The difference between the micrometer readings in step (i) and in step (ii) give the distance x through which the wedge is moved. The phase difference is then calculated by the following formula :

$$\text{Phase difference} = \frac{\pi x}{b} \text{ rad.}$$

(iv) The process is repeated for other inclinations (see table 2) of $\lambda/4$ plate.

(C) Determination of positions and ratio of the axes of the ellipse :

(i) White light source is used for this part.

(ii) The $\lambda/4$ plate is removed and the light is allowed to fall on the compensator so that the light is plane polarised. The wedge W_1 of the compensator is adjusted in such a way that the central black band comes under the cross wire. The micrometer reading is noted.

(iii) The micrometer screw is now moved exactly through a distance $b/2$. The central dark band is no more under the cross wire.

(iv) The $\lambda/4$ plate is inserted between polariser and compensator. With the help of plumb line, $\lambda/4$ plate is made vertical and then it is rotated through an angle 25° (say).

(v) The compensator is rotated until the central band is under cross wire. Here the analyser may also be rotated so that the central band is maximum black. In this case the axes of the incident elliptical vibration are parallel to the axes of the wedges. The orientation of the compensator θ is noted on the circular scale.

(vi) Now the compensator is slowly rotated until the bands just disappear. The field of view will be of uniform illumination. The orientation of compensator θ_2 is noted.

(vii) The difference of the two readings of compensator *i.e.*, $(\theta_1 - \theta_2)$ gives the angle θ of rotation.

(viii) The experiment is repeated for different inclinations of $\lambda/4$ plate.

Observations :

Table 1

(A) For the calibration of micrometer screw (band width $2b$) :

Least count of micrometer screw = ... cm.

S. No.	Band number	Screw reading	Width of 4 bands	Band width ($2b$) cm.	Mean ($2b$) cm.
1	First	...			
2	Second	...			
3	Third	...			
4	Fourth	...	...	...	
5	Fifth	...	...	...	...
6	Sixth	...	...	...	
7	Seventh	...	...	...	
8	Eighth	...			

Table 2

(B) For the measurement of phase difference :

S. No.	Inclination of $\lambda/4$ plate from vertical	Screw reading without $\lambda/4$ plate (p) cm.	Screw reading with $\lambda/4$ plate (q) cm.	Linear displacement $x = (p - q)$ rad.	Phase difference $= \pi x/b$ rad.	Mean Phase difference rad.
1	25°	...	...	...	...	
2	30°	...	...	...	...	
3	35°	...	...	...	...	...
4	40°	...	...	...	...	
5	45°	...	...	...	...	

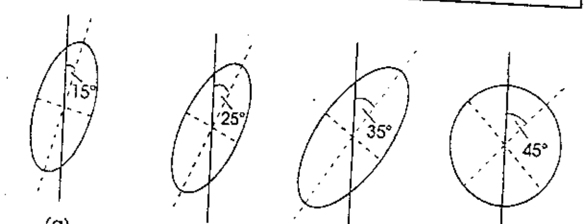
Table 3

(C) For the position and ratio of axes :

S. No.	Inclination of $\lambda/4$ plate from vertical	Position of compensator in maximum contrast θ_1 (degrees)	Position of compensator in uniform illumination θ_2 (degrees)	Angle $\theta = \theta_1 - \theta_2$ (degree)	$\tan\theta = b/a$ Ratio of the axes
1	15°	...	...	...	...
2	25°	...	...	...	...
3	35°	...	...	...	...
4	45°	...	...	...	...

Graph : The ellipse of different eccentricities corresponding to different orientations of $\lambda/4$ plate are shown in fig. (2). When $\theta = 45°$, the circle so obtained corresponds to circularly polarised light.

Results : (i) The phase difference between two components of the elliptical vibration = ... rad. (This is nearly equal to $\pi/2$).



(a) (b) (c) (d)

Fig. (2)

(ii) For various inclinations the ratios of the axes of the ellipses are shown in fig. (2). The value of θ is approximately equal to the inclination of $\lambda/4$ plate.

Sources of error and Precautions :

(i) It is not possible to locate the middle point of dark band correctly and hence the cross wire should be adjusted at one end.

(ii) For the measurement of phase difference and for the ratio of the axes, the monochromatic source of light should be replaced by white light source.

(iii) Plumb line should be used to make the $\lambda/4$ plate vertical.

(iv) In determining θ_1 the position of maximum contrast should be adjusted carefully.

(v) For the measurement of the ratio of axes, the experiment should be repeated for different inclinations of $\lambda/4$ plate.

Viva-Voce

Q. 1. ***What is Babinet compensator ?***

Ans. See experimental arrangement part of the experiment.

Q. 2. ***What is $\lambda/4$ plate ?***

Ans. This is a calcite plate with optic axis in the surface of crystal of such a thickness so that it introduces a path difference of $\lambda/4$ or phase difference of $\pi/2$ between ordinary and extra-ordinary rays.

Q. 3. ***What is advantage of a Babinet compensator over a simple quarter wave plate ?***

Ans. $\lambda/4$ plate can be used only for a particular frequency while Babinet compensator may be used over a wide range of frequencies.

Q. 4. ***What do you mean by elliptically polarised light ?***

Ans. When two plane polarised waves at right angle to each other superimpose over each other, then the resultant light vector rotates with a constant magnitude in a plane perpendicular to the direction of propagation. If the light vector rotates along ellipse *i.e.*, changes its magnitude while rotating, the light is known as elliptically polarised light.

Q. 5. ***What do you mean by analysis of elliptically polarised light ?***

Ans. The analysis of elliptically polarised light includes :

(i) Measurement of phase difference between components of elliptical vibratation produced by $\lambda/4$ plate.

(ii) Determination of positions and ratio of the axes of the ellipse.

Q. 6. ***Why do you get dark and bright bands ?***

Ans. Due to the variation in thickness of the wedges, we get dark and bright bands.

Q. 7. ***What will happen if monochromatic source is replaced by white light source ?***

Ans. The central band will appear dark while other band on both sides will be coloured.

Q. 8. ***Describe a Nicol prism.***

Ans. This is an optical device made from calcite crystal to produce and analyse the plane polarised light. A calcite crystal whose length is three times as its width is taken. The end faces are cut in such a way that the angles in principal section become 68° and 112°. The crystal is then cut along a direction perpendicular to both the principal section and end face. The cut surfaces are grounded, polished and cemented by a layer of canada balsam. The crystal is then enclosed in a tube.

Polarisation of Light

EXPERIMENT No. 23

Object : To verify Fresnel's formulae for the reflection of light.

Apparatus used : Spectrometer, prism, sodium lamp, a pair of polaroids fitted inside circular stands provided with circular scales which may be clamped on the telescope and collimator tubes, reading lens, etc.

Theory of the experiment :

According to Fresnel's formulae

$$\tan\theta = -\frac{\cos(i-r)}{\cos(i+r)}.$$

where,
θ = Angle between the direction of reflected light and the plane of incidence
i = Angle of incidence of plane polarised light.
r = corresponding angle of refraction.

A graph is plotted between $\tan\theta$ and $[-\cos(i-r)/\cos(i+r)]$. If the graph comes out to be a straight line inclined at 45° to the axes, then this may be taken as a verification of the Fresnel's formulae.

Procedure : The experiment is performed is the following three parts :

(1) Determination of refractive index μ of the material of the prism and then to calculate the polarising angle.

(2) Setting of the collimator polaroid to make the plane of vibration of plane polarised light (incident light) inclined at 45° to the plane of incidence.

(3) Determination of θ for various values of i.

(1) Determination of refractive index μ of the material of the prism and then to calculate the polarising angle :

(i) The slit of collimator is illuminated with sodium light.

(ii) Without polaroids, the spectrometer is adjusted for parallel rays using Schuster's method.

(iii) The angle of the prism (A) is determined as usual.

(iv) The angle of minimum deviation (δ_m) for sodium light is determined in usual way.

(v) The refractive index (μ) of the material of the prism is calculated by using the following formula :

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

(vi) The polarising angle (ϕ) is calculated from Brewster's law

$$\phi = \tan^{-1}\mu$$

(2) Setting of the collimator polaroid to make the plane of vibration of plane polarised light inclined at 45° to the plane of incidence.

(i) The prism is removed from the prism table and the telescope is adjusted for the direct image of the slit. The position of the telescope is noted.

(ii) The telescope is turned through an angle $(180 - 2\phi)^\circ$ from the direct position as shown in fig. (1) and clamped.

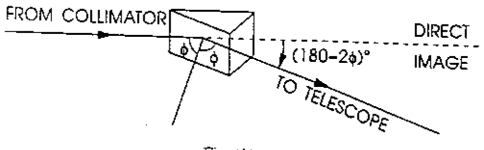


Fig. (1)

(iii) The prism is placed on the prism table. The prism table is rotated slowly to receive the reflected image of the slit on the cross-wire of the telescope. In this position, the light incident on the prism face is at polarising angle ϕ. Now the light is plane polarised. The vibration of plane polarised light is perpendicular to the plane of incidence.

(iv) The polaroid (Analyser) is mounted on the objective of the telescope. Viewing through the telescope and rotating the polaroid slowly, the image of the slit is reduced to a minimum. The position of the pointer of the polaroid in its graduated scale is noted. Let it is β.

(v) The prism is removed from the prism table and the telescope is brought in the line of collimator to receive the direct image of slit on the cross wire. The second polaroid (Polariser) is mounted on the collimator lens. This is rotated till the direct image of the slit in the telescope reduces to minimum intensity. The reading of polariser is read on the circular scale attached with it. Further the polaroid is rotated through 45°. Now the polaroid is transmitting light whose plane of vibration is inclined at 45° to the plane of incidence.

(3) Determination of ϕ for various values of i :

(i) The telescope is rotated through a small angle α (say, about 10°) and clamped.

(ii) The prism is placed on the prism table and the prism table is rotated to receive the image of the slit on the cross wire of the telescope.

(iii) The analyser (Polaroid on telescope) is rotated from its initial setting β until the intensity of image of slit in telescope reduces to minimum. The angle of rotation will be θ *i.e.*, the angle which the reflected vibration makes with the plane of incidence. The angle of incidence (as shown in fig. (2)) for this setting will be

$$i = \frac{180 - \alpha}{2}$$

For $$\alpha = 10^\circ,\ i = \frac{180 - 10}{2} = 85^\circ$$

and $$\mu = \frac{\sin i}{\sin r} \quad \text{or} \quad r = \sin^{-1}\left(\frac{\sin i}{\mu}\right)$$

(iv) The angle of incidence is varied in steps of 10° by turning the telescope and angle θ is measured for all values of i.

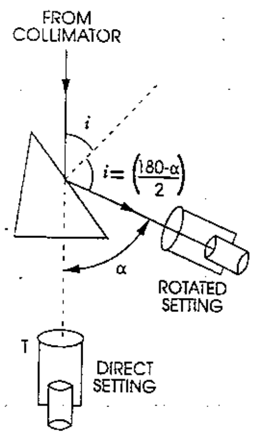


Fig. (2)

Observations and Calculations :

(1). Table for the angle of prism (A)

S. No.	Position of telescope for the image of slit from one face		Position of telescope for the image of slit from other face		Difference 2A			Mean 2A
	Vernier V_1	Vernier V_2	Vernier V_1	Vernier V_2	V_1	V_2	Mean	
1	...	...	...	...	...	...	...	
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	

(2) Table for the angle of minimum deviation (δ_m)

S. No.	Position of telescope for the minimum deviation		Position of telescope for direct image of the slit		Difference			Mean δ_m
	Vernier V_1 (a)	Vernier V_2 (b)	Vernier V_1 (c)	Vernier V_2 (d)	V_1 $(a-c)$	V_2 $(b-d)$	Mean	
1	...	...	...	...	...	...	...	
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	

Angle of the prism $A = \ldots$

$$\therefore \quad \mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin (A/2)} = \ldots \quad \text{and } \phi = \tan^{-1}\mu = \ldots$$

(3) Readings for setting the plane of vibration of incident light at 45° with the plane of incidence.

(i) Position of telescope on veriner V_1 for direct image of slit = ...

(ii) The angle through which the telescope is rotated = $(180 - 2\phi) = \ldots$

(iii) New position of telescope on vernier = ...

(iv) Reading of analyser for minimum intensity $\beta = \ldots$

(v) Reading of polariser for minimum intensity = ...

(vi) Reading of polariser after rotation of 45° = ...

(4) Table for finding θ for different values of i.

S. No.	Angle of rotation of telescope α	Reading of analyser for minimum intensity β'	Initial reading of analyser β	$\theta = (\beta' - \beta)$	$\tan\theta$
1	10°	...		...	...
2	20°	...		...	...
3	30°	...		...	...
4	40°	...		...	...
5	50°	...		...	...
6	60°	...	...	...	...
7	70°	...		...	...
8	80°	...		...	...
9	90°	...		...	...

(5) Table for calculation of $[-\cos(i - r)/\cos(i + r)]$

S. No.	Angle of incidence $i = \left(\frac{180 - \alpha}{2}\right)^\circ$	Angle of refraction $r = \sin^{-1}\left(\frac{\sin i}{\mu}\right)$	$(i - r)$	$(i + r)$	$-\frac{\cos(i - r)}{\cos(i + r)}$
1	...	...	...	...	...
2	...	...	...	...	...
3	...	...	...	...	...
4	...	...	...	...	...
5	...	...	...	...	...
6	...	...	...	...	...
7	...	...	...	...	...
8	...	...	...	...	...
9	...	...	...	...	...

A graph is plotted between $\tan\theta$ and corresponding values of $-\frac{\cos(i-r)}{\cos(i+r)}$. The graph comes out to be a straight line inclined at an angle 45° to the axes as shown in fig. (3).

Result : The graph between $\tan\theta$ and $-[\cos(i-r)/\cos(i+r)]$ is a straight line passing through origin and inclined at an angle 45° with the axes. This shows the verification of Fresnel's formulae for reflection.

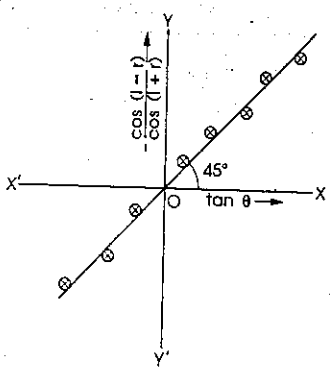


Fig. (3)

Sources of error and Precautions :

(1) Spectrometer should be adjusted properly.
(2) The reflecting face of the prism should be absolutely clean.
(3) The angle θ should be measured for several values of i at interval of 10°.
(4) To find the value of θ, the analyser is set several times to minimise the intensity inside telescope and then mean value should be recorded.
(5) The setting of polariser should not be disturbed throughout the part third of the experiment.

Polarisation of Light

EXPERIMENT No. 24

Object : To study elliptically polarised light by means of a photo-electric cell.

Apparatus used : Photo-electric cell, optical bench with suitable uprights, dead beat galvanometer, source of light, doubly refracting plate, polaroids or nicols, lamp and scale arrangement, slit, etc.

Theory of the experiment : The intensity of the light transmitted by the analyser is given by

$$I=(a^2-b^2)\cos^2\theta+b^2 \qquad \ldots (1)$$

where a and b are the semi-major and semi-minor axes of the elliptical vibration and θ, the angle between the major axis and the plane of transmission for the analyser.

For
$$\theta=0° \text{ and } 180°, \quad I=I_{max}=a^2 \qquad \ldots (2)$$
and for
$$\theta=90° \text{ and } 270°, \quad I=I_{min}=b^2 \qquad \ldots (3)$$

So during a complete rotation of the analyser, the intensity will be maximum twice and also minimum twice.

It is obvious from eq. (1) that if a graph is drawn between I and $\cos^2\theta$, it would be a straight line. The slope of the straight line with $\cos^2\theta$ axis will give (a^2-b^2). Moreover, a^2 can be found by observing the maximum intensity (intensity is measured in terms of galvanometer deflection). With the help of above data b^2 and hence the ratio of a/b can be obtained.

Experimental arrangement : The experimental arrangement is shown in fig. 1. An electric bulb (fed either by a battery cell or by mains through step down transformer), slit, converging lens L, polariser nicol N_1, λ/4 plate, analyser nicol N_2 and photo cell (connected to galvanometer G) are mounted in suitable uprights of an optical bench. Polariser N_1, λ/4 plate and analyser N_2 can be rotated in their own planes about the axis of light beam and their positions can be read on circular scales.

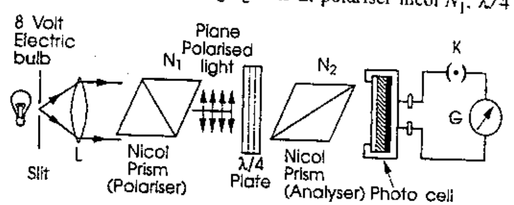


Fig. (1)

Light after passing through polariser N_1 becomes plane polarised as shown in figure. The λ/4 plate makes the plane polarised light as elliptically polarised (if plane polarised light is not incident at an angle of 45° with optic axis of λ/4 plate). The elliptically polarised light is then transmitted through analyser N_2. The intensity of transmitted light is different for different orientations of analyser. Now the transmitted light is received by photo-cell which converts it into a current. The current produces a deflection in the galvanometer. Obviously, the deflection of the galvanometer is different for different orientations of N_2.

Procedure :

(1) First of all, by adjusting polariser N_2 and λ/4 plate, elliptically polarised light is obtained. For this purpose the photo-cell is removed from the optical bench. The transmitted light is viewed by rotating the analyser N_2. The orientation of λ/4 plate adjusted in such a way that intensity varies between maximum and minimum but never zero. Now the light emerging from λ/4 plate is elliptically polarised. It should be remembered that the position of λ/4 plate should not be disturbed throughout the experiment.

(2) The coil of the galvanometer is made free. Keeping the source of light (bulb) switched off, the initial position of the spot of light is adjusted on zero of the scale.

(3) Place the photo-cell at its proper place of the optical bench. The pointer of the analyser N_2 is adjusted to read zero on the circular scale.

(4) The source of light is swiched on. Note down the deflection of the spot of light on the scale.

(5) The source of light is switched off and the spot of light is brought to zero postion. The analyser is rotated through 20°.

(6) The source of light is switched on. The deflection of spot of light is noted.

(7) By rotating the analyser in steps of 20° and following procedure 5th and 6th, the corresponding deflections of spot of light are noted.

Observations :

Table for orientation of analyser and galvanometer deflection

S. No.	Orientation of analyser α°	Galvanometer deflection (Intensity I)	S. No.	Orientation of analyser α°	Galvanometer deflection (Intensity I)
1	0	...	11	200	...
2	20	...	12	220	...
3	40	...	13	240	...
4	60	...	14	260	...
5	80	...	15	280	...
6	100	...	16	300	...
7	120	...	17	320	...
8	140	...	18	340	...
9	160	...	19	360	...
10	180	...			

Calculations : A graph is drawn between galvanometer deflection (Intensity I) and various orientations of analyser (α). The graph is shown in fig. (2). The shape of the graph is like a figure of eight. The maximum value of radius vector defines $\theta = 0°$ (or 180°) and minimum defines $\theta = 90°$ (or 270°).

Now we draw radius vectors (like OB) at angles $\theta = 0°, 20°, \ldots 90°$ with respect to longest radius vector OP and measure their lengths. The radius vectors give the intensity. The values are tabulated below :

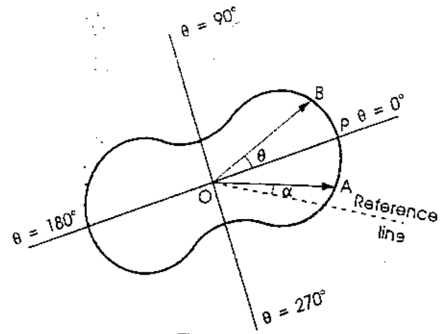


Fig. (2)

S. No.	θ°	cos θ	cos² θ	I (in cm.)
0	0	...	...	...
1	10	...	...	...
2	20	...	...	...
3	30	...	...	...
4	40	...	...	...
5	50	...	...	...
6	60	...	...	...
7	70	...	...	...
8	80	...	...	...
9	90	...	...	...
10	100	...	...	...

Finally a graph is drawn between I and $\cos^2\theta$. This comes out to be a straight line as shown in fig. (3).

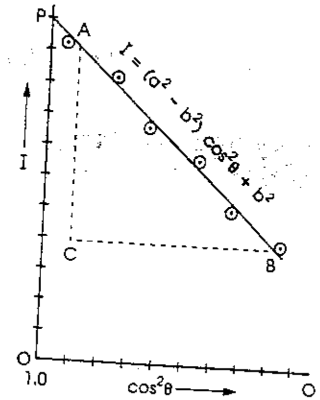


Fig. (3)

From graph, $a^2 = I_{max}$ (for $\theta = 0$ *i.e.*, $\cos^2\theta = 1 \cdot 0000$)

$= OP = \ldots\ldots\ldots$

$(a^2 - b^2)$ = slope of the line $= AC/CB = \ldots\ldots\ldots$

$\therefore \quad b^2 = \ldots\ldots\ldots$ Further $a^2/b^2 = \ldots\ldots\ldots$

Now $\frac{a}{b} \ldots\ldots\ldots$

Result : The ratio of $\frac{a}{b} = \ldots\ldots\ldots$

Precautions and sources of error :

(1) The heights of the uprights should be properly adjusted.

(2) The source of light should be switched on only when the reading is to be taken.

(3) The galvanometer used should have a very high sensitivity.

(4) After each observation, the galvanometer coil should be brought to rest (*i.e.*, initial position of spot of light should be at zero).

(5) Experiment should be performed in a dark room.

Rydberg's Constant

EXPERIMENT No. 25

Object : To determine the value of Rydberg's constant with the help of diffraction grating and a hydrogen tube.

Apparatus required : Spectrometer, grating, hydrogen discharge tube and induction coil.

Theory and Formula used :

The value of the Rydberg's constant can be obtained with the help of Bohr's theory of Hydrogen spectrum. This theory is mainly based on the following postulates :

(i) An electron moves round the nucleus in circular orbit, the nucleus being stationary. The centripetal force required for circular motion is provided by electrostatic attraction between the positively charged nucleus and the negatively charged electron.

Hence,

$$\frac{m v^2}{a} = \frac{e^2}{a^2} \quad \dots (1)$$

where m = mass of the electron,
v = its linear velocity,
a = radius of the electron orbit,
e = negative charge on the electron.

(ii) The electron revolves around the nucleus in various circular orbits for which the angular momentum of the electron is an integral multiple of $h/2\pi$, where h is the Planck's constant. Hence

$$m v a = \frac{n h}{2\pi}$$

where $n = 1, 2, 3$ etc. gives the quantum number. ... (2)

(iii) When an electron jumps from a lower energy state to a higher energy state it absorbs energy and when it jumps from a higher energy level to lower energy level it gives out electromagnetic radiation of a particular frequency

$$W_{n_2} - W_{n_1} = h\nu \quad \dots (3)$$

where W_{n_2} is the energy of the n_2 energy level, W_{n_1} is the energy of n_1 energy level and ν is the frequency of radiations.

Squaring (2) and dividing by (1), we have

$$a = \frac{n^2 h^2}{4\pi^2 m e} \quad \dots (4)$$

The energy W_n of the electron in an orbit is the sum of the potential and kinetic energies. The potential energy, which is equal to the workdone in bringing the electron from infinity to a is

$$P.E. = \int_{\infty}^{a} \frac{e^2}{a^2} da = -\frac{e^2}{a}$$

$$K.E. = \frac{1}{2} m v^2 = \frac{e^2}{2a}$$

$$W_n = P.E. + K.E. = -\frac{e^2}{a} + \frac{e^2}{2a} = -\frac{e^2}{2a}$$

Substituting the value of a from equation (4), we have ... (5)

$$W_n = -\frac{2\pi^2 m e^4}{n^2 h^2}$$

Let W_{n_1} and W_{n_2} be the energies corresponding to n_1th and $n_2$the orbits respectively, then

$$W_{n_1} = -\frac{2\pi^2 m e}{n_1^2 h^2} \quad \dots (6)$$

and

$$W_{n_2} = -\frac{2\pi^2 m e^4}{n_2^2 h^2} \quad \dots (7)$$

Now from equation (3),

$$\nu = \frac{W_{n_2} - W_{n_1}}{h}$$

$$= \frac{2\pi^2 m e^4}{h^2}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

and the wave numbers of the emitted lines are given by

$$\frac{\nu}{c} = \bar{\nu} = \frac{1}{\lambda} = \frac{2\pi^2 m e^4}{c h^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

or

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

where $R_H = \frac{2\pi^2 m e^4}{c h^3}$ (Rydberg's constant for hydrogen).

Spectral series of hydrogen atom :

(i) Lyman series : When an electron jumps from an outer orbits to the first orbit, the spectral lines are in the ultra violet region

$$n_1 = 1 \text{ and } n_2 = 2, 3, 4, 5, \dots \text{ etc.}$$

(ii) Balmer series : When an electron jumps from outer orbits to the second orbit, we obtain the Balmer series $n_1 = 2$ and $n_2 = 3, 4, 5, \dots$ etc. This series lies in the visible region of the spectrum.

(iii) Paschen series : When $n_1 = 3$ and $n_2 = 4, 5, 6,$ etc. we obtain the Paschen series.

(iv) Brackett series : When $n_1 = 4$ and $n_2 = 5, 6, 7,$ etc. we obtain the Brackett series.

(v) Pfund series : When $n_1 = 5$ and $n_2 = 6, 7, 8, \dots$ etc. we obtain the fund series.

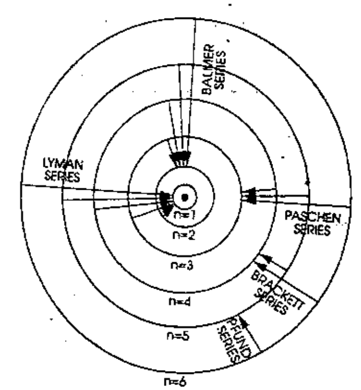


Fig. (1)

Formula used :

In Balmer series, the wavelength corresponding to the quantum number n_2 is given by

$$\frac{1}{\lambda}=R_H\left[\frac{1}{2^2}-\frac{1}{n_2^2}\right]$$

where R_H = Rydberg's constant.

Some of the prominent lines corresponding to $n_2 = 3, 4, 5, 6$, are as follows :

H_α	Red	λ= 6583 A.U.
H_β	Green Blue	λ= 4861 A.U.
H_γ	Blue	λ= 4342 A.U.
H_δ	Violet	λ =4102 A.U.

Thus the value of the Rydberg's constant can easily be calculated by experimentally determining the wavelength of the above prominent lines for the corresponding value of n_2.

Procedure :

(A) Make the following preliminary adjustments of the spectrometer :

(i) Focussing of the eyepiece of the telescope on the crosswire.

(ii) The axis of the telescope and that of collimator must intersect the principal vertical axis of rotation of the telescope.

(iii) Prism table should be levelled.

(iv) Telescope and collimator are adjusted for parallel light by Schuster's method.

(B) Grating should be normal to the axis of collimator :

The adjustment is shown in figure (2).

(i) Collimator and telescope are arranged in a line and the image of the slit is focussed on the vertical cross wire. The reading is noted on both the verniers.

(ii) The telescope is now rotated through 90°.

(iii) Mount the grating on the prism table and rotate the prism table so that the reflected image is seen on the vertical cross wire. Take the reading of the verniers.

(iv) Turn the prism table from this position through 45° or 135°. In this position the grating is normal to the incident beam.

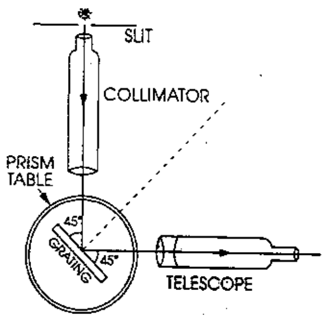


Fig. (2)

(C) Procedure for the determination of angle of diffraction :

The spectrum obtained in a grating is shown in figure (3).

(i) Rotate the telescope to the left side of the direct image and adjust the different spectral lines (violet, green and red) of 1st order on the vertical cross wire. Note down the readings of both the verniers in each settings.

(ii) Rotate the telescope further to obtain the second order spectrum and again adjust the spectral lines on the vertical cross wire and note the readings.

(iii) Now rotate the telescope to the right of direct image and repeat the above procedure for first order as well as for second order.

(iv) Find out the difference of the same kind of verniers for the same spectral lines in the first order and in the second order. The angle is the twice the angle of diffraction for that particular colour. Half of it will be the angle of diffraction.

(v) Find out the angles of diffraction for other colours in first and second order

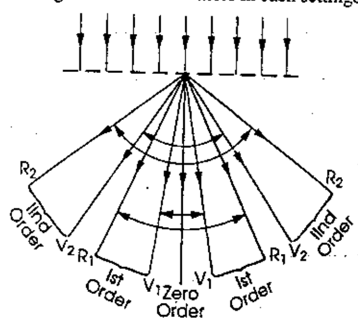


Fig. (3)

Observations :

No. of lines, N, per inch on the grating = ...

Least count of spectrometer = ... cm.

Reading of telescope for direct image = ...

Reading of telescope after rotating it through 90° = ...

Reading of circular scale when reflected image is obtained on the cross wire = ...

Reading after rotating the prism table through 45° or 135° = ...

Determination of angles of diffraction :

Order of Spectrum	Colour of light	Kinds of vernier	Specrum on left side Reading of Telescope M.S. Reading	V.S. Reading	Total a Degrees	Spectrum on right side Reading of Telescope M.S. reading	V.S. Reading	Total reading b Degrees	$2\theta = a \sim b$	Mean θ Degrees
First	Violet	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
	Green	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
	Red	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
Second	Violet	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
	Green	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	
	Red	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	

Calculations :

$$(a+b)=\frac{2\cdot 54}{n}= \ldots \text{ per cm.}$$

where N is the number of ruling per inch on the grating surface.

Wavelength of H_α line :

For first order $\lambda_\alpha = (a+b)\sin\theta$, because $n = 1$ for first order

$= \ldots \times 10^{-8}$ cm.

For second order $\lambda_\alpha = \dfrac{(a+b)\sin\theta}{2}$

$= \ldots \times 10^{-8}$ cm.

Hence, mean wavelength λ_α for H_α line = .., $\times 10^{-8}$ cm.

Similarly, calculate the wavelength of H_β, H_γ and H_δ lines,

Now, for H_α line $\dfrac{1}{\lambda_\alpha}=R_H\left[\dfrac{1}{2^2}-\dfrac{1}{3^2}\right]$

$\therefore$ $R_H=\dfrac{1}{\lambda_\alpha}\times\dfrac{36}{5}$

$= \ldots \text{cm}^{-1}$.

For H_β line
$$\frac{1}{\lambda_\beta} = R_H\left[\frac{1}{2^2} - \frac{1}{4^2}\right]$$
$\therefore$
$$R_H = \frac{1}{\lambda_\beta} \times \frac{16}{12}$$
$$= \ldots \text{cm}^{-1}.$$

For H_γ line
$$\frac{1}{\lambda_\gamma} = R_H\left[\frac{1}{2^2} - \frac{1}{5^2}\right]$$
$\therefore$
$$R_H = \frac{1}{\lambda_\gamma} \times \frac{16}{21}$$
$$= \ldots \text{cm}^{-1}.$$

$\therefore$ Mean value of $R_H = \ldots \text{cm}^{-1}$.

Theoretically,
$$R_H = \frac{2\pi^2 m e^4}{c h^3}$$

where
$m = 9{\cdot}10660 \times 10^{-28}$ gm.
$h = 6{\cdot}624 \times 10^{-27}$ ergs sec.
$e = 4{\cdot}8025 \times 10^{-10}$ e.s.u.
$c = 2{\cdot}9980 \times 10^{10}$ cms./sec.

$\therefore$ $R_H = \ldots \text{cm}^{-1}$.

Result : The value of Rydberg's constant = ... cm^{-1}.

Standard value : Standard value of $R_H = \ldots \text{cm}^{-1}$.

Percentage error : ... %.

Sources of error and Precautions :

(i) Before performing the experiment, the spectrometer should be adjusted.
(ii) Grating should not be touched by fingers.
(iii) Grating should be set normal to the incident light.
(iv) Both Verniers should be read.
(v) While taking observations, telescope and prism table should be kept fixed.

Experiment with Prism :

If instead of using grating, we use prism, then we perform the experiment in two parts.

First Part with Hydrogen tube : Set the telescope and collimator for parallel rays and then place the prism in the position of minimum deviation and then calculate the deviations 'δ' for the following four lines of hydrogen :

1. Red (H_α)
2. Green Blue (H_β)
3. Blue (H_γ)
4. Violet (H_δ)

and then using the relation,
$$\mu = \frac{\sin\frac{A+\delta}{2}}{\sin\frac{A}{2}} \quad \text{(where } A \text{ is the angle of prism)}$$
calculate μ for all the aforesaid four lines. Let they be μ_R, μ_{BG}, μ_B and μ_V.

Observation table :

S. No.	Colour	Vernier	Dispersed Image			Direct Image			Difference $a - b$	Minimum deviation δ
			M.S.	V.S.	Total (a)	M.S.	V.S.	Total (b)		
1	Red	V_1	...	...	...	...	...	...	...	} Mean
		V_2	...	...	...	...	...	...	...	...
2.	Blue Green	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	...
3	Blue	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	...
4	Violet	V_1	...	...	...	...	...	...	...	...
		V_2	...	...	...	...	...	...	...	...

Second part with Hg Source : Replace hydrogen source by a mercury source and then calculate the deviations for the different colours observed in the spectrum. Calculate the values of refractive index, μ, for every colour. Standard wavelengths in mercury spectrum are noted below :

Orange I	6234 Å
Orange II	6152 Å
Yellow I	5791 Å
Yellow II	5770 Å
Green	5461 Å
Blue Green	4916 Å
Blue	4358 Å
Violet I	4078 Å
Violet II	4047 Å

Then plot a graph in these wavelength values and corresponding μ values. From this graph, corresponding to μ_R, μ_{BG}, μ_B and μ_V calculated in first part, the wavelength for the four lines *i.e.*, λ_{red}, $\lambda_{blue\ green}$, λ_{blue} and λ_{violet} can be obtained. This gives the wavelength values of H_α, H_β, H_γ and H_δ lines. Knowing the values of wavelengths, calculate the values of R_H as calculated on page 100L.

Observation table :

(To note the deviation of mercury lines, similar table as in first part is prepared).

Viva-Voce

Q. 1. ***What do you mean by a spectral series ?***
Ans. The sequence of the lines emitted by an element is known as spectral series.

Q. 2. ***Describe the nature of hydrogen spectrum ?***
Ans. The hydrogen spectrum consists of Lyman series, Balmer series, Paschen series, Brackett series and Pfund series. The Balmer series lies in the visible range. It consists of four prominent lines as H_α, H_β, H_γ and H_δ.

Q. 3. ***How will you find out Rydberg's constant from the spectrum ?***
Ans. We know that $\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n_2^2}\right)$

where R_H is Rydberg's constant. The wavelength of a line corresponding n_2 is determined by using a grating.

Q. 4. ***What is theoretical value of Rydberg's constant ?***
Ans.
$$R_H = \frac{2\pi^2 m e^4}{c h^3} = 109678 \text{ cm}^{-1}.$$

Reflection of Light

EXPERIMENT No. 26

Object : To determine the height of a tower with the help of a sextant.

Apparatus required : Sextant and measuring tape.

Formula used :

The height h of a tower is given by the following formula :

$$h = \frac{x}{\cot\beta - \cot\alpha}$$

where x = distance between the two points of observation.

β = angular elevation of the tower from one point of observation.

α = angular elevation at a point distant x from the previous point towards the tower.

Description and theory of the experiment :

Description of sextant : Sextant is shown in fig. (1). The sextant consists of a graduated circular arc of about 60° having two radial fixed arms A and B. There is another arm known as third moving arm C (index arm) which moves over the circular graduated scale. It carries a vernier scale V on one side and plane mirror M_1 (index glass) on the another side. This arm is fitted with clamp and tangent screw, so that it can be adjusted in any desired position. The plane of the mirror M_1 is perpendicular to the plane of the arc. A second mirror M_2, called the horizon glass is fixed to the arm whose lower half is silvered while upper half is transparent. The plane of this mirror is also perpendicular to the circular arc. A telescope T is fitted to the arm B with its axis perpendicualr to the horizon glass. The telescope receives the direct rays through the transparent portion of M_2 and the twice reflected rays from M_1 and M_2.

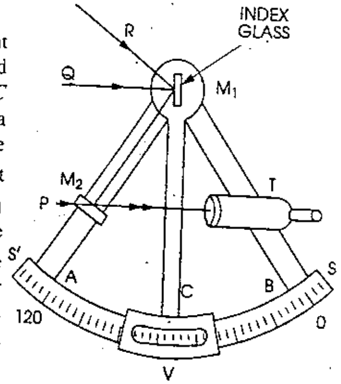


Fig. (1)

Principle of working : The distant object is viewed directly through the clean part of mirrors M_2 and then the movable arm is so rotated that the mirror M_1 and M_2 become parallel. In this position the telescope receives rays from distant object in two paths as shown in fig. (2). One set of rays PM_2T through clear part of M_2 and other set of rays starting from R reflected from mirror M_1 and then from the silvered portion of mirror M_2 enter the telescope. Now the zero of the main scale should coincide with the zero of the vernier scale and if it is not so then there is a zero error in the instrument which should be noted with proper sign.

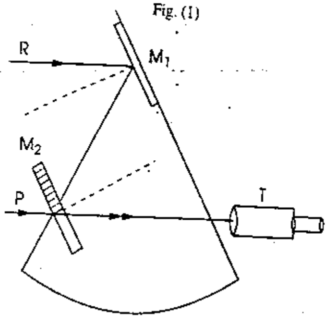


Fig. (2)

In order to calculate the angle between two objects situated in the direction M_1R and M_2P as shown in fig. (3), the movable arm containing mirror M_1 is moved such that the rays coming directly from P towards telescope and rays coming through the paths RM_1, M_1M_2 and M_2T coincide with each other. The angle RM_1Q is the angle between the directions of the two objects which is twice the angle BM_1C. To facilitate this, the circular scale is directly marked as twice the actual degrees.

The difference between this reading and zero reading gives the required angle.

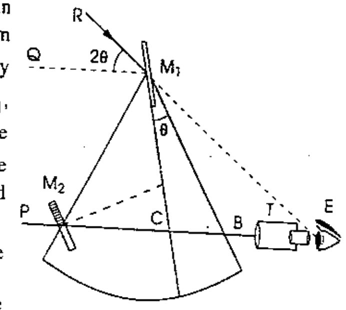


Fig. (3)

Theory : Let h be height of the tower MN with point N as the top. Let α and β be the angles subtended by the top of the wall at E and F, distant x in a line passing through M and perpendicular to the plane MN as shown in fig. (4).

In ΔNME

$$\tan\alpha = \frac{NM}{ME} = \frac{h}{ME}$$

or

$$ME = \frac{h}{\tan\alpha} = h\cot\alpha$$

In ΔNMF

$$\tan\beta = \frac{NM}{MF} = \frac{h}{MF}$$

or

$$MF = h\cot\beta$$

Now

$$MF - ME = h\cot\beta - h\cot\alpha$$

$$x = h\cot\beta - h\cot\alpha$$

$$h = \frac{x}{\cot\beta - \cot\alpha}$$

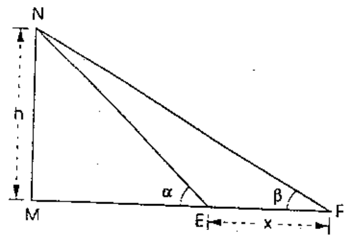


Fig. (4)

Adjustments :

Before performing the experiment following adjustments are made.

(i) Plane of the index glass should be perpendicular to the plane of the arc.

(ii) In the zero reading the index glass and the horizon glass should be parallel.

(iii) The axis of the telescope must be parallel to the plane of the graduated circular scale and must pass through the centre of the horizon glass.

Procedure :

(i) First of all determine the vernier constant of the scale provided with the instrument *i.e.* by dividing the value of one division of main scale by the total number of vernier divisions.

(ii) Draw a short horizontal line on the tower with a piece of chalk in the level of your eye and place the sextant at a fairly large distance from the tower. Mark this position on the ground. This will be the first point of observation.

(iii) See a part of horizontal line through the transparent portion of the horizon glass and the other portion of the same line through the reflecting part of this mirror. Now turn the movable arm such that the horizontal line is seen continuous. Note down the main scale and vernier scale readings. The reading will be the zero reading and should coincide with zero of main scale. If not so, note down the zero with proper sign.

(iv) Now rotate the movable arm gradually so that the wall begins to descend down. Continue till the image of top coincide with the image of marked line. Note down the reading. The difference of this reading and previous reading will be angular elevation α.

(v) From the point of observation move a known distance x say about 10 feets away the tower.

Again record the zero error with proper sign at this point and then repeat the above procedure mentioned in (v) point to find the angular elevation β at the point.

(vi) Calculate the height of the tower with the help of the derived formula. Measure the distance of the horizontally marked line from the ground. Add this reading to height of tower calculated with the formula, which will give the total height.

Observations :

(A) Value of one main scale division = ...

No. of divisions on the vernier = ...

Least count of the instrument = ...

(B) **Table for angular elevation α and β.**

Distance	Zero error			Angular elevation			Angle of elevation $(b-a)$	$(\beta$ & $\alpha)$ for different distances
	M.S.	V.S.	Total (a)	M.S.	V.S.	Total (b)		
... (0 ft.) initial position	...	...	...	...	...	...	$\alpha = ...$	
... (6 ft.)	...	...	...	...	...	...	$\beta = ...$	... for 6'
... (12 ft.)	...	...	...	...	...	...	$\beta = ...$	... for 12'
... (18 ft.)	...	...	...	...	...	...	$\beta = ...$	... for 18'

Calculations :

The height of the tower is given by

$$h = \frac{x}{\cot\beta - \cot\alpha}$$

= .... ft.

Height of the chalk mark from the foot of tower

$h' =$ .... ft.

Result : Total height $(h + h') = ...$ft.

Precautions and Sources of error :

(i) Before performing the experiment the adjustement should be made carefully.

(ii) Zero reading must be found separately at different places.

(iii) The foot of the tower and two points of observations should be in a straight line.

(iv) To find out the acutal height of the tower, the height of the chalk mark from the foot of tower should be added.

ADDITIONAL EXPERIMENTS

EXPERIMENT (26–1)

Ex. 1. ***To determine the height of a distant object with the help of a sextant by artificial horizon.***

(i) First of all the sextant is held with its plane vertical. Now the inverted image of the top of the distant object (say a tower) formed in the artificial horizon (like water surface or mercury surface) is seen through the transparent portion of glass M_2 as shown in fig. (5).

(ii) The index arm is rotated till the image of the top of the tower as reflected from mirror M_1 and silvered portion of M_2 is also seen. The index arm is clamped.

(iii) The tangent screw is adjusted in such a way that the images coincide and the reading is noted.

(iv) The object is directly seen through transparent portion of horizon glass M_2. The index arm is moved till the image of the object formed by reflection in M_1 and M_2 is observed. Index arm is clamped.

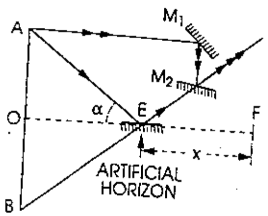


Fig. (5)

(v) The tangent screw is adjusted in such a way that the two images coincide and the reading is noted. This is the zero reading of the sextant.

(vi) The angle of elevation of the object is the difference of two readings.

(vii) Now move through a distance x and measure the angle of elevation at this place as described above.

(viii) Calculate the height of the tower with the help of the derived formula.

EXPERIMENT (26–2)

To determine the altitude of the sun :

(i) To determine the altitude of the sun, artificial horizon is required. For this purpose a dish full of mercury is used.

(ii) To determine the zero error of the sextant, the movable arm C is turned till the image of sun seen by reflection from the two mirrors M_1 and M_2 coincides with the image seen directly through the transparent portion of the horizon glass. Let this reading be θ.

(iii) Now artificial horizon AB be placed in such a portion so that the image S' of the sun can be seen directly as well as by reflection. Gradually rotate the movable arm C till the image formed by reflection from the two mirrors coincides with the direct image. Let this reading be θ'. Then angular elevation of the sun (α) is given by

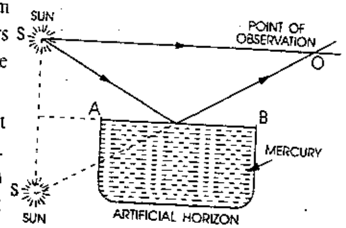


Fig. (6)

$$2\alpha = \theta' - \theta$$

$$\alpha = \frac{1}{2}(\theta' - \theta).$$

EXPERIMENT (26–3)

To determine the angular diameter of sun :

(i) To determine the angular diameter of sun, the sextant is held vertical and sun-glasses are used to reduce the intensity.

(ii) See the direct image of the sun through the transparent portion of horizon glass. This is denoted by S in the fig. (7).

(iii) Turn the movable arm C of the sextant such that the image B obtained by double reflection from the two mirrors just touches the rim of S. Note this reading also.

(iv) Now again rotate the movable arm such that the image B may be on the other side of S in the position A just touching the image S. Note this reading also.

(v) The difference of the two readings gives $2d$ and half of it will be the angular diameter of sun.

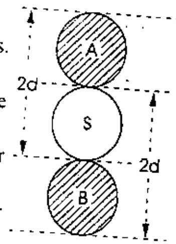


Fig. (7)

Viva-Voce

Q. 1. ***Why this instrment is called a sextant ?***

Ans. The circular scale of the instrument is only one sixth of a circle *i.e.*, an arc of 60°.

Q. 2. ***On what principle does the working of a sextant depend ?***

Ans. This is based on the principle that when a plane mirror is rotated through an angle θ, the reflected ray is turned through 2θ.

Q. 3. ***Why do you see two images formed in the telescope when the sextant is pointed towards an object ?***

Ans. One image is formed by the rays directly entering the telescope through the transparent portion of horizon glass and the second by those rays which enter the telescope after reflections from index glass and silvered portion of horizon glass.

Q. 4. ***Is the incident ray fixed here as mirror is rotated ? Then ?***

Ans. Here the incident ray is not fixed but the reflected ray is fixed. Due to the reversibility of light path, the two rays (incident and reflected) are interchangeable.

Q. 5. ***What are these coloured glasses meant for ?***

Ans. These are used when measurements are made with sun or any other bright object.

Q. 6. ***What do you mean by zero error of sextant ?***

Ans. When direct image of a distant object seen through transparent portion of the horizon glass is made to coincide with the image formed by reflections at the index and horizon glasses, the two glasses are parallel. The reading of index arm on the scale should be zero. If it is not zero, then there is zero error.

Q. 7. ***What is the relative setting of M_1 and M_2 when the scale reads zero ?***

Ans. The two mirrors are parallel to each other and perpendicular to the bed of the apparatus.

Q. 8. ***What are other uses of sextant ?***

Ans. This is used by mariners to find latitude and longitude at a particular place during their voyage.

Q. 9. ***What is meant by angular diameter θ of the sun ?***

Ans. The angle subtended by sun's disc at the earth is called angular diameter θ of the sun.

Q. 10. ***How the angular diameter of the sun is related to the actual diameter ?***

Ans. The actual diameter D of the sun is related to angular diameter θ by the relation $D = x\,\theta$, where x is the distance between earth and sun.

Photometry

EXPERIMENT No. 27

Object : To compare the illuminating powers of two given sources of light with a Lummer-Brodhum photometer and to study the variation of illuminating power of a filament lamp with the applied voltage.

Apparatus required : Lummer-Brodhum photometer, optical bench, two sources of light and auto transformer.

Formula used :

If the illuminating powers of two sources of light be P_1 and P_2 and their respective distances from the photometer be d_1 and d_2 then

$$\frac{P_1}{P_2} = \frac{d_1^2}{d_2^2}$$

The distances d_1 and d_2 are such that they produce equal illumination.

Description of the Apparatus and Theory :

Illuminating power : The illuminating power of a source is the quantity of light falling per second on a unit area placed at a unit distance form the source in a direction normal to the rays. It is measured in candle power.

Intensity of Illumination : The intensity of illumination at a point is defined as the light falling per second on a unit area of the surface placed at a point under consideration.

$$\text{Intensity of illumination} = \frac{\text{Candle power}}{(\text{Distance})^2}$$

Description of photometer : The Lummer-Brodhum photometer is shown in fig. (1).

It consists of a magnesium carbonate slab AB arranged such that each face is illuminated by the sources S_1 and S_2. P_1 and P_2 are the two right angled prisms which receive the light after the reflection from the slab AB. The light now reflected from these prisms, enter into a double prisms P_3 and P_4. The two prisms are placed with their hypotenuse faces together and separated by a thin air film except at the centre. The central portion is cemented with canada balsam. The rays striking the cemented part are totally transmitted while those striking the air film are totally reflected. This is shown in the left adjoining figure. The rays 1 and 3 coming from prism P_1 are reflected while ray 2 is transmited. Similarly rays 4 and 6 coming from the prism P_2 are reflected while ray 5 is transmitted. In this way light

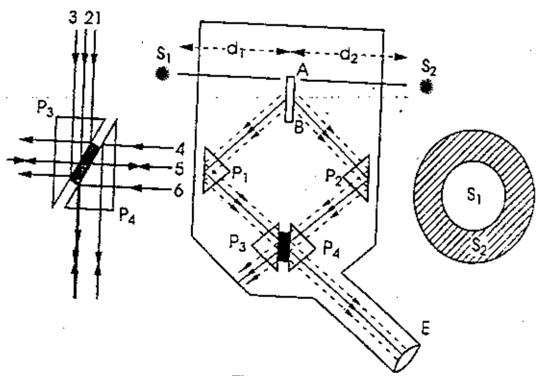


Fig. (1)

reflected from prism P_1 and transmitted through P_3 illuminate the central portion of the field of view and light reflected from P_2 and again reflected from P_4 illuminate the rest of the field of view of the telescope as shown at the right in figure (1). Due to the different illuminating powers of the two sources, the intensities of the two portions are different. When the distances of the sources are so adjusted that the two parts are eqally bright, then

$$\frac{P_1}{d_1^2} = \frac{P_2}{d_2^2}$$

Principle : To compare the illuminating powers of any two sources of light we make them illuminate two neighbouring surfaces. The distance of one or the other of the sources is adjusted until the two portions appear equally bright. In this way the intensity of illumination due to both the sources is same. Now if P_1 and P_2 are illuminating powers of the sources, and d_1 and d_2 their respective distances from the surface they illuminate, the intensity of illumination due to each respectively, is

$$\frac{P_1}{d_1^2} \quad \text{and} \quad \frac{P_2}{d_2^2}$$

When these two are equal

$$\frac{P_1}{d_1^2} = \frac{P_2}{d_2^2} \quad \text{or} \quad \frac{P_1}{P_2} = \frac{d_1^2}{d_2^2}$$

Hence the illuminating powers of the two sources are directly proportional to the square of the distances at which they respectively produce equal intensity of illumination. Note if P_2 and d_1 are fixed then $P_1 \propto 1/d_2^2$.

Procedure :

First Part :

(i) The photometer upright is mounted nearly in the middle of an optical bench and adjusted in such a way that photometer head becomes normal to the line joining the two sources as shown in figure (2).

(ii) Remove the shutters from both sides of photometer and allow the light to fall on each face of the head.

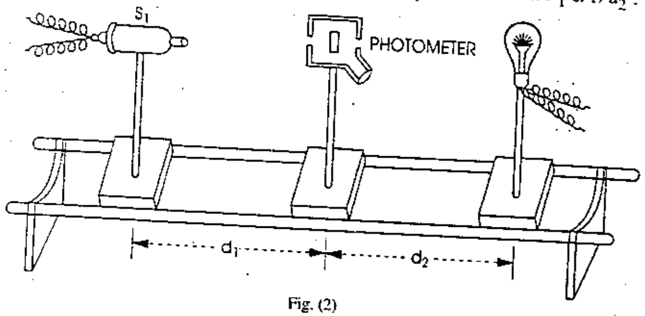


Fig. (2)

(iii) The positions of one lamp and photo- meter head are noted. For one set of observation, position of photometer head should not be disturbed.

(iv) Move the other lamp from one end of the bench towards photometer till the field of view in photometer is eqally illuminated. Note down the position of the lamp.

(v) The distance of the first lamp is changed by 5 cms. and the other lamp is adjusted till again the field of view is equally illuminated. The experiment is repeated for several times and the mean value of P_1/P_2 is determined.

Second Part :

In order to study the variation of candle power of the lamp with applied voltage, the auto transformer is used as shown in fig. (3). In this case one of the lamp (say S_1) is fixed with respect to photometer (d_1 is fixed) and the bulb is subjected to desired voltage with the help of auto transformer. For a particular voltage, the distance (say d_2) of the second lamp (say S_2) is so adjusted that the field of view is equally illuminated. The voltage of S_1 is now varied and again the distance of S_2 is adjusted for equal illumination. Now for each voltage, the illuminating power of this lamp is calculated in terms of the

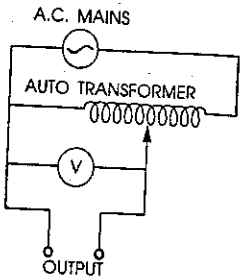


Fig. (3)

illuminating power of first lamp. A graph is now plotted between illuminating power and applied voltage which comes out a straight line showing thereby that the illuminating power is directly proportional to the applied voltage.

Observations :

First Part :

(a) Table for the comparison of illuminating powers.

S. No.	Position of Source S_1	Position of Photometer	Position of Source S_2	d_1	d_2	$\frac{P_1}{P_2}=\frac{d_1^2}{d_2^2}$	Mean
1	...	...	...	...	...	...	...
2	...	...	...	...	...	...	
3	...	...	...	...	...	...	
4	...	...	...	...	...	...	

Second Part :

(b) Table for variation of illuminating power with voltage.

S. No.	Applied Voltage to Source S_1 V volts	Position of Source S_1	Position of photometer	Position of Source S_2	d_1	d_2	$1/d_2^2$
1	...	...	...	...	...	...	...
2	...			...		...	...
3	...			...		...	...
4	...			...		...	...
5	...			...		...	...

Graph :

A graph is plotted between applied voltages and corresponding illuminating power in terms of source S_1. This graph is shown in fig. (4). Or plot a graph in applied voltages and $1/d_2^2$ (provided source S_1 and hence distance d_1 remains constant).

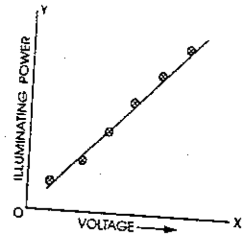


Fig. (4)

Result : (a) The ratio of illuminating powers of two sources is = ...

(b) The illuminating power is proportional to the applied voltage.

Precautions and Sources of Error :

(i) Heights of the two sources and photometer should be adjusted carefuly.

(ii) The field of view should be matched carefully.

(iii) The distances d_1 and d_2 should be measured accurately.

ADDITIONAL EXPERIMENT

EXPERIMENT (27–1)

Object : To determine the transmission coefficient of a given transmitting plate.

Formula used :

The transmission coefficient t is given by

$$t = d^2/d_2^2$$

where d_2 and d are the respective distances of the source from the photometer without introducing the transmitting plate and by introducing the plate for equal illumination.

Procedure : (i) Adjust the photometer uprights as shown in fig. (2). Keeping the sources S_1 at a distance d_1, adjust S_2 at a distance d_2 till the field of view in photometer is equally illuminated.

(ii) Now interpose the transmitting plate between photometer and source S_2. Move S_2 till the field of view in photometer is equally illuminated. Note the distance d of source from photometer.

(iii) Repeat above procedure by changing the distance d_1 of source S_1 from photometer.

Observations :

S. No.	d_1	Position of Photometer a	Positoon of source S_2		$d_2 = (b - a)$	$d = (c - a)$	$t = d^2/d_2^2$	Mean t
			Without Plate b	With Plate c				
1	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	
3	...	...	...	...	...	...	...	
4	...	...	...	...	...	...	...	

Result : The transmission coefficient of given plate = ...

Viva-Voce

Q. 1. ***What do you mean by photometry ?***

Ans. The branch of the optics which deals with the comparison and measurements of the quantity of radiant energy, emitted or received or absorbed by light bodies.

Q. 2. ***Define illuminating power ?***

Ans. The illuminating power of a source is the quantity of light falling per second on a unit area placed at a unit distance from the source in a direction normal to the rays. It is measured in candle power.

Q. 3. ***What is intensity of illumination ?***

Ans. The intensity of illumination at a point is defined as the light falling per second on a unit area of the surface placed at a point under consideration.

Q. 4. ***What is a candle power ?***

Ans. The candle power is the ratio of illuminating power of a given source of light and that of a standard candle.

Q. 5. ***What is inverse square law ?***

Ans. The intensity of illumination I at a point due to a point source varies inversely as the square of the distance r of the given point from the source, $I \propto 1/r^2$.

Q. 6. ***Is eye equally sensitive to all colours in the visible range of radiations ?***

Ans. In visible range of the spectrum, eye is not equally sensitive to all colours *i.e.*, wavelengths. It has maximum sensitivity at $\lambda = 5550$ Å in yellow region.

Q. 7. ***What is the sensitivity of the eye in comparing illuminance of two surfaces ?***

Ans. The eye can distinguish between two surfaces, placed side by side and seen simultaneously which differ in brightness by one percent.

Nodal Slide

EXPERIMENT No. 28

Object : To determine the focal length of the combination of two lenses separated by a distance with the help of a nodal slide and to verify the formula :

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{x}{f_1 f_2}$$

where F = focal length of the combination,

f_1, f_2 = focal lengths of the given lenses,

x = separation of the two lenses.

Apparatus required : Nodal slide arrangement (optical bench, plane mirror, cross slit and a lamp) and two convex lenses.

Description of apparatus and theory :

Description : The nodal slide arrangement is shown in figure (1).

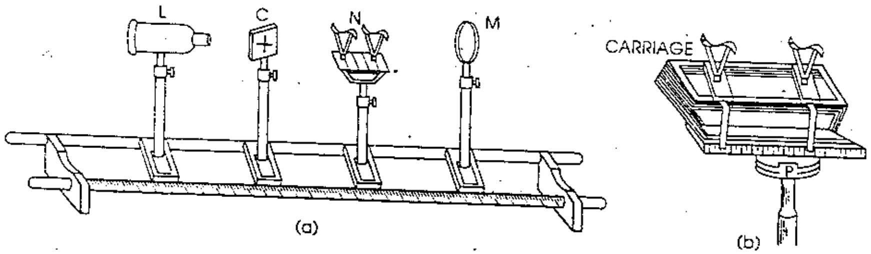


Fig. (1)

The nodal slide assembly consists of an optical bench provided with four uprights. The one upright carries a bulb placed in a metallic cover having a circular aperture; which illuminates a cross slit in the adjacent upright. The third upright carries the nodal slide. Nodal slide is essentially a horizontal metal support capable of rotating about a vertical axis; and lens or lenses can be mounted upon the support. The metallic support can be fixed or it can be moved back and forth by means of a screw so that the relative position of the two lenses can vary with respect to this upright. The support can be rotated in a horizontal plane. The fourth up-right carries a plane mirror which can be rotated about a horizontal axis perpendicular to the bed of the bench.

Theory : If parallel beam of light is incident on a converging lens system thus forming an image on screen in its second focal plane, the image does not shift laterally when the system is rotated about a vertical axis passing through its second nodal points.

The principle is based on the property of nodal points, *i.e.*, when a ray of light passes through one of them, its conjugate ray passes through the other and is always parallel to the incident ray. If the system is now rotated slightly about a vertical axis, the image will not be shifted from its position as shown in fig. (2).

The distance of the screen from the axis of rotation gives the principal focal length of the lens system.

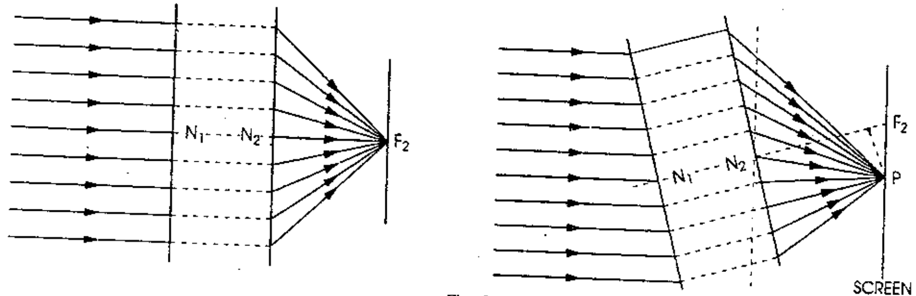


Fig. (2)

Procedure :

(i) One of the lenses L_1, the source of light, cross slit and mirror are mounted on uprights of the optical bench and the heights of uprights are adjusted in such a manner that the line joining the centres of each part is parallel to the bed of the bench.

(ii) Illuminate the cross slit and adjust the plane of the plane mirror to get the image of cross slits very near to it. The image may be blurred but the well defined image is formed by moving the upright of nodal slide away or towards the cross slits.

(In this case light from the source after passing through the cross slits emerges from the lens as a parallel beam which is reflected again as parallel beam from plane mirror and brought to a focus on the plane of cross slits).

(iii) The lens is now rotated slightly about the vertical axis which shifts the position of image either towards the left or right but no shift of the image is obtained by moving the carriage carrying the lens axially. In this situation the cross slits are in the focal plane of the lens. The distance between cross slits and lens gives the focal length of the lens.

(iv) Remove the first lens and mount the second lens on the upright. As described above, find the focal length of this lens.

(v) Mount both the convex lenses on the nodal slide arrangement and note down their positions. This gives the distance between the two lenses.

(vi) Move the upright carrying the lenses towards or away from the cross slits to obtain a well defined image. Now rotate the carriage on its upright by a few degrees and if there is a shift of the image, move the carriage on its upright by means of rack and pinion arrangement till there is no shift. Note down the positions of the uprights carrying the cross slits and nodal slide assembly on the optical bench. This distance gives the combined focal length of the two lenses.

(vii) Rotate the lens system by 180° and repeat the above procedure.

(viii) Alter this distance between two lenses and find out the combined focal lengths.

(ix) Find out the bench error between the uprights carrying cross slits and nodal assembly.

Observations :

Table for focal length of a lens :

Bench error = ... cms.

S. No.	Light incident on	Lens L_1			Mean f_1	Lens L_2			Mean f_2
		Position of cross slit (a)	Position of lens (b)	f_1 $a \sim b$		Position of cross slit (a)	Position of lens (b)	f_2 $a - b$	
1	one face	...	...	...		...	...		
	other face	.	...	...		...	...		
2	one face	...	...	...		...	...		
	other face	...	...	...	...	...	...	...	...
3	one face	...	...	...		...	...	...	
	other face	...	...	...		...	...	...	

Verification of Newton's Formula

EXPERIMENT No. 29

Object : To verify the Newton's formula $x_1 x_2 = f^2$ for lenses separated by a given distance.

Apparatus required : Optical bench, two convex lenses of nearly equal focal lengths, plane mirror, two pins and uprights.

Theory : Let AB and CD represent two lenses separated at fixed distance and F_1 and F_2 are the first and second focal points on the axis of lens [Fig. 1].

If for a source at O, distant x_1 from F_1, the image is formed at O' distant x_2 from F_2 then according to Newton's formula

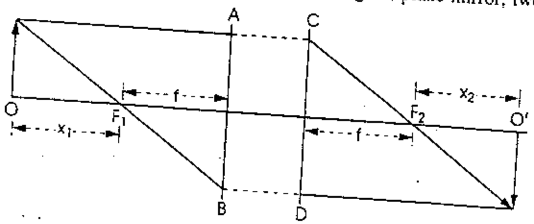


Fig. (1)

$$x_1 x_2 = f^2$$

where f is the focal length of the combination.

As shown in figure,

$$u = (f + x_1) \quad \text{and} \quad v = (f + x_2)$$

$$\therefore \quad \frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{f} = \frac{1}{f + x_2} + \frac{1}{f + x_1}$$

$$\frac{1}{f} = \frac{(f + x_1 + f + x_2)}{(f + x_1)(f + x_2)}$$

$$2f^2 + fx_1 + fx_2 = f^2 + x_1 x_2 + f(x_1 + x_2)$$

$$f^2 = x_1 x_2$$

$$f = \sqrt{(x_1 x_2)}$$

Knowing x_1 and x_2, the focal length can be determined.

Procedure :

This experiment is performed in two parts :

(A) Determination of focal length f of the lens system by Newton's formula.

(i) Both the convergent lenses L_1 and L_2 are mounted on the optical bench at a certain fixed distance d apart. The positions of the uprights carrying these lenses are noted on the optical bench. These positions are not disturbed throughout this part of the experiment.

(ii) A plane mirror M is mounted on one side of the lens system while a pin P on other side of the lens system as shown in fig. (2).

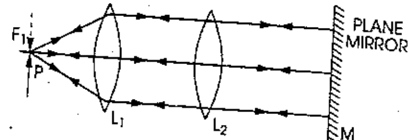


Fig. (2)

(iii) The distance of the pin is so adjusted that there is no parallax between the pin and its inverted image. The tip of the pin locates the position of first focal point F_1. Its position is read on the optical bench.

(iv) Keeping the positions of lenses fixed, the positions of pin and mirror are interchanged. Again the position of the pin is so adjusted that there is no parallax between the pin and its inverted image. The tip of the pin therefore located the position of second focal point F_2. Its position is also noted on the optical bench. This situation is shown in fig. (3).

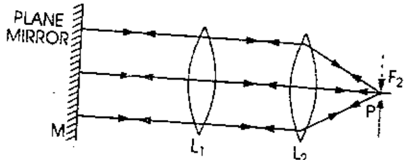


Fig. (3)

(v) Now the plane mirror M and pin P are removed from the optical bench. Two pins P and Q are placed on two sides of the system one away from F_1 and other away from F_2. The position of pin Q is adjusted for no parallax. In this way the first pin serves as object while the second as image. The positions of the pins are noted on optical bench from which x_1 and x_2 are obtained as shown in fig. (4).

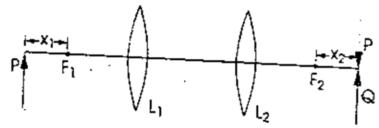


Fig. (4)

(vi) By changing the distance x_1 of the object pin from F_1, and determining the corresponding positions of the image pin Q for no parallax, several sets of observations are taken.

(vii) Calculate the focal length of the lens system by Newton's formula $f = \sqrt{(x_1 x_2)}$ for each set and find the mean value of f.

(B) Determination of the individual focal lengths f_1 and f_2 of the two lenses and then to evaluate the equivalent focal length of the lens system by theoretical formula :

(i) The convergent lens L_1 is mounted on the optical bench together with a pin P on one side and a plane mirror M on the other side as shwon in fig. (5). Adjust the position of pin P on the optical bench by moving it backward or forward so that there is no parallax between the pin and its inverted image.

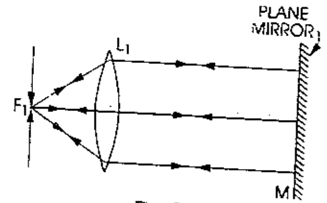


Fig. (5)

(ii) The positions of the uprights carrying the pin and the convergent lens are noted. The difference of the two readings gives the focal length f_1 of the lens L_1.

(iii) The experiment is repeated twice or thrice and the mean value of f_1 is calculated.

(iv) The first lens L_1 is replaced by second lens L_2 and its mean focal length f_2 is determined by the procedure explanined above.

(v) The focal length f of the lens combination is calculated by theoretical formula for the known value of d. This value is compared with the experimentally obtained value by Newton's formula.

Location of Cardinal Points

EXPERIMENT No. 30

Object : To locate the cardinal points of a system of two thin convergent lenses separated by a distance and then to verify the formulae

$$L_1 H_1 = +\frac{xF}{f_2} \quad \text{and} \quad L_2 H_2 = -\frac{xF}{f_1}$$

Apparatus required : Nodal slide assembly and two thin convergent lenses.

Formula used :

(1) The distance of the first principal point H_1 from the first lens L_1 is given by

$$L_1 H_1 = +\frac{xF}{f_2}$$

(2) The distance of the second principal point H_2 from the second lens is given by

$$L_2 H_2 = -\frac{Fx}{f_1}$$

where $f_1 f_2$ = Focal length of the two lenses L_1 and L_2 respectively.

x = The distance between two lenses.

F = Focal length of the lens combination.

Procedure :

(1) Determine the focal lengths f_1 and f_2 of the two lenses separately as described in experiment no. 29.

(2) Mount the two convex lenses on the carriage of nodal slide upright provided with scale so that position of lenses can be read over it. This upright can also be rotated about its support in horizontal plane. The support stand represents the axis of rotation. As shown in fig. (1) keep lens L_1 towards plane mirror and lens L_2 towards cross slit. Then as described in experiment no. 28 proceed to calculate the focal length of the combination of lenses. For this the positions of the carriage on the nodal slide upright and the position of the upright on the optical bench are adjusted to obtain 'no lateral shift' position of the cross slit. In this position cross slit lies in the second focal plane and the axis of rotation of the nodal slide passes through the second nodal point of the lens combination. When the system is situated in air, nodal points and principal points coincide. Therefore distance between lens L_2 and axis of rotation is $H_2 L_2$. Note the distance $H_2 F_2$ between axis of rotation and cross slit. This is F, the focal length of combination. By convention, F is positive whereas $L_2 H_2$ is negative as it lies left to the lens L_2 (taking the reference direction of light from plane mirror).

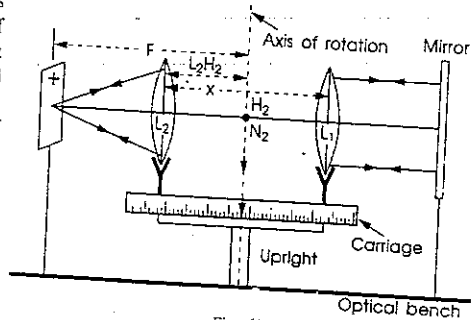


Fig. (1)

(3) Now rotate the carriage through 180° and again obtain 'no lateral shift' position. Again note $L_1 H_1$ and focal length of combination F (distance $H_1 F_1$). According to sign convention $L_1 H_1$ will be positive and F negative.

(4) Find the mean values of F from the values obtained in procedure (2) and (3).

Observations :

(1) Focal length of first lens, f_1 = ... cm.

(2) Focal length of second lens, f_2 = ... cm.

(3) Focal length, F, of combination and practical values of distance $L_1 H_1$ and $L_2 H_2$:

Distance, x, between the two lenses = ... cm.

Lens towards cross slit	S. No.	Position of cross slit (a) cm.	Position of the axis of rotation of nodal slide (b) cm.	Focal length of combination F cm. = (a − b)	Mean F cm.	Distance between lens towards cross slit and axis of rotation of nodal slide in cm.	Mean distance cm. Practical value
L_2	1.	...	...	...	$H_2 F_2$ =	...	$L_2 H_2$ =
	2.	...	...	...	...	...	
	3.	...	...	...		...	
L_1	1.	...	...	...	$H_1 F_1$ =	...	$L_1 H_1$ =
	2.	...	...	...	...	...	
	3.	...	...	...		...	

Calculations : (i) Take Mean value of focal length F of combination. Then calculate theoretical values of $L_1 H_1$ and $L_2 H_2$ by the relations :

$$L_1 H_1 = \frac{xF}{f_2} = + \ldots \text{ cm.}$$

and

$$L_2 H_2 = \frac{-xF}{f_1} = \ldots \text{ cm.}$$

Result : (i) Comparison of theoretical and practical values of $L_1 H_1$ and $L_2 H_2$:

	Theoretical value	Practical value	Difference
$L_1 H_1$	...	...	...
$L_2 H_2$	...	...	...

Since the two values nearly agree, relations

$$L_1 H_1 = \frac{xF}{f_2} \quad \text{and} \quad L_2 H_2 = \frac{xF}{f_1}$$

are verified.

(2) Location of Cardinal Points :

Draw two lenses L_1 and L_2 at a known distance x apart. Then make the position of first and second principal points H_1 and H_2 at distance $L_1 H_1$ from lens L_1 and at distance $L_2 H_2$ from lens L_2 on the common axis, respectively, with

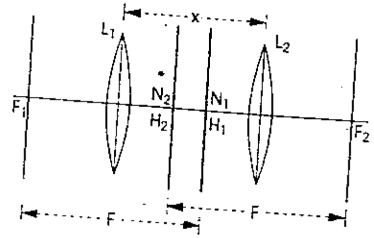


Fig. (2)

Observations :

(1) Thickness of the lens by screw gauge $t = \ldots$ cm.
(2) Focal length of the convex lens of $f = \ldots$ cm.
(3) Table for R_1 and R_2

Surface of the lens	Distance d of pin from the top of the lens cm.	$u = d + \frac{t}{2}$	$R = \frac{uf}{f-u}$	Mean cm.
First surface	... ...	... ...	... ...	$R_1 = \ldots$
Second surface	... ...	... ...	... ...	$R_2 = \ldots$

Calculations :

$$R_1 = \frac{u_1 f}{f - u_1} = \ldots\ldots \text{ cm.}$$

$$R_2 = \frac{u_2 f}{f - u_2} = \ldots\ldots \text{ cm.}$$

Further,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = (\mu - 1)\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

$$\mu = \left[1 + \frac{f(R_1 R_2)}{(R_1 + R_2)}\right]$$

$$= \ldots\ldots$$

Result : The refractive index of the material of the given lens = ...

Sources of error and Precautions :

(i) Mercury taken should be pure.
(ii) Parallax should be removed very carefully.
(iii) Surfaces of the lens should be clean.
(iv) Half of the thickness of lens should be added in d to obtain the value of u.
(v) Focal length should be measured accurately.

Refractive Index

EXPERIMENT No. 32

Object : To determine the refractive index of the material of a concave lens.

Apparatus used : Optical bench, Pins, concave lens, metre scale, plane mirror, spherometer.

Formula used :

The refractive index μ of the material of a concave lens is given by

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

where, f = focal length of the concave lens
R_1 = radius of curvature of first surface
R_2 = radius of curvature of second surface.

The radius of curvature R is given by

$$R = \frac{l^2}{6h} + \frac{h}{2}$$

where l = distance between the two legs of the spherometer
h = difference of readings of the spherometer when it is placed on the lens as well as when placed on plane surface.

Procedure :

(A) Determination of the focal length of concave lens :

(i) The given concave lens is mounted on one of the uprights of optical bench. A bright vertical pin O (mounted on the upright of optical bench) is placed at a certain distance from concave lens as shown in fig. (1).

(ii) The image of O is viewed through the lens from the other side. Another pin I is placed on the object side. The pin I is moved and adjusted such that there is no parallax between the image of O and pin I. Then I is the position of image of O.

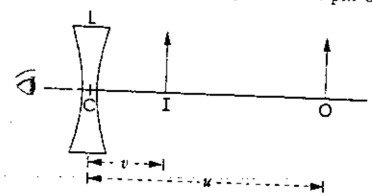


Fig. (1)

(iii) The positions of C, I and O are noted.

(iv) The experiement is repeated three or four times.

(B) Determination of radius of curvature :

(i) Determine the least count of the spherometer.

(ii) The spherometer is placed on the plane surface and the screw is lowered until it just touches the surface. Note down the reading of spherometer.

(iii) Next, the spherometer is placed on one surface of the concave lens and the screw is turned until it touches the lens surface. The spherometer reading is noted.

(iv) Procedure (iii) is repeated for the second surface of the concave lens.

Result : The refractive index of concave lens = ...

Precations and sources of error :

(i) Optical bench should be levelled.
(ii) Object pin and Image pin heights should be upto the centre of concave lens.
(iii) Radius of curvature of both the surfaces should be determined.
(iv) Spherometer readings should be taken carefully.
(v) At least three or four readings should be taken for the determination of focal-length of the lens.

Refraction

EXPERIMENT No. 33

Object : To determine the refractive index of a liquid using Pulfrich refractometer.

Apparatus used : Pulfrich refractometer, glass cell, liquid, source of light, right angled prism.

Formula used :

The refractive index of liquid is given by

$$\mu = \sqrt{(\mu_0 - \sin^2 i)}$$

where μ_0 = refractive index of the material of the prism.

i = minimum angle of emergence.

Description of apparatus :

Pulfrich refractrometer is shown in fig. (1). It consists of a right angled prism A having its two faces perfectly plane. The liquid whose refractive index is to be determined is taken in a glass cell B and placed on prism A. Light is incident in a direction parallel to the horizontal surface so that light entering prism A is incident at the critical angle C with the normal. Finally it emerges from the prism at an angle i. The emergent light is viewed with the help of telescope T which can be moved on a graduated circular scale.

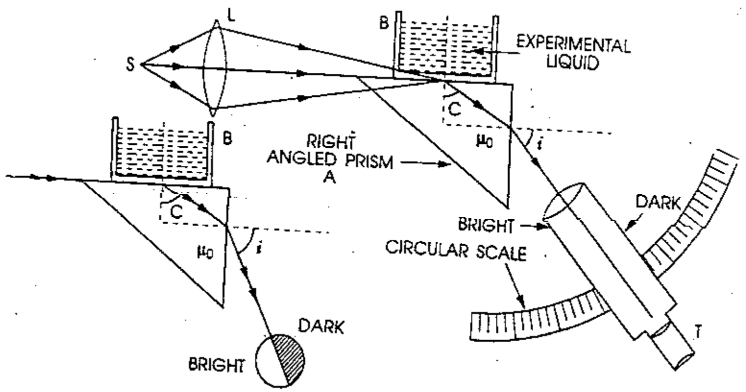


Fig. (1)

Procedure :

(i) The glass cell is cleaned and experimental liquid is filled in it. This is properly placed at its place in the apparatus.

(ii) The source of light is switched on and light is allowed to incident on the prism-cell system.

(iii) The emergent light from the prism is viewed by telescope T. The telescope is moved on the circular scale. One side of field of view appears dark while the other side appears bright. The telescope is adjusted so that the cross wire lies on the dark edge of the field of view. This gives the position of the minimum angle of emergence i.

(iv) The experiment is repeated for three or four times to obtain the minimum angle of emergence. Then mean i is calculated.

Note : In modern instruments, the circular scale is calibrated in terms of the refractive index. So the readings can be read directly from the scale. In some cases, a table is provided with the instruments which gives the value of μ corresponding to i.

Observations :

(1) Refractvie index of the material of the prism. μ_0 = ...

(2) Table for the minimum angle i of emergence

S. No.	Minimum angle of emergence i degrees	Mean i degrees	sin i
1	...		
2	...	...	...
3	...		
4	...		

Calculation :

$$\mu = \sqrt{\mu_0^2 - \sin^2 i}$$

$$= ....$$

Result : The refractive index of given liquid = ...

Precautions and sources of error :

(1) There should be no air bubble in the liquid.
(2) The glass cell should be clean.
(3) The field of view should be judged correctly.
(4) The position of the cross-wire should be set on field of view carefully.
(5) A number of readings should be taken for the measurement of i.

Voltage Volts	No. of counts	Background counts	Net no. of counts
1150	....	....	....
1200	....	....	....
1250	....	....	....
1300	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....

Result : A graph is plotted in number of counts and applied voltage. This is plateau characteristic of G.M. counter.

Precautions : Radioactive sources should be placed in supporting blocks. Every care should be taken to shield one self from radiations.

PHYSICAL CONSTANTS AND MATHEMATICAL TABLES

Universal Physical Constants :

Gravitational constant G	$= 6.67 \times 10^{-11}$ newton–m^2/kg^2
Boltzmann constant	$= 1.38 \times 10^{-23}$ joule/K
Mass of H_2 atom (m_H)	$= 1.67399 \times 10^{-27}$ kg
Mass of proton (m_H)	$= 1.67399 \times 10^{-27}$ kg
Mass of electron (m_e)	$= 9.1083 \times 10^{-31}$ kg
Charge on electron	$= 1.6 \times 10^{-19}$ coulomb
Velocity of light in vacuum	$= 3 \times 10^8$ m/s
Planck's constant	$= 6.63 \times 10^{-34}$ J–s

Densities

At ordinary temperature (17°–23°)

Substance	Density × 10^3 kg/m^3	Substance	Density × 10^3 kg/m^3
Metals and alloys		Liquids	
Aluminium	2.7	Alcohol	0.80
Iron. Pure	7.88	Benzene	0.88
Wrought	7.85	Ether	0.74
Cast	7.6	Glycerine	1.26
Steel	7.7	Lubricating oil	0.91
Brass	8.4–8.7	Mercury	13.60
Chromium	6.92	Aniline	1.02
Copper	8.89	Ether	0.736
Gold	19.3	Turpentine	0.87
Antimony	6.62		
Bismith	9.78		
Silver	10.5		
Mica	2.6–3.2		
Platinum	21.45		
Tungsten	19.3		
Tin	7.3		
Lead	11.34		
Magnesium	1.74		
Nickle	8.8		
Selenium	4.8	Gases :	
Germanium	5.3	Air	0.00129
Bronze	8.8–8.9	Carbon dioxide	0.00198
Constantan	8.88	Hydrogen	0.00609
Maganin	8.50	Steam (100°C)	0.00091
Asbestos	2.0–2.8	Helium	0.000179
Cork	0.22–0.26		
Glass Crown	2.0		
Flint	4.0		
Zinc	7.1		

Acceleration due to gravity :

Place	g	Place	g
Pole	9.8222	Allahabad	9.7895
Equator	9.7803	Gorakhpur	9.7905
Delhi	9.7915	Gwalior	9.7897
Meerut	9.7915	Indore	9.7860
Dehra Dun	9.7907	Jaipur	9.7852
Lucknow	9.7900	Ajmer	9.7890
Kanpur	9.7901	Bombay	9.7865
Varanasi	9.7899	Calcutta	9.7878
Agra	9.7606	Madras	9.7828
Aligarh	9.7808		

Elastic Constants :

Substance	Young's Modulus Y Newton/m^2 × 10^{11}	Modulus of rigidity η Newton/m^2 × 10^{11}	Poison's ratio σ
Aluminium	0.69–0.72	0.25–0.27	0.33–0.35
Brass	0.9–1.0	0.34–0.23	0.39–0.40
Copper	1.1–1.29	0.34–0.46	0.25–0.35
Iron Wrought	1.9–2.2	0.77–0.83	0.27–0.29
Cast	1.0–1.3	0.35–0.53	0.24–0.31
Steel Cast	1.9–2.1	0.74–0.76	–
Mild	2.1–2.3	0.80–0.89	0.25–0.31
Zinc	0.8–1.1	0.39–0.38	0.23–0.31
Glass Crown	0.6–0.78	0.26–0.32	0.25–0.27
Flint	0.5–0.6	0.2 –0.25	0.21–0.26

Viscosity of Water :

Temperature °C	Viscosity (Poise)	Temp. °C	Viscosity (Poise)
0	0.01793	60	0.00469
10	0.01311	70	0.00406
20	0.01000	80	0.00356
30	0.00800	90	0.00316
40	0.00657	100	0.00284
50	0.00550		

Surface tension of water :

Temperature °C	Surface tension Newton/m × 10^{-2}	Temperature °C	Surface tension Newton/m × 10^{-2}
0	7.5	60	6.56
10	7.35	70	6.38
20	7.21	80	6.20
30	7.06	90	6.02
40	6.89	100	5.82
50	6.73		

Velocity of Sound (meter/sec) :

Substance	Velocity	Substance	Velocity
Solid :		Liquid :	
Aluminium	5100	Alcohol	1275
Brass	3400	Mercury	1407
Copper	3560	Water	1447
Glass	5000	Gases :	
Iron	5130	Air	331.1
Steel	4990	Hydrogen	1262
		Nitrogen	338
		Oxygen	316

Referactive Index of Substances at 15°C for D–line of Sodium relative to air :

Substance	μ	Substance	μ
Solids :		Liquid :	
Glass crown	1.50	Aniline	1.590
Glass flint	1.55	Benzene	1.504
Diamond	2.417	Chloroform	1.53
Mica	1.56–1.69	Glycerin	1.449
Sugar	1.56	Sulphuric acid	1.47
Quartz	1.544	Turpentine	1.43
		Water	1.333

Wavelength of spectral lines (A.U.) :

Hydrogen :	Mercury :	Neon :
6562.784	4047 V	5765 y
4861.327	4078 V	5853 y
4340.466	4358 V	5882 o
4101.736	4916 bg	6507 r
Sodium :	4960 g	Cadmium :
5890 D_1	5461 g	6438
5896 D_2	5770 y	5085
Helium :	5791 y	4799
3889		4678
4026		4662
4471		
5876		

Specific rotation:

Optically active substance	Solvent	Specific rotation
Cane sugar	Water	+ 66.5°C
Glucose	Water	+ 52°
Fructose	Water	– 91°
Camphor	Alcohol	+ 41°
Turpentine	Pure	– 37°
Nicotine	Pure	– 122°

Thermal constants : (C.G.S. units)

Substance	Melting point, °C	Boiling point, °C	Specific heat	Latent heat	Thermal Conductivity
Aluminium	658	1800	0.22	92.4	0.504
Bismuth	269	1560	0.03	13.4	0.0194
Copper	1084	2360	0.093	43	0.918
Gold	1063	2360	0.032	16	0.7
Ice	0	100	0.5	79	0.005
Iron (wrought)	1530	2450	0.12	49	0.144
Lead	327	1755	0.031	5	0.083
Platinum	1774	4300	0.032	27	0.166
Siver	961	2152	0.056	22	0.974
Tungsten	3387	4830	0.03	......	0.35
Steel	1400	......	0.11	......	0.115
Benzene	5.5	80.2	0.34	95	3.3
Water	0	100	1.00	539	14.7
Mercury	−38.9	357	0.033	68	......
Ether	−132	34.6	0.56	88	3.1

Magnetic Elements :

Station	Dip	H oersted	Station	Dip	H oersted
Agra	40° 41'	0.348	Gorakhpur	39° 40'	0.358
Aligarh	41° 50'	0.346	Jaipur	40° 30'	0.347
Allahabad	37° 10'	0.353	Kanpur	38° 39'	0.363
Delhi	42° 52'	0.345	Khurja	42° 10'	0.343
Meerut	43° 30	0.339	Lucknow	40° 00'	0.354
Varanasi	37° 10'	0.364	Bareilly	42° 20'	0.344
Dehra Dun	45° 50'	0.332	Bombay	25° 30'	0.376
Gwalior	39° 00'	0.353	Calcutta	31° 30'	0.382

Wire Resistances :

S.W.G. No.	Diameer m.m.	Resistance (ohm/meter)		
		Copper	Constantan	Manganin
10	3.25	0.0021	0.057	0.051
12	2.64	0.0032	0.086	0.077
14	2.03	0.0054	0.146	0.131
16	1.63	0.0083	0.228	0.205
18	1.22	0.0148	0.495	0.361
20	0.914	0.0260	0.722	0.645
22	0.711	0.0235	1.20	1.07
24	0.559	0.070	1.93	1.73
26	0.457	0.105	0.89	2.58
28	0.374	0.155	4.27	3.82
30	0.315	0.222	6.08	5.45
32	0.274	0.293	8.02	7.18
34	0.234	0.404	11.1	9.9
36	0.193	0.590	16.2	14.5
38	0.152	0.950	26.2	23.2
40	0.122	1.48	40.6	36.3

Specific Resistance and Temperature Coefficient of Resistance :

Substance	Composition	Sp. resistance ohm × cm × 10^{-6}	Temperature coefficient of resistance per °C × 10^{-4}
Constantan	60% Cu, 40% Zn	49.0	− 0.4 to + 0.1
Silver		1.64	36.0
German Silver	62% Cu, 15% Ni, 22% Zn	26.6	2.3 to 6.0
Copper		1.78	42.8
Nichrome	80% Ni, 20% Cr	110.0	1.7
Mercury	......	99.8	9.0
Brass	70% Cu, 30%Zn	6.6	10.0
Platinum	......	11.0	37.0
Manganin	84% Cu, 4% ni, 12% Mn	43.0	0.02 to 0.5

Electro-chemical Equivalent :

Element	Atomic weight	Valency	E.C.E. gm./coulomb
Aluminium	26.97	3	0.0000935
Oxygen	16.00	2	0.0000829
Silver	107.88	1	0.0011180
Copper	63.57	2	0.0003294
Zinc	65.38	2	0.0003383
Gold	197.20	3	0.0006809
Nickle	58.69	2	0.0000304
Hydrogen	1.007	1	0.0000105

Thermo E.M.F.

Thermocouple	Thermo e.m.f.
Copper-constantan	41.8 Microvolt/°C
Copper–Iron	8.6 Microvolt/°C
Antimony–Bismuth	113 Microvolt/°C

Internal Resistance and E.M.F. of Cells :

Cell	Internal resistance (ohms)	E.M.F. (volts)
Cadmium	900 Ω (very high)	1.0183 volt at 20°C
Daniel	3–4 Ω (fairly constant)	1.08
Leclanche	High, increases with usage	
Alkali accumulator	Low	1.46
Lead acumulator	Very Low	2.1

COMMON LOGARITHMS

$\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δm +	1	2	3	4	5	6	7	8	9
												ADD								
10	·0000	0043	0086	0128	0170	0212					42	4	8	13	17	21	25	29	34	38
						0212	0253	0294	0334	0374	40	4	8	12	16	20	24	28	32	36
11	·0414	0453	0492	0531	0569	0607					39	4	8	12	16	19	23	27	31	35
						0607	0645	0682	0719	0755	37	4	7	11	15	19	22	26	30	33
12	·0792	0828	0864	0899	0934	0969					35	4	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	34	3	7	10	14	17	20	24	27	31
13	·1139	1173	1206	1239	1271	1303					33	3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	32	3	6	10	13	16	19	22	26	29
14	·1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	30	3	6	9	12	15	18	21	24	27
15	·1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	28	3	6	8	11	14	17	20	22	25
16	·2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	26	3	5	8	10	13	16	18	21	23
17	·2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	25	2	5	7	10	12	15	17	20	22
18	·2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	24	2	5	7	10	12	14	17	19	22
19	·2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	22	2	4	7	9	11	13	15	18	20
	·3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	21	2	4	6	8	11	13	15	17	19
21	·3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	20	2	4	6	8	10	12	14	16	18
22	·3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	19	2	4	6	8	10	11	13	15	17
23	·3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	18	2	4	5	7	9	11	13	14	16
24	·3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	18	2	4	5	7	9	11	13	14	16
25	·3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	17	2	3	5	7	9	10	12	14	15
26	·4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	16	2	3	5	6	8	10	11	13	14
27	·4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	16	2	3	5	6	8	10	11	13	14
28	·4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	15	2	3	5	6	8	9	11	12	14
29	·4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	15	1	3	4	6	7	9	10	12	13
30	·4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	14	1	3	4	6	7	8	10	12	13
31	·4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	14	1	3	4	6	7	8	10	11	13
	·5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	13	1	3	4	5	7	8	9	10	12
33	·5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	13	1	3	4	5	6	8	9	10	12
34	·5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	13	1	3	4	5	6	8	9	10	12
35	·5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	12	1	2	4	5	6	7	8	10	11
36	·5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	12	1	2	4	5	6	7	8	10	11
37	·5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	12	1	2	4	5	6	7	8	10	11
38	·5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	11	1	2	3	4	6	7	8	9	10
39	·5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	11	1	2	3	4	6	7	8	9	10
40	·6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	11	1	2	3	4	5	7	8	9	10
41	·6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	10	1	2	3	4	5	6	7	8	9
42	·6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	10	1	2	3	4	5	6	7	8	9
43	·6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	10	1	2	3	4	5	6	7	8	9
44	·6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	10	1	2	3	4	5	6	7	8	9
45	·6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	10	1	2	3	4	5	6	7	8	9
46	·6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	9	1	2	3	4	5	5	6	7	8
47	·6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	9	1	2	3	4	5	5	6	7	8
48	·6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	9	1	2	3	4	4	5	6	7	8
49	·6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	9	1	2	3	4	4	5	6	7	8

	No.	log
π =	3·14159	0·49715
e =	2·71828	0·43429

ln x = $\log_e x$ = (1/M) $\log_{10} x$
log x = $\log_{10} x$ = M $\log_e x$

	No.	log
(1/M) =	2·30259	0·36222
M =	0·43429	1·63778

p	1	2	3	4	5	6	7	8	9	10
log e^p	0·4343	0·8686	1·3029	1·7372	2·1715	2·6058	3·0401	3·4744	3·9087	4·3429
log e^{-p}	1·5657	1·1314	2·6971	2·2628	3·8285	3·3942	4·9599	4·5256	4·0913	5·6571

COMMON LOGARITHMS

$\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δm +	1	2	3	4	5	6	7	8	9
												ADD								
50	·6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	9	1	2	3	4	4	5	6	7	8
51	·7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	8	1	2	2	3	4	5	6	6	7
52	·7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	8	1	2	2	3	4	5	6	6	7
53	·7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	8	1	2	2	3	4	5	6	6	7
54	·7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	8	1	2	2	3	4	5	6	6	7
55	·7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	8	1	2	2	3	4	5	6	6	7
56	·7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	8	1	2	2	3	4	5	6	6	7
57	·7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	8	1	2	2	3	4	5	6	6	7
58	·7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	8	1	2	2	3	4	5	6	6	7
59	·7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	7	1	1	2	3	4	4	5	6	6
60	·7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	7	1	1	2	3	4	4	5	6	6
61	·7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7	1	1	2	3	4	4	5	6	6
62	·7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	7	1	1	2	3	3	4	5	6	6
63	·7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	7	1	1	2	3	3	4	5	6	6
64	·8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	7	1	1	2	3	3	4	5	6	6
65	·8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	7	1	1	2	3	3	4	5	6	6
66	·8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	7	1	1	2	3	3	4	5	6	6
67	·8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	6	1	1	2	2	3	4	4	5	5
68	·8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	6	1	1	2	2	3	4	4	5	5
69	·8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	6	1	1	2	2	3	4	4	5	5
70	·8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	6	1	1	2	2	3	4	4	5	5
71	·8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	6	1	1	2	2	3	4	4	5	5
72	·8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	6	1	1	2	2	3	4	4	5	5
73	·8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	6	1	1	2	2	3	4	4	5	5
74	·8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	6	1	1	2	2	3	4	4	5	5
75	·8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	6	1	1	2	2	3	4	4	5	5
76	·8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	6	1	1	2	2	3	4	4	5	5
77	·8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	6	1	1	2	2	3	4	4	5	5
78	·8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	6	1	1	2	2	3	4	4	5	5
79	·8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	6	1	1	2	2	3	4	4	5	5
80	·9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	5	1	1	2	2	3	3	4	4	5
81	·9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	5	1	1	2	2	3	3	4	4	5
82	·9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	5	1	1	2	2	3	3	4	4	5
83	·9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	5	1	1	2	2	3	3	4	4	5
84	·9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	5	1	1	2	2	3	3	4	4	5
85	·9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	5	1	1	2	2	3	3	4	4	5
86	·9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	5	1	1	2	2	3	3	4	4	5
87	·9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	5	0	1	1	2	2	3	3	4	4
88	·9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	5	0	1	1	2	2	3	3	4	4
89	·9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	5	0	1	1	2	2	3	3	4	4
90	·9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	5	0	1	1	2	2	3	3	4	4
91	·9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	5	0	1	1	2	2	3	3	4	4
92	·9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	5	0	1	1	2	2	3	3	4	4
93	·9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	5	0	1	1	2	2	3	3	4	4
94	·9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	5	0	1	1	2	2	3	3	4	4
95	·9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	5	0	1	1	2	2	3	3	4	4
96	·9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	4	0	1	1	2	2	2	3	3	4
97	·9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	4	0	1	1	2	2	2	3	3	4
98	·9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	4	0	1	1	2	2	2	3	3	4
99	·9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	4	0	1	1	2	2	2	3	3	4

ANTILOGARITHMS

$\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δm	1	2	3	4	5	6	7	8	9
											+	ADD								
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	2	0	0	1	1	1	1	1	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	2	0	0	1	1	1	1	1	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	2	0	0	1	1	1	1	1	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	2	0	0	1	1	1	1	1	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	3	0	1	1	1	1	2	2	2	3
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	3	0	1	1	1	1	2	2	2	3
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	3	0	1	1	1	1	2	2	2	3
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	3	0	1	1	1	1	2	2	2	3
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	3	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	3	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	3	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	3	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	3	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	3	0	1	1	1	2	2	2	2	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	3	0	1	1	1	2	2	2	2	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	3	0	1	1	1	2	2	2	2	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	3	0	1	1	1	2	2	2	2	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	4	0	1	1	2	2	2	3	3	4
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	4	0	1	1	2	2	2	3	3	4
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	4	0	1	1	2	2	2	3	3	4
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	4	0	1	1	2	2	2	3	3	4
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	4	0	1	1	2	2	2	3	3	4
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	4	0	1	1	2	2	2	3	3	4
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	4	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	4	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	4	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	4	0	1	1	2	2	2	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	4	0	1	1	2	2	2	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	4	0	1	1	2	2	2	3	3	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	4	0	1	1	2	2	2	3	3	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	5	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	5	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	5	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	5	1	1	2	2	3	3	4	4	5
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	5	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	5	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	5	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	6	1	1	2	2	3	4	4	5	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	6	1	1	2	2	3	4	4	5	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	6	1	1	2	2	3	4	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	6	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	6	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	6	1	1	2	2	3	4	4	5	5
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	6	1	1	2	2	3	4	4	5	5
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	6	1	1	2	2	3	4	4	5	5
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	7	1	1	2	3	3	4	5	6	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	7	1	1	2	3	3	4	5	6	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	7	1	1	2	3	3	4	5	6	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	7	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	7	1	1	2	3	4	4	5	6	6

ANTILOGARITHMS

$\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δm	1	2	3	4	5	6	7	8	9
											+	ADD								
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	7	1	1	2	3	4	4	5	6	6
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	8	1	2	2	3	4	5	6	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	8	1	2	2	3	4	5	6	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	8	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	8	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	8	1	2	2	3	4	5	6	6	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	8	1	2	2	3	4	5	6	6	7
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	9	1	2	3	4	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	9	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	9	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	9	1	2	3	4	5	5	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	10	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	10	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	10	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	10	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	10	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	11	1	2	3	4	5	7	8	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	11	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	11	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	11	1	2	3	4	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	12	1	2	4	5	6	7	8	10	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	12	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	12	1	2	4	5	6	7	8	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	12	1	2	4	5	6	7	8	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	13	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	13	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	13	1	3	4	5	7	8	9	10	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	14	1	3	4	6	7	8	10	11	13
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	14	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	14	1	3	4	6	7	8	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	15	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	15	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	15	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	16	2	3	5	6	8	10	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	16	2	3	5	6	8	10	11	13	14
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	16	2	3	5	6	8	10	11	13	14
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	17	2	3	5	7	8	10	12	14	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	17	2	3	5	7	9	10	12	14	15
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	18	2	4	5	7	9	11	13	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	18	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	18	2	4	5	7	9	11	13	14	16
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	19	2	4	6	8	10	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	19	2	4	6	8	10	11	13	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	20	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	20	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	21	2	4	6	8	10	13	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	21	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	22	2	4	7	9	11	13	15	18	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	22	2	4	7	9	11	13	15	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	23	2	5	7	9	11	14	16	18	21

NATURAL SINES

	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	Mean Differences 4 5
0	.0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3 6 9	12 15
1	.0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3 6 9	12 15
2	.0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3 6 9	12 15
3	.0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3 6 9	12 15
4	.0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3 6 9	12 14
5	.0872	0899	0906	0924	0941	0958	0976	0993	1011	1028	3 6 9	12 14
6	.1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3 6 9	12 14
7	.1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3 6 9	12 14
8	.1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3 6 9	12 14
9	.1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3 6 9	12 14
10	.1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3 6 9	11 14
11	.1908	1925	1942	1959	1977	1994	2011	2088	2045	2062	3 6 9	11 14
12	.2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	3 6 9	11 14
13	.2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3 6 8	11 14
14	.2419	2436	2453	2470	2487	2304	2521	2538	2554	2571	3 6 8	11 14
15	.2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3 6 8	11 14
16	.2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3 6 8	11 14
17	.2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3 6 8	11 14
18	.3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3 6 8	11 14
19	.3256	3772	3289	3305	3322	3338	3355	3371	3387	3404	3 5 8	11 14
20	.3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3 5 8	11 14
21	.3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3 5 8	11 14
22	.3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3 5 8	11 14
23	.3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3 5 8	11 14
24	.4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3 5 8	11 13
25	.4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3 5 8	11 13
26	.4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3 5 8	10 13
27	.4540	4545	4571	4586	4602	4617	4633	4648	4664	4679	3 5 8	10 13
28	.4695	4710	4725	8741	4756	4772	4787	4802	4818	4833	3 5 8	10 13
29	.4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3 5 8	10 13
30	.5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3 5 8	10 13
31	.5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2 5 7	10 12
32	.5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2 5 7	10 12
33	.5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2 5 7	10 12
34	.5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2 5 7	10 12
35	.5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2 5 7	9 12
36	.5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2 5 7	9 12
37	.6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2 5 7	9 12
38	.6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2 5 7	9 11
39	.6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2 4 7	9 11
40	.6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2 4 7	9 11
41	.6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2 4 7	9 11
42	.6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2 4 6	9 11
43	.6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2 4 6	8 11
44	.6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2 4 6	8 10

NATURAL SINES

	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	Mean Differences 4 5
45	.7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2 4 6	8 10
46	.7391	7206	7218	7230	7242	7254	7266	7278	7290	7302	2 4 6	8 10
47	.7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2 4 6	8 10
48	.7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2 4 6	8 10
49	.7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	2 4 6	8 9
50	.7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2 4 6	7 9
51	.7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2 4 5	7 9
52	.7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2 4 5	7 9
53	.7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2 3 5	7 9
54	.8090	8100	8111	8121	8131	8139	8151	8161	8171	8181	2 3 5	7 8
55	.8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2 3 5	7 8
56	.8290	8300	8110	8320	8329	8329	8348	8358	8368	8377	2 3 5	6 8
57	.8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2 3 5	6 8
58	.8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2 3 5	6 8
59	.8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1 3 4	6 7
60	.8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1 3 4	6 7
61	.8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1 3 4	6 7
62	.8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1 3 4	5 7
63	.8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1 3 4	5 6
64	.8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1 3 4	5 6
65	.9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1 2 4	5 6
66	.9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1 2 3	5 6
67	.9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1 2 3	4 6
68	.9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1 2 3	4 5
69	.9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1 2 3	4 5
70	.9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1 2 3	4 5
71	.9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1 2 3	4 5
72	.9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1 2 3	3 4
73	.9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1 2 2	3 4
74	.9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1 2 2	3 4
75	.9659	9664	9668	9672	9677	9681	9686	9690	9694	9699	1 1 2	3 4
76	.9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1 1 2	3 3
77	.9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1 1 2	3 3
78	.9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1 1 2	2 3
79	.9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1 1 2	2 3
80	.9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0 1 1	2 2
81	.9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0 1 1	2 2
82	.9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0 1 1	2 2
83	.9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0 1 1	1 2
84	.9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0 1 1	1 2
85	.9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0 0 1	1 1
86	.9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0 0 1	1 1
87	.9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0 0 0	1 1
88	.9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0 0 0	0 0
89	.9998	9999	9999	9999	9999	1.000	1.000	1.000	1.000	1.000	0 0 0	0 0
90	1.000											

NATURAL COSINES

	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1'2'3'	4' 5'
0	1.000	1.000	1.000	1.000	1.000	1.000	.9999	9999	9999	9999	0 0 0	0 0
1	.9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0 0 0	0 0
2	.9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0 0 0	1 1
3	.9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0 0 1	1 1
4	.9976	9974	9973	9972	9971	9969	9969	9966	9965	9963	0 0 1	1 1
5	.9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0 1 1	1 2
6	.9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0 1 1	1 2
7	.9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0 1 1	2 2
8	.9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0 1 1	2 2
9	.9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0 1 1	2 2
10	9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1 1 2	2 3
11	.9816	9813	9810	9806	9803	9799	9796	9792	9789	9885	1 1 2	2 3
12	.9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	1 1 2	3 3
13	.9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	1 1 2	3 3
14	.9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	1 1 2	3 4
15	.9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	1 2 2	3 4
16	.9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	1 2 2	3 4
17	.9663	9558	9553	9548	9542	9537	9532	9527	9521	9516	1 2 3	3 4
18	.9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	1 2 3	4 5
19	.9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	1 2 3	4 5
20	9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	1 2 3	4 5
21	.9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	1 2 3	4 5
22	.9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	1 2 3	4 6
23	.9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	1 2 3	5 6
24	9135	9128	.9121	9114	9107	9100	9092	9085	9078	9070	1 2 4	5 6
25	9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	1 3 4	5 6
26	.8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	1 3 4	5 6
27	.8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	1 3 4	5 7
28	.8829	8821	8813	8805	8796	8788	8880	8771	8763	8755	1 3 4	6 7
29	.8746	8738	9729	8721	8712	8704	8695	8686	8678	8669	1 3 4	6 7
30	.8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	1 3 4	6 7
31	.8572	8563	8554	8545	8536	8526	8571	8508	8499	8490	2 3 5	6 8
32	.8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	2 3 5	6 8
33	.8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	2 3 5	6 8
34	.8290	8281	8271	8261	8251	8241	8231	8221	8211	8220	2 3 5	7 8
35	.8192	8181	8174	8161	8151	8141	8131	8121	8111	8100	2 3 5	7 8
36	.8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	2 3 5	7 9
37	.7966	7976	7965	7955	7944	7934	7923	7912	7902	7891	2 4 5	7 9
38	.7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	2 4 6	7 9
39	.7771	7760	7749	7738	7727	7716	7705	7694	7683	7672	2 4 6	7 9
40	.7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	2 4 6	8 9
41	.7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	2 4 6	8 10
42	.7431	7402	7408	7396	7385	7373	7361	7349	7337	7325	2 4 6	8 10
43	.7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	2 4 6	8 10
44	.7193	7181	7969	7157	7145	7133	7120	7108	7096	7083	2 4 6	8 10

NATURAL COSINES

	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	4 5
45	.7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2 4 6	8 10
46	.7391	7206	7218	7230	7242	7254	7266	7278	7290	7302	2 4 6	8 10
47	.7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2 4 6	8 10
48	.7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2 4 6	8 10
49	.7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	2 4 6	8 9
50	.7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2 4 6	7 9
51	.7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2 4 5	7 9
52	.7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2 4 5	7 9
53	.7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2 3 5	7 9
54	.8090	8100	8111	8121	8131	8139	8151	8161	8171	8181	2 3 5	7 8
55	.8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2 3 5	7 8
56	.8290	8300	8110	8320	8329	8329	8348	8358	8368	8377	2 3 5	6 8
57	.8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2 3 5	6 8
58	.8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2 3 5	6 8
59	.8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1 3 4	6 7
60	.8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1 3 4	6 7
61	.8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1 3 4	6 7
62	.8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1 3 4	5 7
63	.8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1 3 4	5 6
64	.8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1 3 4	5 6
65	.9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1 2 4	5 6
66	.9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1 2 3	5 6
67	.9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1 2 3	4 6
68	.9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1 2 3	4 5
69	.9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1 2 3	4 5
70	.9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1 2 3	4 5
71	.9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1 2 3	4 5
72	.9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1 2 3	3 4
73	.9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1 2 2	3 4
74	.9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1 2 2	3 4
75	.9659	9664	9668	9672	9677	9681	9686	9690	9694	9699	1 1 2	3 4
76	.9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1 1 2	3 3
77	.9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1 1 2	3 3
78	.9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1 1 2	2 3
79	.9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1 1 2	2 3
80	.9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0 1 1	2 2
81	.9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0 1 1	2 2
82	.9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0 1 1	2 2
83	.9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0 1 1	1 2
84	.9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0 1 1	1 2
85	.9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0 0 1	1 1
86	.9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0 0 1	1 1
87	.9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0 0 0	1 1
88	.9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0 0 0	0 0
89	.9998	9999	9999	9999	9999	1.000	1.000	1.000	1.000	1.000	0 0 0	0 0
90	.0000											

NATURAL TANGENTS

	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1	2	3	4	5
0	.0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	.0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	.0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	.0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	.0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	.0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	.1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	2	15
7	.1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	.1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	.1594	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	.1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	.1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	.2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	.2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	.2403	2512	2530	2549	2568	.2586	2605	2623	2642	2661	3	6	9	12	16
15	.2679	2698	2117	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	.2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	10	13	16
17	.3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	.3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	.3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20	.3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	.3839	3859	3879	3899	3919	3939	3959	3989	4000	4020	3	7	10	13	17
22	.4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	.4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	.4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	.4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	.4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	.5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	.5317	5340	5362	5384	54-7	5430	5452	5475	5498	5520	4	8	11	15	19
29	.5543	5566	5589	5612	5635	5638	5681	5704	5727	5750	4	8	12	15	19
30	.5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	.6009	6997	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	.6249	6032	6297	6322	6346	6371	.4395	6420	6445	6469	4	8	12	16	20
33	.6494	6273	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	.6745	6519	6796	6822	6847	6873	4899	6924	6694	6976	4	9	13	17	21
35	.7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	.7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	22
37	.7536	7563	7590	7618	7646	6773	7701	7729	7757	7785	5	9	14	18	22
38	.7813	7841	7869	7898	7926	7954	7883	8012	8040	8069	5	9	14	19	24
39	.8098	8127	8151	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	.8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	.8693	8724	8754	8785	8816	8847	8868	8910	8941	8972	5	10	16	21	27
42	.9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	.9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	.9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29

Practical Physics

NATURAL TANGENTS

	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1'	2'	3'	4'	5'
45	1.0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6	12	18	24	30
46	1.0355	0392	0248	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1.0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1.1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	27	33
49	1.1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1.1018	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	36
51	1.2349	2393	2437	2482	2527	2572	2617	2662	2708	2853	8	15	23	30	38
52	1.2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	24	31	39
53	1.3270	3319	3367	3416	3465	3514	3564	3613	3663	3813	8	16	25	33	41
54	1.3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1.4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1.4826	4882	4938	4994	5051	5108	5108	5224	5282	5340	10	19	29	38	48
57	1.5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	20	30	40	50
58	1.6003	6066	.5128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1.6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	56
60	1.7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12	24	36	48	60
61	1.8040	8115	8190	8265	8341	8418	8495	8672	8650	8728	13	26	38	51	64
62	1.8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1.9626	9711	9797	9883	9970	2.0057	2.0145	2.0233	2.0323	2.0413	15	29	44	58	73
64	2.0503	0594	0686	0778	0870	.0965	1060	1153	1251	1348	16	31	47	63	78
65	2.1445	1543	1642	1742	1842	1943	2045	2148	.2251	2355	17	34	51	68	85
66	2.2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	73	92
67	2.3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2.4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2.6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71	95	119
70	2.7475	7625	7776	7929	8083	8239	8397	8556	7816	8878	26	52	78	104	131
71	2.9042	9208	9375	9544	9714	9887	3.0061	3.0237	3.0415	3.0595	29	58	87	116	145
72	3.0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96	129	161
73	3.2709	2914	3122	3332	3544	3759	3977	4196	4420	.4646	36	72	108	144	180
74	3.4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	163	204
75	3.7321	7583	7848	8118	8391	8667	8947	923 2	9520	9812	46	93	139	186	232
76	4.0108	0408	0713	1022	1335	1653	1976	2303	2635	2972					
77	4.3315	3662	4015	4374	4737	.5107	5483	5864	6252	6646	53	107	160	213	267
78	4.7046	7453	7867	8288	8716	9152	9594	5.0045	5.0504	5.0970					
79	5.1446	1929	2422	2924	3435	3955	4486	5026	5578	6140					
80	56713	7297	7894	8502	4124	9758	6.0405	6.1.06	6.1742	6.2432					
81	6.3138	3859	4596	5350	6122	6912	7720	8548	9395	7.0264	Mean differences cease to be sufficiently accurate				
82	7.1154	2066	3002	3962	4847	5912	6996	8062	9158	8.0285					
83	8.1443	2636	3863	5126	6427	7769	9152	9.0579	9.2052	9.3572					
84	9.5144	9.677	9.845	10.02	10.20	10.39	10.58	10.78	10.99	11.20					
85	11.43	11.66	11.91	12.16	12.43	12.71	13.00	13.30	13.62	13.95					
86	14.30	14.67	15.06	15.46	15.89	16.35	16.83	17.34	17.89	18.46					
87	19.30	19.74	20.45	21.20	22.02	22.90	23.86	24.90	26.03	27.27					
88	28.64	30.14	31.82	33.69	35.80	38.19	40.92	44.07	47.74	52.08					
89	57.29	63.66	71.62	81.85	95.49	114.6	143.2	141.0	286.5	573.0					
90	∞														

POWERS, ROOTS AND RECIPROCALS

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	$\sqrt{10n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
1	1	1	1	1	3.162	2.154	4.642	1
2	4	8	1.414	1.260	4.472	2.714	5.848	.5000
3	9	27	1.732	1.442	5.477	3.107	6.694	.3333
4	16	64	2	1.587	6.325	3.420	7.368	.2500
5	25	125	2.236	1.710	7.071	3.684	7.937	.2000
6	36	216	2.449	1.817	7.746	3.915	8.434	.1667
7	49	343	2.646	1.913	8.367	4.121	8.879	.1429
8	64	512	2.828	2.000	8.944	4.309	9.283	.1250
9	81	729	3.000	2.080	9.487	4.481	9.655	.1111
10	100	1000	3.162	2.154	10.000	4.642	10.000	.1000
11	121	1331	3.317	2.224	10.488	4.791	10.323	.09091
12	144	1728	3.464	2.289	10.954	4.932	10.627	.08333
13	169	2197	3.666	2.351	11.402	5.066	10.914	.07692
14	196	2744	3.742	2.410	11.832	5.192	11.187	.07143
15	225	3375	3.873	2.466	12.247	5.313	11.447	.06667
16	256	4096	4.000	2.520	12.649	5.429	11.696	.06250
17	289	4913	4.123	2.571	13.038	5.540	11.935	.05882
18	324	5832	4.243	2.621	13.416	5.646	12.164	.05556
19	361	6859	4.359	2.668	13.784	5.749	12.386	.05263
20	400	8000	4.472	2.714	14.142	5.848	12.599	.05000
21	441	9261	4.583	2.759	14.491	5.944	12.806	.04762
22	484	10648	4.690	2.802	14.832	6.037	13.006	.04545
23	529	12167	4.796	2.844	15.166	6.127	13.200	.04348
24	576	13824	4.899	2.884	15.492	6.214	13.389	.04167
25	625	15625	5.000	2.924	15.811	6.300	13.572	.04000
26	676	17576	5.099	2.962	16.125	6.383	13.751	.03846
27	729	19683	5.196	3.000	16.432	6.463	13.925	.03704
28	784	21952	5.292	3.037	16.733	6.542	14.095	.03571
29	841	24389	5.385	3.072	17.029	6.619	14.260	.03448
30	900	27000	5.477	3.107	17.321	6.694	14.422	.03333
31	961	29791	5.568	3.141	17.607	6.768	14.581	.03226
32	1024	32768	5.657	3.175	17.889	6.840	14.736	.03125
33	1089	35937	5.745	3.208	18.166	6.910	14.888	.03030
34	1156	39304	5.831	3.240	18.439	6.850	15.037	.02941
35	1225	42875	5.916	3.271	18.708	7.047	15.183	.02857
36	1296	46656	6.000	3.302	18.974	7.114	15.326	.02778
37	1369	50653	6.083	3.332	19.235	7.179	15.467	.02703
38	1444	54872	6.164	3.382	19.494	7.243	15.605	.02632
39	1521	59319	6.245	3.391	19.748	7.306	15.741	.02564
40	1600	64000	6.325	3.420	20.000	7.368	15.874	.02500
41	1681	68021	6.403	3.448	20.248	7.429	16.005	.02439
42	1764	74088	6.481	3.476	20.494	7.489	16.134	.02381
43	1849	79507	6.557	3.503	20.736	7.548	16.261	.02326
44	1936	85184	6.633	3.530	20.976	7.606	16.386	.02273
45	2025	91125	6.708	3.557	21.213	7.663	16.510	.02222
46	2116	97336	6.782	3.583	21.448	7.719	16.631	.02174
47	2209	103823	6.856	3.609	21.679	7.775	16.751	.02128
48	2304	110592	6.928	3.634	21.909	7.830	16.869	.02083
49	2401	117649	7.000	3.659	22.136	7.834	16.985	.02041
50	2500	125000	7.071	3.684	22.361	7.937	17.100	.02000

POWERS, ROOTS AND RECIPROCALS

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	$\sqrt{10n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
51	2601	132651	7.141	3.708	22.583	7.990	17.213	.01961
52	2704	140608	7.211	3.733	23.804	8.041	17.325	.01923
53	2809	148877	7.280	3.756	23.022	8.093	17.435	.01887
54	2916	157464	7.348	3.780	23.238	8.143	17.544	.01852
55	3025	165375	7.416	3.803	23.452	8.193	17.652	.01818
56	3136	175616	7.483	3.826	23.664	8.243	17.758	.01786
57	3249	185193	7.550	3.849	23.875	8.291	17.863	.01754
58	3364	195112	7.616	3.871	24.083	8.340	17.967	.01724
59	3481	205379	7.681	3.893	24.290	8.387	18.070	.01695
60	3600	216000	7.746	3.915	24.485	8.434	18.171	.01667
61	3721	226981	7.810	3.936	24.698	8.481	18.272	.01639
62	3844	238328	7.874	3.958	24.900	8.527	18.371	.01613
63	3969	250047	7.937	3.979	25.100	8.573	18.469	.01587
64	4006	262144	8.000	4.000	25.298	8.618	18.566	.01562
65	4225	274625	8.062	4.021	25.485	8.662	18.663	.01538
66	4056	287496	8.124	4.061	25.690	8.707	18.758	.01515
67	4489	300763	8.185	4.062	25.884	8.750	18.852	.01493
68	4624	314432	8.246	4.082	26.077	8.794	18.945	.01471
69	4761	328509	8.307	4.102	26.268	8.837	19.038	.01449
70	4900	343000	8.367	4.121	26.458	8.879	19.129	.01429
71	5041	357911	8.426	4.141	26.646	8.921	19.220	.01408
72	5184	373248	8.485	4.160	26.833	8.963	19.310	.01389
73	5329	389057	8.544	4.179	27.019	9.004	19.399	.01370
74	5476	405224	8.602	4.198	27.203	9.045	19.487	.01351
75	5625	421875	8.660	4.217	27.386	9.086	19.574	.01333
76	5776	438976	8.718	4.236	27.568	9.126	19.661	.01316
77	5929	456533	8.775	4.254	27.749	9.166	19.747	.01299
78	6084	474552	8.832	4.273	27.928	9.205	19.832	.01282
79	6241	493039	8.888	4.291	28.107	9.244	19.916	.01266
80	6400	512000	8.944	4.309	28.284	9.283	20.000	.01250
81	6561	531441	9.000	4.327	28.460	9.322	20.083	.01235
82	6724	551368	9.055	4.344	28.636	9.360	20.165	.01220
83	6889	571787	9.110	4.362	28.810	9.398	20.247	.01205
84	7056	591702	9.163	4.380	28.983	9.435	20.328	.01190
85	7225	614125	9.220	4.397	29.155	9.473	20.408	.01176
86	7396	636056	9.274	4.414	29.326	9.510	20.488	.01163
87	7569	658503	9.327	4.431	29.496	9.546	20.567	.01149
88	7744	681472	9.381	4.443	29.665	9.583	20.646	.01136
89	7921	704969	9.434	4.465	29.833	9.619	20.724	.01124
90	8100	729000	9.478	4.481	30.000	9.655	20.801	.01111
91	8281	753571	9.539	4.498	30.166	9.691	20.878	.01099
92	8464	778633	9.590	4.514	30.332	9.726	20.954	.01087
93	8649	804357	9.644	4.531	30.496	9.761	21.029	.01075
94	8836	830584	9.695	4.547	30.659	9.796	21.105	.01064
95	9025	857875	9.747	4.563	30.822	9.830	21.179	.01053
96	9216	884736	9.798	4.579	30.984	9.865	21.253	.01042
97	9409	912673	9.849	4.595	31.145	9.899	21.327	.01031
98	9604	941192	9.899	4.610	31.305	9.933	21.400	.01020
99	9801	970299	9.950	4.626	31.464	9.967	21.472	.01010
100	10000	1000000	10.000	4.642	31.623	10.000	21.544	.01000

REFRACTIVE INDEX OF A PRISM

Aim:

To determine the refractive index of a given prism by using a Na Light.

Apparatus Required:

Spectrometer, prism, mercury vapour lamp, spirit level and reading lens.

Formula Used:

The refractive index μ of the prism is given by the following formula:

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Where A = angle of the prism, δm = angle of minimum deviation.

Procedure:

The following initial adjustments of the spectrometer are made first.

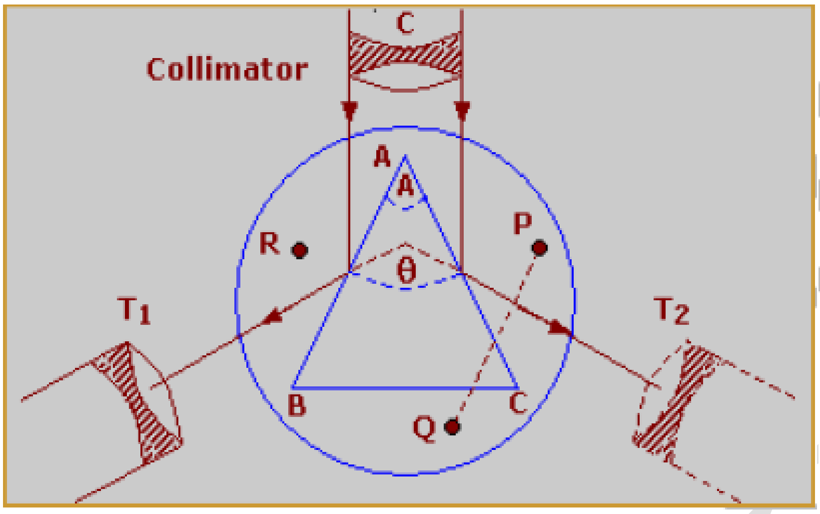
• The spectrometer and the prism table are arranged in horizontal position by using the levelling screws.
• The telescope is turned towards a distant object to receive a clear and sharp image.
• The slit is illuminated by a mercury vapour lamp and the slit and the collimator are suitably adjusted to receive a narrow, vertical image of the slit.
• The telescope is turned to receive the direct ray, so that the vertical slit coincides with the vertical crosswire.

(A) Measurement of the angle of the prism:

• Determine the least count
• Place the prism on the prism table with its refracting angle A towards the collimator and with its refracting edge A at the centre. In this case some of the light falling on each face will be reflected and can be received with the help of the telescope.
• The telescope is moved to one side to receive the light reflected from the face AB and the cross wires are focused on the image of the slit. The readings of the two verniers are taken.
• The telescope is moved in other side to receive the light reflected from the face AC and again the cross wires are focused on the image of the slit. The readings of the two verniers are taken.
• The angle through which the telescope is moved; or the difference in the two positions gives twice of the refracting angle A of the prism. Therefore half of this angle gives the refracting angle of the prism.

(B) Measurement of the angle of minimum deviations:

• Place the prism so that its centre coincides with the centre of the prism table and light falls on one of the polished faces and emerges out of the other polished face, after refraction. In this position the spectrum of light is obtained.
• The spectrum is seen through the telescope and the telescope is adjusted for minimum deviation position for a particular colour (wavelength) in the following way: Set up telescope at a particular colour and rotate the prism table in one direction, of course the telescope should be moved in such a way to keep the spectral line in view. By doing so a position will come where a spectral line recede in opposite direction although the rotation of the table is continued in the same direction. The particular position where the spectral line begins to recede in opposite direction is the minimum deviation position for that colour. Note the readings of two verniers.
.• Remove the prism table and bring the telescope in the line of the collimator. See the slit directly through telescope and coincide the image of slit with vertical crosswire. Note the readings of the two verniers.
• The difference in minimum deviation position and direct position gives the angle of minimum deviation for that colour.
• The same procedure is repeated to obtain the angles of minimum deviation for the other Colours.



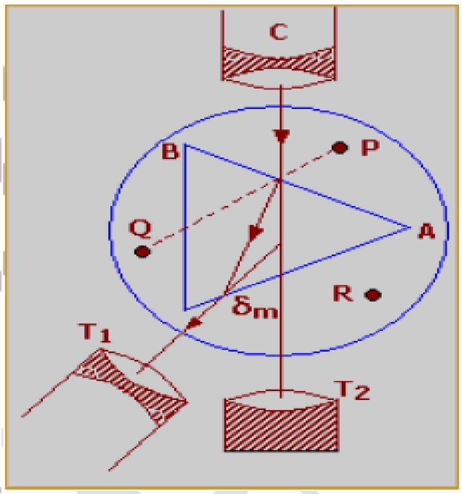


Figure: Left: Arrangement to determine the angle of prim.
Right: Arrangement to determine the angle of minimum deviation.

Observations:

(i) Value of the one division of the main scale = ……… degrees
Total number of vernier divisions = ……….
Least count of the vernier = ………. degrees = ……… second

(ii) Table for the angle (A) of the prism.

S.No	Vernier	Telescope reading for reflection from first face			Telescope reading for reflection from second face			Difference θ = a - b = 2A	Mean value of 2A	A	Mean A degrees
		MSR	VSR	TR (a)	MSR	VSR	TR (b)				
1	V_1								}		
	V_2										
2	V_1								}		
	V_2										
3	V_1								}		
	V_2										

MSR = Main Scale Reading, VSR = Vernier Scale Reading, TR = MSR+VSR = Total Reading.

(iii) Table for the angle of minimum deviation (δm).

S.No	Colour	Vernier	Telescope reading for minimum deviation			Telescope reading for direct image			Difference $\delta_m = a - b$	Mean value of δ_m
			MSR	VSR	TR (a)	MSR	VSR	TR (b)		
1	Violet	V_1								}
		V_2								
2	Yellow	V_1								}
		V_2								
3	Red	V_1								}
		V_2								

MSR = Main Scale Reading, VSR = Vernier Scale Reading, TR = MSR+VSR = Total Reading.

Calculations:

Refractive index for yellow = …………

Angle of minimum deviation for red = ………..
Refractive index for red = …………..
Result: Refractive index for the material of the prism ______

DISPERSIVE POWER OF A PRISM

Aim:
To determine the dispersive power of a prism using Hg light

Apparatus:
A spectrometer, a glass prism, mercury lamp, reading lamp and a magnifying lens.

Formula used: The dispersive power of the medium of the prism is given by

$$\omega = \frac{\mu_b - \mu_r}{\mu_y - 1}$$

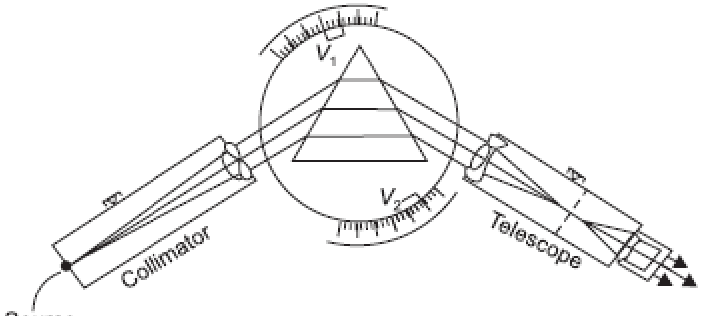
Where μb and μr are the refractive indices of the medium for blue and red lines respectively and μy refers to the refractive index for the *D* yellow line of sodium and may be written as:

$$\mu_y = \frac{\mu_b + \mu_r}{2}$$

The refractive indices μb and μr can be determined by using the formulae

$$\mu_r = \frac{\sin(A + \delta_r)/2}{\sin A/2}, \quad \mu_b = \frac{\sin(A + \delta_b)/2}{\sin A/2}$$

Where *A* is the angle of the prism and *δ*b and *δ*r are the angles of minimum deviation for the blue and red respectively.



Schematic diagram of the spectrometer

Manipulations:
1. Determine the vernier constant of the spectrometer.
2. Turn the telescope towards some brightly illuminated white background and move the eyepiece in or out till the cross-wire is sharply focused.
3. Switch on the neon lamp.
4. Bring the telescope and collimator in the same straight line and move the lamp right and left and up and down and fix its position when the illumination of the slit is maximum.
5. If the image of the slit is not bisected by the horizontal cross-wire in the telescope, adjust the leveling screws of the telescope or collimator till the slit is bisected.
6. Place the prism in the centre of the small prism table in such a way that one of its refracting face is at right angle to the line joining two of the levelling screws on the small prism table.

Optical Leveling:

7. Turn the table till the edge of the prism is opposite to the middle of the collimator lens. The image of slit will now be reflected from each of the two faces.
8. First get the image of the slit from that face of the prism, which has been kept at right angles to the line joining the two leveling screws on the prism table. If it is not bisected by the horizontal cross-wire it should be made to do so by adjusting either of the two screws. This is done to ensure that the faces of the prism are vertical.
9. Now view the slit through the telescope, as it is reflected from the other face of the prism. If it is not bisected, adjust the third screw. This operation makes the edge of the prism vertical and parallel to the slit.
10. The prism table is thus leveled and the two faces of the prism are made vertical.
11. Turn the prism table till the beam of parallel light from the collimator enters the prism at one face and emerges from the other. Now the refractive image of the slit will be seen. The prism table is moved in a direction to increase the angle of incidence. As we increase the angle of incidence, the refractive ray will move in a particular direction. At one particular angle of incidence, the refractive ray will cease to move. This gives the position of minimum deviation for the prism. If the prism is moved still further, the refractive ray will begin to move in opposite direction. Turn the telescope a little to one side of the image and fix it. It is evident that there are now two positions of the prism, one on each side of that of minimum deviation, which will bring the image of the line again into view in the center of the field of the telescope.
12. The prism is first turned to the position where the angle of incidence is greater than that corresponding to minimum deviation. The telescope is now focused while looking at the spectrum through the telescope.
13. Now rotate the prism table in the opposite direction till the image is again visible through the telescope.
14. Focus the collimator.
15. Turn the prism table again so as to increase the angle of incidence till the refracted rays after going out of the field of view are again visible.
16. Focus the telescope.
17. Again rotate the prism table so as to decrease the angle of incidence and when the image reappears focus the collimator.
18. If all the above operations have been performed correctly, you will find that the refracted image will always be in sharp focus, no matter in which direction the prism is turned. This is known as Schuster's method of focusing the telescope and collimator.
19. Find the angle of the prism.
20. Find the angle of minimum deviation for bright red and greenish blue line of the mercury spectrum.

Observations:

1. Vernier constant of the spectrometer =
2. Readings for the angle of the prism 'A

Sl No.	Readings for the Image Reflected				2A	A
	From Right Face		From Left Face		c – a d – b	
	Venier A a	Venier B b	Venier A c	Venier B d		
1.						
2.						
3.						

Mean A =

3. Readings for the angle of minimum deviation

Sl. no.	Colour of Light	Direct Reading		Reading for the Position of Minimum Deviation		δ_m
		A	B	A	B	
1.	Red					
2.	Red					
3.	Red					
1.	Blue					
2.	Blue					
3.	Blue					

Mean: δ_m (red) = δ_r =, δ_m (Blue) = δ_b =

Calculations :

$$\mu_r = \frac{\sin(A+\delta_r)/2}{\sin A/2} =$$

$$\mu_b = \frac{\sin(A+\delta_b)/2}{\sin A/2}$$

$$\mu_y = \frac{\mu_r+\mu_b}{2} =$$

$$\omega = \frac{\mu_b-\mu_r}{\mu_y-1}$$

Result:

The dispersive power of a prism =

RESOLVING POWER OF PRISM

Aim :

To determine the resolving power of a prism.

Apparatus Required:

Spectrometer, prism, prism clamp, mercury lamp, lens.

Principle:

If a spectrograph can just resolve two lines near wavelength with a separation of, the resolving power is defined as $\lambda/\Delta\lambda$.

Resolving power for yellow and blue is given by

$$\omega = \frac{nb-ny}{n-1}$$

Where n_b and n_y are the refractive index of blue and yellow, and $n = \frac{nb+ny}{2}$

Procedure:

Preliminary adjustments:

1. Focus Telescope on distant object.

2. When focus is correct, start button is activated. Then click Start button.
3. Switch on the light by clicking Switch On Light button.
4. Focus the slit using Slit focus slider.
5. Adjust the slit width using Slit width slider.
6. Coincide the slit with cross wire in the telescope.

Performing Real Lab:

1. Turn the telescope towards the white wall or screen and looking through eye-piece, adjust its position till the cross wires are clearly seen.
2. Turn the telescope towards window, focus the telescope to a long distant object.
3. Place the telescope parallel to collimator.
4. Place the collimator directed towards sodium vapour lamb. Switch on the lamp.
5. Focus collimator slit using collimator focusing adjustment.
6. Adjust the collimator slit width.
7. Place prism table, note that the surface of the table is just below the level of telescope and collimator.
8. Place spirit level on prism table. Adjust the base leveling screw till the bubble come at the centre of spirit level.
9. Clamp the prism holder.
10. Clamp the prism in which the sharp edge is facing towards the collimator, and base of the prism is at the clamp.

Least Count of Spectrometer:

One main scale division (N) =...............minute
Number of divisions on vernier (v) = ...
L.C $= \frac{V}{C}$ = ...minute

To determine the Angle of minimum deviation:

Direct method :

Performing simulator:

1. Rotate prism table so as to get the refracted light through the prism.
2. Make the slit coincide with telescope cross wire.
3. Slowly rotate the vernier table by using vernier fine adjusting slider.
4. Note the position where the slit is stationary for some moment.
5. Using telescope fine adjusting slider, make coincide the slit with cross wire.

Performing Real Lab:

1. Rotate the prism table so that the light from the collimator falling on one of the face of the prism and emerges through the other face.
2. The telescope is turned to view the refracted image of the slit on the other face.
3. The vernier table is slowly turned in such a direction that the image of slit is move directed towards the directed ray; ie., in the direction of decreasing angle of deviation.
4. It will be found that at a certain position, the image is stationary for some moment. Vernier table is fixed at the position where the image remains stationary.
5. Note the readings on main scale and vernier scale.
6. Carefully remove the prism from the prism table.
7. Turn the telescope parallel to collimator, and note the direct ray readings.

8. Find the difference between the direct ray readings and deviated readings. This angle is called angle of minimum deviation (D).

To determine the Resolving power of prism :

1. Rotate the vernier table so as to fall the light from the collimator to one face of the prism and emerged through another face. (refer the given figure).
2. The emerged ray has different colors.
3. Turn the telescope to each color, and note the readings for different colors.
4. Remove the prism, hence note direct ray reading.
5. Find the angle of minimum deviation for different color.(Say ,violet, blue, green, yellow).
6. Find the refractive index for these colors. Using equation (3).
7. Resolving power for yellow and blue

$$\omega = \frac{nb - ny}{n-1}$$

Where n_b and n_y are the refractive index of blue and yellow, and $n = \frac{nb+ny}{2}$

Line	Vernier	Refracted ray readings	Direct readings	Difference (Minimum Deviation)	Mean D	n
	V_1					
	V_2					
	V_1					
	V_2					
	V_1					
	V_2					
	V_1					
	V_2					

Refractive index for the line ________ n1 =
Refractive index for the line ________ n2 =
Average refractive index $n = \frac{n1+n2}{2}$
Resolving power for ______ and ______ line = $\omega = \frac{n2-n1}{n-1}$

Result:

Angle of the Prism =……………………………….Degrees
Angle of minimum deviation of the prism =……………………………….Degrees
Refractive index of the material of the prism =……………………………….
Dispersive power of the prism =……………………………….

SPECTROMETER – DETERMINATION OF CAUCHY'S CONSTANT

Aim:

To determine the value of Cauchy constants of a material of a prism

Apparatus Required:

Spectrometer, Prism, Mercury vapour lamp.

Formula

The refractive index n of the material of the prism for a wavelength λ is given by.

$$n = A + \frac{B}{\lambda^2}$$

Where A and B are called Cauchy's constants for the prism.
If the refractive indices n1 and n2 for any two known wavelength λ1 and λ2 are determined by a spectrometer, the Cauchy's constants A and B can be calculated from the above equation.

Procedure:

Preliminary adjustments:

1. Focus Telescope on distant object.
2. When focus is correct, start button is activated. Then click Start button.
3. Switch on the light by clicking Switch On Light button.
4. Focus the slit using Slit focus slider.
5. Adjust the slit width using Slit width slider.
6. Coincide the slit with cross wire in the telescope.

Performing Real Lab:

1. Turn the telescope towards the white wall or screen and looking through eye-piece, adjust its position till the cross wires are clearly seen.
2. Turn the telescope towards window, focus the telescope to a long distant object.
3. Place the telescope parallel to collimator.
4. Place the collimator directed towards sodium vapor lamb. Switch on the lamp.
5. Focus collimator slit using collimator focusing adjustment.
6. Adjust the collimator slit width.
7. Place prism table, note that the surface of the table is just below the level of telescope and collimator.
8. Place spirit level on prism table. Adjust the base leveling screw till the bubble come at the centre of spirit level.
9. Clamp the prism holder.
10. Clamp the prism in which the sharp edge is facing towards the collimator, and base of the prism is at the clamp.

Least Count of Spectrometer :

One main scale division (N) =................minute

Number of divisions on vernier (v) = ...

L.C $= \frac{N}{V} =$ ....minute

To determine the angle of the Prism:

1. Prism table is rotated in which the sharp edge of the prism is facing towards the collimator.

2. Rotate the telescope in one direction up to which the reflected ray is shown through the telescope.
3. Note corresponding main scale and vernier scale reading in both vernier (vernier I and vernier II).
4. Rotate the telescope in opposite direction to view the reflected image of the collimator from the second face of prism.
5. Note corresponding main scale and vernier scale reading in both vernier(vernier I and vernier II).
6. Find the difference between two readings, i.e.θ
7. Angle of prism, A=θ/2

Reading of reflected ray from	Vernier 1			Vernier 2		
	MSR	VSR	Total	MSR	VSR	Total
face 1 (say a)						
face 2 (say b)						
Difference between a & b						

Mean θ =.................Degrees

Angle of prism =.................Degrees

To determine the Cauchy's constants for the prism:

Performing Real Lab

The angle of the prism A and the angle of minimum deviation D for different wave length are determined. From this the refractive index n for these colours are calculated. Taking the value of λ from the mathematical table, the Cauchy's constants A and B are calculated for different pairs of spectral colours using the equation.

The Cauchy's constants can also be determined graphically. A graph is drawn with n along the y-axis and 1/λ2 along x-axis with zero as the origin for both axes. The graph is a straight line. The Y intercept gives A and the slope gives B.

Performing simulator :

1. Rotate the vernier table so as to fall the light from the collimator to one face of the prism and emerged through another face. (refer the given figure).
2. The emerged ray has different colors.
3. Turn the telescope to each color, and note the readings for different colors.
4. Remove the prism, hence note direct ray reading.
5. Find the angle of minimum deviation for different color.(Say ,violet, blue, green, yellow).
6. Find the refractive index for these colors. Using equation (3).
7. Draw the graph with n along the y-axis and 1/λ2 along x-axis with zero as the origin for both axes.

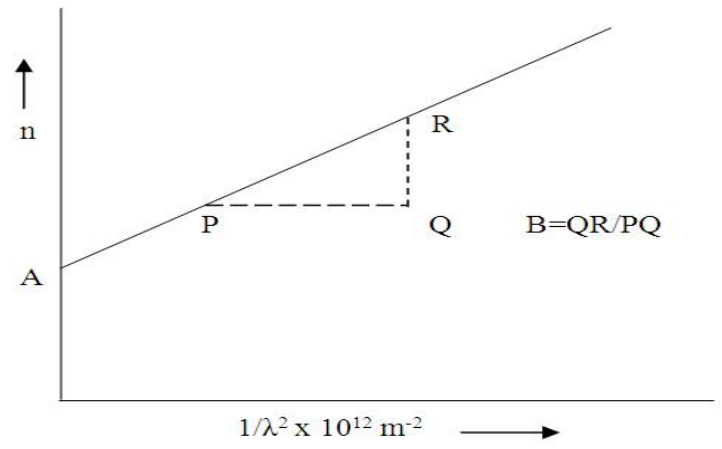
Table (1): To calculate A and B.

Pair of Colors	λ_1 x 10^{-9} m	λ_2 x 10^{-9} m	n_1	n_2	A	B
Yellow1 & Blue						
Green & Violet						

Table (2): To find A and B graphicaly.

Colour	λ x 10^{-9} m	$(1/\lambda^2)$ x 10^{12} m^{-2}	n
Yellow	579.1	2.988	
Green	546.1	3.353	
Blue	435.8	5.265	
Violet 2	404.7	6.103	

Graph:



Result:

Cauchy's constants

A =……………………………

B =…………………………… m2

WAVELENGTH OF LASER USING DIFFRACTION GRATING

Aim:

TO find a wavelength of laser source using diffraction grating.

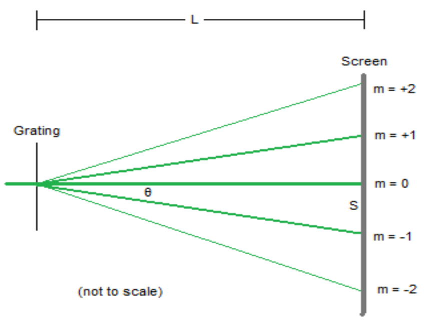
Apparatus required:

Diffraction grating, Laser source, Large screen, Stand with grating mount, metre scale

Formula

$$\text{Sin } \theta_n = Nn\lambda$$

$$\text{Sin } \theta_n = x_n / \sqrt{Xn2 + d2}$$



Procedure:

Laser, grating and a screen are arranged in a line as shown in a figure. Switch on the laser and pass through the grating so that the diffraction pattern can be seen on screen. The pattern consists of bright diffraction bands of orders n = 1,2…etc. On either side of the central spot. For normal incidence, the grating is aligned such that the separation between the central spot to the first order spot on both sides are equal. Adjust the spacing between the grating and the screen d to 0.23 m. Find the distance to the n th order (n=1,2) diffracted spot from the central spot on both sides of it on the screen as x_n. From the mean value of x_n, calculate $\sin\theta_n = x_n / \sqrt{Xn2 + d2}$ for each order. The number of lines per metre of the grating N is also noted. Then the wavelength given by $\lambda = \sin\theta_n / Nn$ is calculated. The experiment is repeated for various distances d= 0.5,0.75 and 1 m and the mean value of wave length is calculated.

Table :

Number of lines per metre on the grating N = ______ lines / m

s.no	Order n	Distance to the diffracted spot from the central spot x_n (m)			$\sin\theta_n = x_n/\sqrt{Xn2 + d2}$	Mean sin θ_n	$\lambda = \sin\theta_n / Nn$ (m)
		Left	Right	Mean			
1 2 3	I						
1 2 3	II						

Result :

Wavelength of the laser light =

MELDE'S APPARATUS

FREQUENCY OF VIBRATOR(TUNING FORK)

Aim:

To determine the frequency of vibrator or tuning fork of Melde's Apparatus by measuring the frequency of 1)transverse vibrations 2)longitudinal vibrations of a string.

Apparatus:

Melde's apparatus of electrically maintained vibrator or tuning fork with a long uniform string, scale pan,weight box etc.

1) TRANSVERSE MODE OF VIBRATIONS

Procedure:

In Melde's apparatus, a long string is attached to one of the prongs of the tuning fork(or vibrator). The other end of the string carrying scale pan is passed over a smooth pulley. The pulley is rigidly fixed to the edge of the table. The electrically maintained tuning fork is placed so that its prong is along the length of the string as shown in Fig28.1 below.

When the circuit is closed, the fork is set into vibration, at right angles to the length of the string. A mass of, say, 5g is placed on the pan. The transverse stationary waves are produced in the string due to the superposition of the traveling wave and reflected wave at the pulley. The length of the string is adjusted to get well defined loop of standing waves. Leaving the loops formed at the ends of the string, total number of loops is counted and total length of the loop is measured using meter scale. The length l of then is calculated. The experiment is repeated by adding the mass into the pan in step of 5g. The mass of entry pan m_p is determined and is added to the mass placed in it. The readings are tabulated as given in table 28.1. The linear density m of string that is, mass per unit length of the string is calculated by knowing the mass of the specimen string 10m in length.

Table 28.1: To determine (M`/ L^2)

Load in scale pan: M g	Total mass M`=(M+m_p)g	Number of loop N	Total length of loops m	Length of one loop l m	(M`/ l^2) kg.m^{-2}

Mean (M`/ l^2) = Kg m^{-2}

Mean (M`/ l^2)$^{1/2}$= Kg m^{-1}

A graph can be drawn connecting M` and $L^2$ as shown in fig 28.2 and the slope (M`/ l^2) can be determined.

M` kg	L^2 m^2

Formula:

In transverse mode of vibration of the string of the loop length L under the tension T, its frequency of vibration is equal to that of vibrating tuning fork. Therefore frequency of the fork

$$n = 1/2l\ [T/m]^{1/2} = 1/2\ [(g/m)(M`/l^2)]^{1/2}$$

where T is the tension in the string = (M+m_p)g =M`g. Here M` is the load including the mass of the pan m_p and g is the acceleration due to gravity.

Observation:

Mass of the scale pan m_p = kg
Mass of 10m of string = kg
Mass per meter of string m = kg m^{-1}
Mean (M`/l^2)$^{1/2}$ 1) by calculation = $kg^{1/2}m^{-1}$

2)by graph = $kg^{1/2}m^{-1}$

Frequency of the fork $n = 1/2[(g/m)(M`/l^2)]^{1/2}$ Hz

Result:

Frequency of tuning fork in transverse mode of vibration of string

1) By calculation = Hz
2) By graph = Hz

2)**LONGITUDINAL MODE OF VIBRATIONS:**

Procedure:

In the longitudinal mode, the fork vibrates in a direction parallel to the length of the string. The experiment is performed as in the case of transverse mode of vibrations. Observations are tabulated for various tensions. The table is identical to the table 28.1 which is already given. Here it should be noted that for same tension, the length of one loop is twice as that for transverse mode. Experiment is also repeated to find the relative density of the given solid and liquid.

Table 28.2: To determine $(M`/ L^2)$

Load in scale pan: M g	Total mass $M`=(M+m_p)$g	Number of loop N	Total length of loops m	Length of one loop l m	$(M`/ l^2)$ $kg.m^{-2}$

Formula:

In longitudinal mode, each and every point of the string makes one complete oscillation during which of fork completes two oscillations.Therefore,

Frequency of the fork $n = [(g/m)(M`/l^2)]^{1/2}$

As in the case of transverse mode, using the same formulae, the relative densities of solid and liquid are determined.

Observation:

Mass of the scale pan m_p = kg
Mass of 10m of string = kg
Mass per meter of string m = $kg\ m^{-1}$
Mean $(M`/l^2)^{1/2}$ 1) by calculation = $kg^{1/2}m^{-1}$
2)by graph = $kg^{1/2}m^{-1}$

Frequency of the fork $n = [(g/m)(M`/l^2)]^{1/2}$ Hz

Result:

Frequency of tuning fork in longitudinal mode of vibration of string

1) By calculation = Hz
2) By graph = Hz

LISSAJOUS FIGURES

Aim:

To use Lissajous figures to take phase measurements.

Apparatus:

General purpose oscilloscope (10MHz) , Function generators (1 Hz to 1 MHz) ,Digital multimeter.

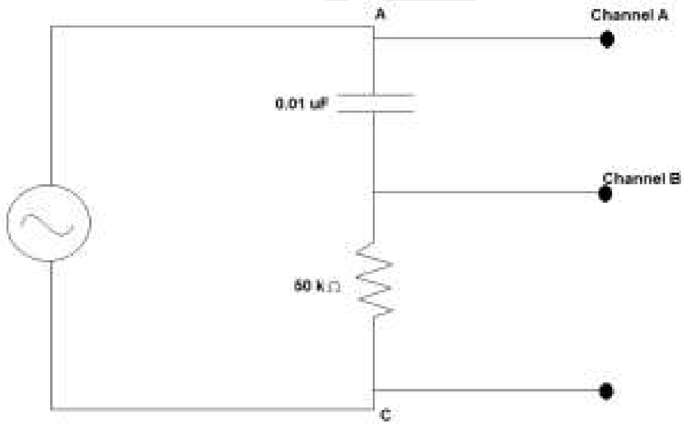
Theory:

A lissajous figure is produced by taking two sine waves and displaying them at right angles to each other. This easily done on an oscilloscope in XY mode. If the oscilloscope has the x-versus-y capability, one can apply one signal to the vertical deflection plates while applying a second signal to the horizontal deflection plates. The horizontal sweep section is automatically disengaged at this time. The resulting waveform is called Lissajous figure. This mode can be used to measure phase or frequency relationships between two signals.

Procedure:

1. The circuit was connected as in Figure 3.8.

2. The frequency of Ein was set at 1 kHz. R was set at 0 Ω. The signal voltage was set at 4 V peak-to-peak. The display was centered. R was changed to 10 kΩ and the pattern in was recorded in Table 3.3. The measured and calculated values was recorded in Table 3.3, for different values of R.



Observation:

S NO	X	Y	Ø= $\sin^{-1}(Y/X)$

Result:

The phase difference of lissajoue's figure =

Chapter 10

Huygens' Principle and Its Applications

Christiaan Huygens, a Dutch physicist, in a communication to the Academie des Science in Paris, propounded his wave theory of light (published in his Traite de Lumiere in 1690). He considered that light is transmitted through an all-pervading aether that is made up of small elastic particles, each of which can act as a secondary source of wavelets. On this basis, Huygens explained many of the known propagation characteristics of light, including the double refraction in calcite discovered by Bartholinus.

—*From the Internet*

10.1 INTRODUCTION

The wave theory of light was first put forward by Christiaan Huygens in 1678. During that period, everyone believed in Newton's corpuscular theory, which had satisfactorily explained the phenomena of reflection, refraction, the rectilinear propagation of light and the fact that light could propagate through vacuum. So empowering was Newton's authority that the scientists around Newton believed in the corpuscular theory much more than Newton himself; as such, when Huygens put forward his wave theory, no one really believed him. On the basis of his wave theory, Huygens explained satisfactorily the phenomena of reflection, refraction and total internal reflection and also provided a simple explanation of the then recently discovered birefringence (see Ch. 19). As we will see later, Huygens' theory predicted that the velocity of light in a medium (like water) shall be less than the velocity of light in free space, which is just the converse of the prediction made from Newton's corpuscular theory (see Sec. 1.2).

The wave character of light was not really accepted until the interference experiments of Young and Fresnel (in the early part of the nineteenth century) which could only be explained on the basis of a wave theory. At a later date, the data on the speed of light through transparent media were also available which was consistent with the results obtained by using the wave theory. It should be pointed out that Huygens did not know whether the light waves were longitudinal or transverse and also how they propagate through vacuum. It was only in the later part of the nineteenth century, when Maxwell propounded his famous electromagnetic theory, could the nature of light waves be understood properly.

10.2 HUYGENS' THEORY

Huygens' theory is essentially based on a geometrical construction which allows us to determine the shape of the wavefront at any time, if the shape of the wavefront at an earlier time is known. A wavefront is the locus of the points which are in the same phase; for example, if we drop a small stone in a calm pool of water, circular ripples spread out from the point of impact, each point on the circumference of the circle (whose center is at the point of impact) oscillates with the same amplitude and same phase and thus we have a circular wavefront. On the other hand, if we have a point source emanating waves in a uniform isotropic medium, the locus of points which have the same amplitude and are in the same phase are spheres. In this case we have spherical wavefronts as shown in Fig. 10.1(a). At large distances from the source, a small portion of the sphere can be considered as a plane and we have what is known as a plane wave [see Fig. 10.1(b)].

Now, according to Huygens' principle, each point of a wavefront is a source of secondary disturbance and the wavelets emanating from these points spread out in all directions with the speed of the wave. The envelope of these wavelets gives the shape of the new wavefront. In Fig. 10.2, S_1S_2 represents the shape of the wavefront (emanating from the point O) at a particular time which we denote as $t = 0$. The medium is assumed to be homogeneous and isotropic, i.e., the medium is characterized by the same property at all points and the speed of propagation of the wave is the same in all directions. Let us suppose we want to determine the shape of the wavefront after a time interval of Δt. Then, with each point on the wavefront as center, we draw spheres of radius $v\,\Delta t$, where v is the speed of the wave in that

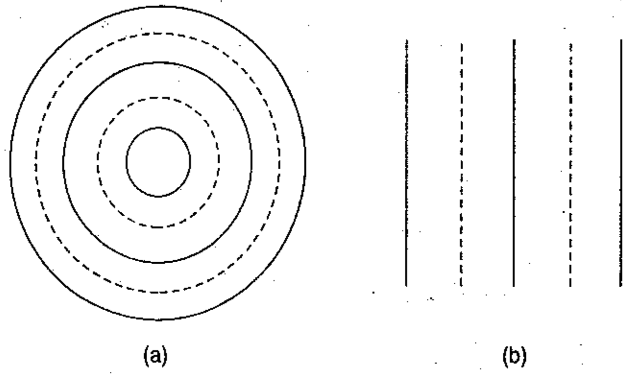


Fig. 10.1 (a) A point source emitting spherical waves. (b) At large distances, a small portion of the spherical wavefront can be approximated to a plane wavefront thus resulting in plane waves.

medium. If we draw a common tangent to all these spheres, then we obtain the envelope which is again a sphere centered at O. Thus the shape of the wavefront at a later time Δt is the sphere $S_1'S_2'$.

There is, however, one drawback with the above model, because we also obtain a backwave which is not present in practice. This backwave is shown as $S_1''S_2''$ in Fig. 10.2. In Huygens' theory, the presence of the backwave is avoided by assuming that the amplitude of the secondary wavelets is not uniform in all directions; it is maximum in the forward direction and zero in the backward direction*. The absence of the backwave is really justified through the more rigorous wave theory.

In the next section we will discuss the original argument of Huygens to explain the rectilinear propagation of light. In Sec. 10.4 we will derive the laws of refraction and reflection by using Huygens' principle. Finally, in Sec. 10.5 we will show how Huygens' principle can be used in inhomogeneous media.

10.3 RECTILINEAR PROPAGATION

Let us consider spherical waves emanating from the point source O and striking the obstacle A (see Fig. 10.3). According to the rectilinear propagation of light (which is also predicted by corpuscular theory) one should obtain a shadow in the region PQ of the screen. As we will see in a later chapter, this is not rigorously true and one does obtain a finite intensity in the region of the geometrical shadow. However, at the time of Huygens, light was known to travel in straight lines and Huygens explained this by assuming that the secondary wavelets do not have any amplitude at any point not enveloped by the wavefront. Thus, referring back to Fig. 10.2, the secondary wavelets emanating from a

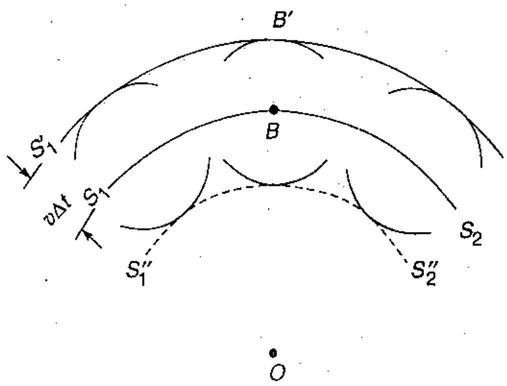


Fig. 10.2 Huygens' construction for the determination of the shape of the wavefront, given the shape of the wavefront at an earlier time. S_1S_2 is a spherical wavefront centered at O at a time, say $t = 0$. $S_1'S_2'$ corresponds to the state of the wavefront at a time Δt, which is again spherical and centered at O. The dashed curve represents the backwave.

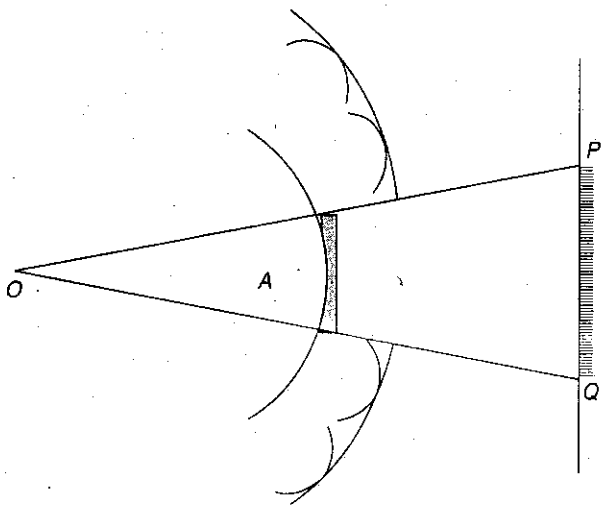


Fig. 10.3 Rectilinear propagation of light. O is a point source emitting spherical waves and A is an obstacle which forms a shadow in the region PQ of the screen.

* Indeed it can be shown from diffraction theory that one does obtain (under certain approximations) an obliquity factor, which is of the form $\frac{1}{2}(1 + \cos\theta)$ where θ is the angle between the normal to the wavefront and the direction under consideration. Clearly when $\theta = 0$, the obliquity factor is 1 (thereby giving rise to maximum amplitude in the forward direction) and when $\theta = \pi$, the obliquity factor is zero (thereby giving rise to zero amplitude in the backward direction).

same time. If the distance of the source is small [Fig. 7.12 (*i*)] the wavefront is spherical. When the source is at a large distance, then any small portion of the wavefront can be considered plane [Fig. 7.12 (*ii*)]. Thus rays of light diverging from or converging to a point give rise to a spherical wavefront and a parallel beam of light gives rise to a plane wave front

According to Huygens principle, all points on the primary wavefront (1, 2, 3 etc., Fig. 7.12) are sources of secondary disturbance. These secondary waves travel through space with the same velocity as the original wave and the envelope of all the secondary wavelets after any given interval of time gives rise to the secondary wavefront. In Fig. 7.12 (*i*), XY is the primary spherical wavefront and in Fig. 7.12 (*ii*) XY is the primary plane wavefront. After an interval of time t', the secondary waves travel a distance vt'. With the points 1, 2, 3 etc. as centres, draw spheres of radii vt'. The surfaces X_1Y_1 and X_2Y_2 refer to the secondary wavefront. X_1Y_1 is the forward wavefront and X_2Y_2 is the backward wavefront. But according to Huygens principle, the secondary wavefront is confined only to the forward wavefront X_1Y_1 and not the backward wavefront X_2Y_2. However, no explanation to the absence of backward wavefront was given by Huygens.

7.13 REFLECTION OF A PLANE WAVE FRONT AT A PLANE SURFACE

Let XY be a plane reflecting surface and AMB the incident plane wavefront. All the particles on AB will be vibrating in phase. Let i be the angle of incidence (Fig. 7.13).

In the time the disturbance at A reaches C, the secondary waves from the point B must have travelled a distance BD equal to AC. With the point B as centre and radius equal to AC construct a sphere. From the point C, draw tangents CD and CD'. Then $BD = BD'$.

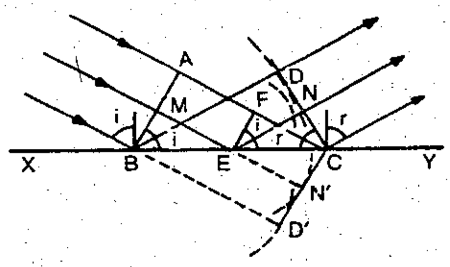


Fig. 7.13

In the Δ s BAC and BDC

BC is common

$$BD = AC$$

and $$\angle BAC = \angle BDC = 90^\circ$$

$\therefore$ The two triangles are congruent,

$$\therefore \quad \angle ABC = i = \angle BCD = r.$$

$$\therefore \quad i = r$$

Thus, the angle of incidence is equal to the angle of reflection. Hence, CD forms the reflected plane wavefront. It can be shown that all the points on CD form the reflected plane wavefront. In the time the disturbance from F reaches the point C, the secondary waves from E must have travelled a distance $EN = FC$. With E as centre and radius FC draw a sphere and draw tangents CN and CN' to the sphere. It can be shown that the triangles EFC and ENC are congruent.

$$AC = AF + FC$$

But $$AF = ME$$

and $$FC = EN$$

$$\therefore \quad AC = ME + EN$$

Thus, all the secondary waves from different points on AB reach the corresponding points on CD at the same time. Therefore, CD forms the reflected plane wavefront and also the angle of incidence is equal to the angle of reflection.

7.14 REFLECTION OF A PLANE WAVEFRONT AT A SPHERICAL SURFACE

Let APB be a convex reflecting surface and QPR the incident plane wavefront (Fig. 7.14). By the time the disturbance at Q and R reaches the points A and B on the reflecting surface, the secondary waves from P must have travelled a distance PK back into the same medium such that $QA = RB = PL = PK$.

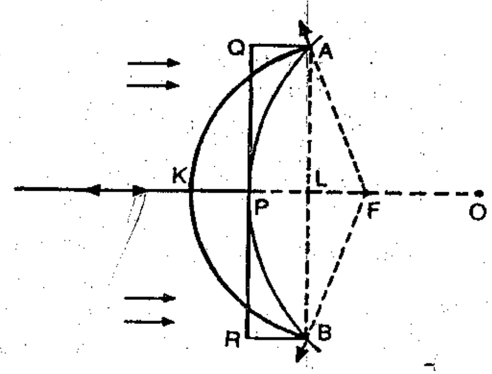


Fig. 7.14

Then AKB forms the reflected spherical wavefront whose centre of curvature is F. Similarly, the secondary waves corresponding to the points lying on the incident wavefront QPR will reach the surface AKB in the same time after reflection. F is called the focus of the spherical mirror APB. PF is the focal length of the mirror.

In Fig. 7.14, APB is a small arc of a circle of radius $PO = R$ and ALB is a chord. PL is called the sagitta of the arc. From geometry,

$$AL^2 = PL\,(2R - PL)$$

$$= 2R.PL - PL^2$$

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{2xy}{ab} = 0$$

or
$$\frac{x}{a}-\frac{y}{b} = 0$$

or
$$y = \left(\frac{b}{a}\right)x \qquad ...(v)$$

This represents the equation of a straight line *BD* (Fig. 7.9) i.e., the particle vibrates simple harmonically along the line *DB*.

(*ii*) If $\alpha = \pi$; $\sin\alpha = 0$;

$$\cos\alpha = -1$$

$$\therefore \quad \frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{2xy}{ab} = 0$$

$$\left(\frac{x}{a}+\frac{y}{b}\right) = 0$$

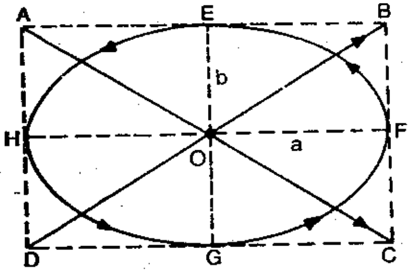


Fig. 7.9

$$y = -\left(\frac{b}{a}\right)x \qquad ...(vi)$$

This represents equation of a straight line *AC* (Fig. 7.9).

(*iii*) If $\alpha = \frac{\pi}{2}$ or $\frac{3\pi}{2}$; $\sin\alpha = 1$;

$$\cos\alpha = 0$$

$$\therefore \quad \frac{x^2}{a^2}+\frac{y^2}{b^2} = 1$$

This represents the equation of an ellipse *EHGF* (Fig. 7.9) with *a* and *b* as the semi-major and semi-minor axes.

(*iv*) If $\alpha = \frac{\pi}{2}$ or $\frac{3\pi}{2}$

and $a = b$

then $\frac{x^2}{a^2}+\frac{y^2}{b^2} = 1$

or $x^2+y^2 = a^2$

This represents the equation of a circle of radius *a* (Fig. 7.10).

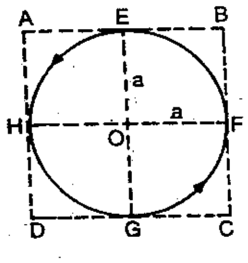


Fig. 7.10

(*a*) If $\alpha = \frac{\pi}{4}$ or $\frac{7\pi}{4}$ the resultant vibration is an oblique ellipse *KLMN* as shown in Fig. 7.11 (*i*)

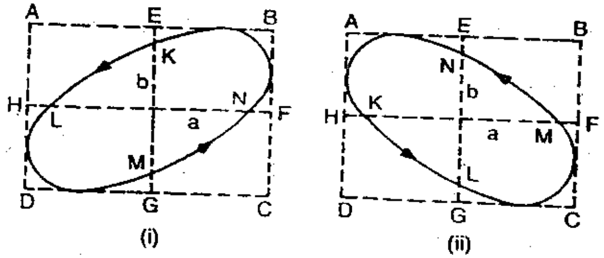


Fig. 7.11

On the other hand if $\alpha = \frac{3\pi}{4}$ or $\frac{5\pi}{4}$, the resultant vibration is again an oblique ellipse *KLMN* is shown in Fig. 7.11 (*ii*). The cycle of changes is repeated after every time period.

7.12 HUYGENS PRINCIPLE

According to Huygens, a source of light sends out waves in all directions, through a hypothetical medium called ether. In Fig. 7.12 (*i*), *S* is a source of light sending light energy in the form of waves in all directions. After any given interval of time (*t*), all the particles of the medium on the surface *XY* will be vibrating in phase. Thus, *XY* is a portion of the sphere of radius *vt* and centre *S*. *v is the velocity of propagation of the wave. XY* is called the primary wavefront. A wavefront can be defined as the locus of all the points of the medium which are vibrating in phase and are also displaced at the

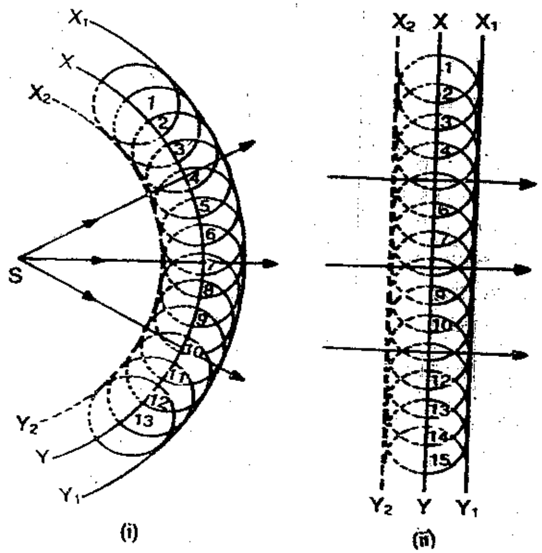


Fig. 7.12

...gligible.

$$AL^2 = 2R.PL$$

$$R = \frac{AL^2}{2PL} \qquad \ldots(i)$$

Similarly for the spherical surface AKB

$$KL = \frac{AL^2}{2KF}$$

$$KF = \frac{AL^2}{2KL} = f \text{ approximately}$$

But

$$KL = KP + PL = 2PL$$

$\therefore$

$$f = \frac{AL^2}{2 \times 2PL} = \frac{1}{2}\left(\frac{AL^2}{2PL}\right)$$

$$= \frac{R}{2}$$

Thus, the incident plane wavefront QPR is reflected as the spherical wavefront AKB with the centre of curvature at F. Further the focal length of the mirror is equal to half the radius of curvature of the mirror.

7.15 REFLECTION OF A SPHERICAL WAVEFRONT AT A PLANE SURFACE

Let XY be the plane reflecting surface and O a point source of light at a distance OP from it. APB is the incident spherical wavefront meeting the surface XY at P. By the time the disturbance at the points A and B reaches C and D, the secondary waves from P must have travelled a distance $PM = AC = BD$. In the absence of the reflecting surface, the wavefront must have advanced a distance PL and taken the position CLD (Fig. 7.15). Also $PL = PM$. The secondary waves from the points in between A and B will reach the corresponding points on the reflected spherical wave front CMD in the same time. I is the centre of curvature of the surface CMD. Hence I is the image of O. Further the curvature of the incident spherical wavefront is the same as the reflected wavefront.

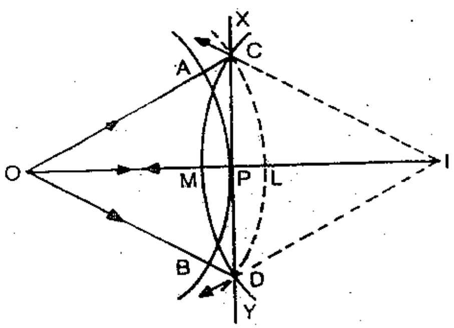


Fig. 7.15

$Cp^2 = PL(2LO - PL)$
$= PL \cdot 2LO - PL^2$
$Cp^2 = PL \cdot 2LO$
PL^2 is negligible

For the surface CLD,

$$PL = \frac{CP^2}{2LO} \qquad \ldots(i)$$

and for the surface CMD

$$MP = \frac{CP^2}{2MI} \qquad \ldots(ii)$$

But

$$PL = MP$$

$\therefore$

$$LO = MI$$

or

$$OP + PL = MP + PI$$

$$OP = PI$$

i.e., the image is formed as far behind the mirror as the object is in front of it.

7.16 REFLECTION OF A SPHERICAL WAVEFRONT AT A SPHERICAL SURFACE

Let XPY be a concave reflecting surface whose radius of curvature is R and centre of curvature is C. O is a point source of light on the axis of the mirror and ALB is the incident spherical wavefront touching the surface at the points A and B (Fig. 7.16). By the time the disturbance at L reaches P, the secondary waves from A and B must have travelled a distance $AE = BD = PL$. Therefore, EPD is the reflected spherical wavefront whose centre of curvature is I. I is the image of the object O.

Take $PO = u$, $PI = v$ and $PC = R$. Considering the aperture to the small, for the spherical surface ALB,

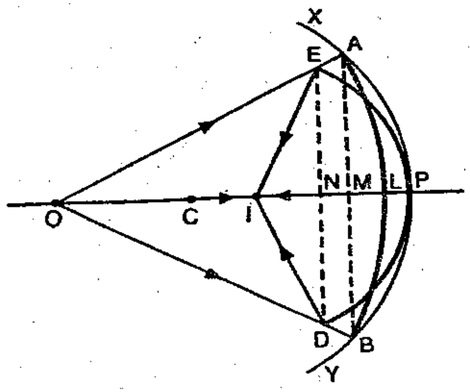


Fig. 7.16

$$LM = \frac{AM^2}{2LO} = \frac{AM^2}{2PO} = \frac{AM^2}{2u} \qquad \ldots(i)$$

For the spherical surface EPD,

$$PN = \frac{EN^2}{2PI} = \frac{EN^2}{2v} = \frac{AM^2}{2v} \qquad \ldots(ii)$$

$[EN = AM \text{ approximately}]$

For the spherical surface XPY

$$PM = \frac{AM^2}{2PC} = \frac{AM^2}{2R} \qquad ...(iii)$$

Also, $PL = AE = MN$ approximately

$$PN = PM + MN = PM + PL$$

$\therefore$ $= PM + PM - LM$

$\therefore$ $PN + LM = 2PM \qquad ...(iv)$

Substituting the values of LM, PN and PM in equation (iv)

$$\frac{AM^2}{2v} + \frac{AM^2}{2u} = \frac{2\,AM^2}{2R}$$

$$\frac{1}{v} + \frac{1}{u} = \frac{2}{R} = \frac{1}{f}$$

According to the sign convention, u, v and f are all negative.

$\therefore$ $$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \qquad ...(v)$$

7.17 REFRACTION OF A PLANE WAVEFRONT AT A PLANE SURFACE

Let XY represent the surface separating the media 1 and 2 of refractive indices μ_1 and μ_2 respectively (Fig. 7.17). v_1 and v_2 are the velocities

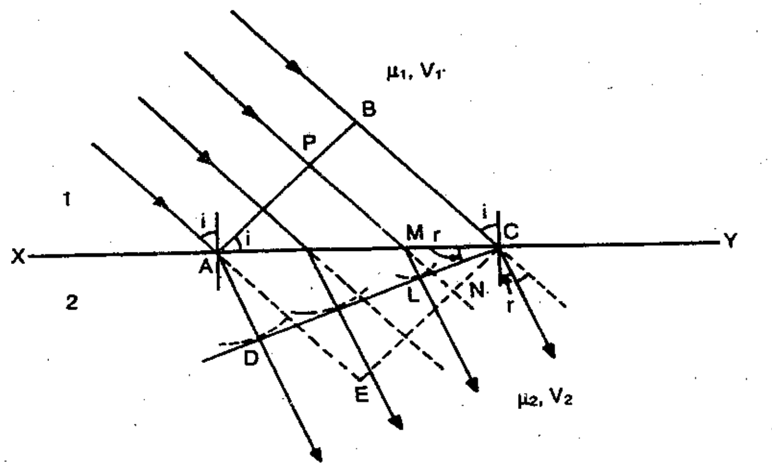


Fig. 7.17.

of light in the two media. The second medium is optically denser than the first and hence $v_1 > v_2$. APB is the incident plane wavefront. By the

time the disturbance at B reaches C, the secondary waves from A must have travelled a distance $AD = v_2 t$ where t is the time taken by the waves travel the distance BC.

$\therefore$ $BC = v_1 t$

and $AD = v_2 t$

With A as centre and radius AD ($= v_2 t$) draw a sphere. Draw a tangent CD to the sphere from the point C. Then CD represents the refracted plane wavefront. To prove that CD is the common wavefront, it is enough to show that in the time the disturbance travels from B to C or A to D, the disturbance at P reaches L. With the point M as centre, draw a sphere such that CD happens to be the tangent to the sphere. From the $\Delta s\, ACD$ and MCL

$$\frac{AD}{ML} = \frac{AC}{MC} \qquad ...(i)$$

Similarly from the $\Delta s\, ACE$ and MCN

$$\frac{AE}{MN} = \frac{AC}{MC} \qquad ...(ii)$$

From equation (i) and (ii)

$$\frac{AD}{ML} = \frac{AE}{MN}$$

or $$\frac{AE}{AD} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t} = \frac{MN}{ML}$$

or $$\frac{BC}{AD} = \frac{MN}{ML} = \frac{v_1}{v_2} \qquad ...(iii)$$

Hence, if AD is the radius of the secondary wavefront for the point A, then ML is the radius of the secondary wavefront for the point M.

Let i and r be the angles of incidence and refraction respectively. From the $\Delta s\, ABC$ and ACD

$$\frac{\sin i}{\sin r} = \frac{BC}{AC} \Big/ \frac{AD}{AC}$$

or $$\frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$$

$\therefore$ $$\mu_1 \sin i = \mu_2 \sin r$$

This is the Snell's law of refraction.

Special cases :

(*i*) If $\mu_2 > \mu_1$; $r < i$, *i.e.*, when a ray of light travels from a rarer to a denser medium, the ray is bent towards he normal.

(*ii*) If $\mu_2 < \mu_1$; $r > i$, *i.e.*, when a ray of light travels from a denser to a rarer medium it is refracted away from the normal.

(*iii*) If the incident beam is normal to the refracting surface, the angle of incidence is zero and hence the angle of refraction is also zero. The secondary waves from all the points start at the same instant and the refracted waves travel in a direction perpendicular to the refracting surface.

(*iv*) **Total internal reflection**. If the velocity of light v_2 in the second medium is greater than the velocity of light v_1 in the first medium and $AD > AC$ (Fig. 7.17), then no tangent can be drawn from the point C to the sphere drawn with A as centre. There will be no refracted wavefront. In the limiting case, $AD = AC$

$$BC = AC \sin i$$

$$v_1 t = AD. \sin i$$

$$= v_2 t \sin i$$

or

$$v_1 = v_2 \sin i$$

$$\sin i = \frac{v_1}{v_2} = {}_1\mu_2 = \frac{1}{{}_2\mu_1}$$

where ${}_2\mu_1$ is the refractive index of the first medium with respect to the second medium. Here $i = c$,

$$\sin c = \frac{1}{{}_2\mu_1}$$

c is called the critical angle and is defined as the angle of incidence in the denser medium for which the corresponding angle of refraction in the rarer medium is 90°.

7.18 REFRACTION OF A SPHERICAL WAVEFRONT AT A PLANE SURFACE

Let XPY represent the surface separating two media of refractive indices μ_1 and μ_2. v_1 and v_2 are the velocities of light in the two media respectively. O is a point in the first medium at a distance u from the surface XPY (Fig. 7.18). CPD is the incident spherical wavefront. In the absence of the surface XPY, the wavefront should have occupied the position AEB after a time t. By the time the disturbance at the points C and D reaches the surface at A and B respectively, the secondary waves at P must have travelled a distance PM where $PM = v_2 t$ and $CA = DB = PE = v_1 t$

$$\therefore \quad \frac{PM}{PE} = \frac{v_2 t}{v_1 t} = \frac{v_2}{v_1} = \frac{\mu_1}{\mu_2}$$

For the surface AMB,

$$PM = \frac{AP^2}{2MI} = \frac{AP^2}{2PI} = \frac{AP^2}{2v} \text{ (approximately)}$$

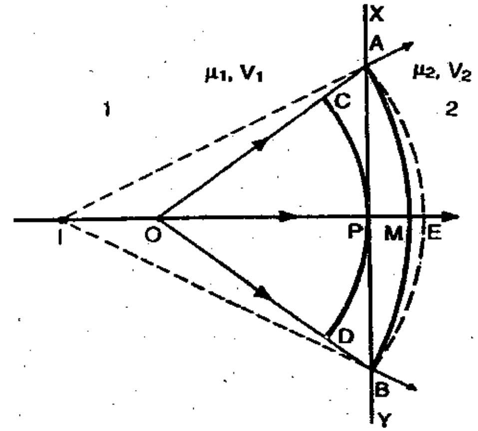


Fig. 7.18

For the surface AEB,

$$PE = \frac{AP^2}{2EO} = \frac{AP^2}{2PO} = \frac{AP^2}{2u} \text{ (approximately)}$$

$$\therefore \quad \frac{PM}{PE} = \frac{u}{v} \quad \text{...(ii)}$$

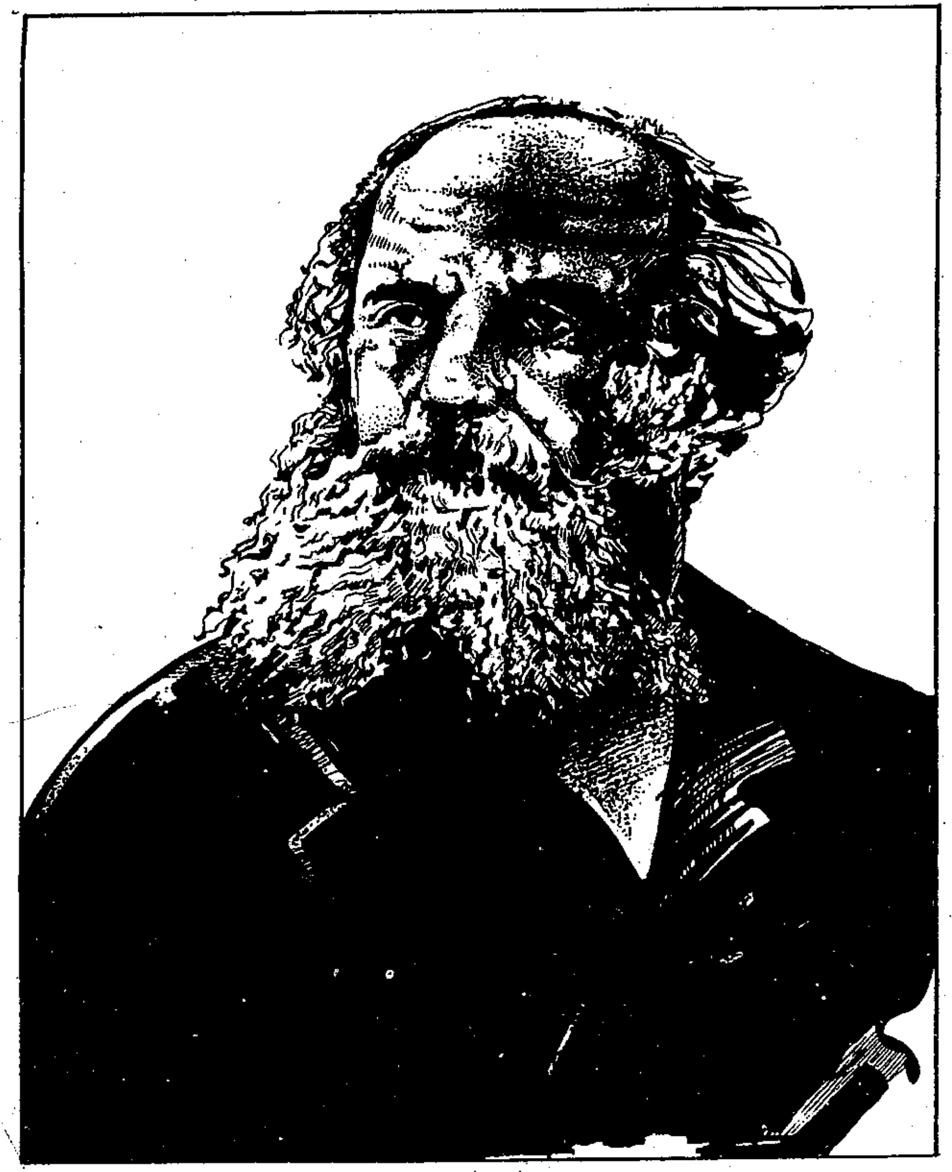
From equations (*i*) and (*ii*)

$$\frac{PM}{PE} = \frac{u}{v} = \frac{\mu_1}{\mu_2}$$

Here, u is the distance of the object and v is the distance of the image.

$$\frac{\text{Actual distance}}{\text{Apparent distance}} = \frac{\mu_1}{\mu_2} = \frac{1}{{}_1\mu_2}$$

where ${}_1\mu_2$ represents the refractive index of the second medium with respect to the first. If the second medium is denser then the first $v > u$ and if the first medium is denser then $u > v$.



JAMES CLERK MAXWELL (1831-1879)

He did fundamental work in colour vision and colour photography. He is well known for the discovery of the Electromagnetic Theory of Light.

$$\therefore \quad \mu AC = LP + \mu PQ + QN$$

But, $$AC = KM \text{ (approximately)}$$

$$\therefore \quad \mu KM = LP + \mu PQ + QN$$

$$\mu [KP + PQ + QM] = LP + \mu PQ + QN$$

or $$\mu [KP + QM] = (KP - KL) + (QM + MN) \quad ...(i)$$

Here $$AL = CM = h \text{ (approximately)}$$

$$\therefore \quad KP = \frac{h^2}{2R_1}; \quad QM = \frac{h^2}{2R_2}$$

$$KL = \frac{h^2}{2u} \text{ and } MN = \frac{h^2}{2v}$$

Substituing these values in equation (*i*)

$$\mu\left[\frac{h^2}{2R_1} + \frac{h^2}{2R_2}\right] = \frac{h^2}{2R_1} - \frac{h^2}{2u} + \frac{h^2}{2R_2} + \frac{h^2}{2v}$$

$$\mu\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = \left(\frac{1}{R_1} + \frac{1}{R_2}\right) + \left(\frac{1}{v} - \frac{1}{u}\right)$$

or $$\frac{1}{v} - \frac{1}{u} = (\mu - 1)\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

According to the convention of signs, u is $-ve$, v is $-ve$ R_1 is $-ve$ and R_2 is $+ve$

$$\therefore \quad -\frac{1}{v} + \frac{1}{u} = (\mu - 1)\left(-\frac{1}{R_1} + \frac{1}{R_2}\right)$$

or $$\frac{1}{v} - \frac{1}{u} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(ii)$$

If $$u = \infty, \ v = f$$

$$\therefore \quad \frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(iii)$$

7.22 NATURE OF LIGHT

(*i*) **Corpuscular theory**. Rectilinear propagation of light is a natural deduction on the basis of corpuscular theory. This theory can also explain reflection and refraction, though the theory does not clearly envisage why, how and when the force of attraction or repulsion is experienced perpendicular to the reflecting or refracting surface by a corpuscle. Newton assumed that the corpuscles possess fits which allow them easy reflection at one stage and easy transmission at the other. According to Newton's corpuscular theory the velocity of light in a denser medium is higher than the velocity in a rarer medium. But the experimental results of Foucault and Michelson show that the velocity of light in a rarer medium is higher than that in a denser medium. Interference could not be explained on the basis of corpuscular theory because two material particles cannot cancel one another's effect. The phenomenon of diffraction *viz.*, bending of light round corners or illumination of geometrical shadow cannot be conceived according to corpuscular theory, because a corpuscle travelling at high speed will not be deviated from its straight line path. Certain crystals like quartz, calcite etc. exhibit the phenomenon of double refraction. Explanation of this has not been possible with the corpuscle concept. The unsymmetrical behaviour of light about the axis of propagation (viz. polarization of light) cannot be accounted for by the corpuscular theory.

(*ii*) **Wave theory**. Huygens wave theory could explain satisfactorily the phenomena of reflection and refraction. Applying the principle of secondary wave points, rectilinear propagation of light can be correlated. The phenomenon of interference can also be understood considering that light energy is propagated in the form of waves. Two wave trains of equal frequency and amplitude and differing in phase can annul one another's effect and produce darkness. Similar to sound waves, bending of waves round obstacles is possible, thus enabling the understanding of the phenomenon of diffraction. Double refraction can also be explained on the basis of wave theory. According to Huygens, propagation of light is in the form of longitudinal waves. But in the case of longitudinal waves, one cannot expect the unsymmetrical behaviour of a beam of light about the axis of propagation. This difficulty was overcome when Fresnel suggested that the light waves are transverse and not longitudinal. On the basis of this concept, the phenomenon of polarization can also be understood. Finally, on the basis of wave theory it can be shown mathematically, that the velocity of light in a rarer medium is higher than the velocity of light in a denser medium. This is in accordance with the experimental results on the velocity of light.

(*iii*) **Conclusion**. The controversy between the corpuscular theory and the wave theory existed till about the end of the eighteenth century. At one time the corpuscular theory held the ground and at another time the wave theory was accepted, the discovery of the phenomenon of interference by Thomas Young in 1800, the experimental results of Foucault and Michelson on the velocity on light in different media and the revolutionary hypothesis of Fresnel in 1816 that the vibration of the ether particles is transverse and not longitudinal gave, in a way, a solid ground to the wave theory.

The next important advance in the nature of light was due to the work of Clerk Maxwell. Maxwell's electromagnetic theory of light lends support to Huygens wave theory whereas quantum theory strengthens the particle concept. It is very interesting to note, that light is regarded as a wave motion at one time and as a particle phenomenon at another time.

EXERCISES VII

1. What is Huygens principle in regard to the conception of light waves ? Using Huygens conception show that μ is equal to the ratio of wave velocities in the two media.
2. Obtain an expression for refraction of a spherical wave at a spherical surface.
3. State Huygens principle for the propagation of light. Using the same, deduce the formula connecting object and image distances with the constants of a thin lens.
4. Explain how the phenomena of reflection and refraction of light are accounted for on the wave theory and point out the physical significance of refractive index. (*Mysore 1991*)
5. What is a wavefront ? How is it produced ? Derive the lens formula for a thin lens on the basis of the wave theory of light.
6. Write a short note on the wave theory of light. How is refraction explained on this theory ? (*Delhi 1992*)
7. Explain Huygens principle. Derive the refraction formula for a thin lens on the basis of wave theory. (*Agra 1992*)
8. Write a short discussion on the nature of light. Deduce with the help of Huygens wave theory of light, an expression for the focal length of a thin lens in terms of the radii of curvature of its two surfaces and the refractive index of the material of which it is made. (*Rajasthan 1991*)
9. Write short notes on :
   (*i*) Wave theory of light. (*Punjab 1985*)
   (*ii*) Huygens principle. [*Delhi (Hons.) 1993*]
   (*iii*) Newton's corpuscular theory.
10. Show how the wave theory and the corpuscular theory of light account for (*a*) refraction and (*b*) total internal reflection of light. How was the issue decided in favour of the wave theory ? (*Rajasthan 1990*)
11. Discuss the nature of light. How do you explain the phenomenon of reflection, refraction and rectilinear propagation of light on the basis of wave theory ? (*Mysore 1990 ; Rajasthan 1986*)
12. Write an essay on the nature of light. (*Agra 1986*)
13. What is Huygens principle ? Obtain the laws of reflection and refraction on the basis of wave theory of light. (*Gorakhpur 1987*)

14. Apply Huygens principle to derive the relation

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right),$$

for a thin lens. *(Mysore 1990)*

15. State and explain Huygens principle of secondary waves. Apply this principle for explaining the simultaneous reflection and refraction of a plane light wave from a plane surface of separation of two optical media. *[Delhi 1984 ; Delhi (Hons.) 1984]*

16. Explain Huygens principle of wave propagation and apply it to prove the laws of reflection of a plane wave at a plane surface. *[Delhi B.Sc.(Hons.) 1991)*

17. State the principle of superposition. Give the mathematical theory of interference between two waves of amplitude a_1 and a_2 with phase difference ϕ. Discuss some typical cases. *[Rajasthan 1985]*

18. Deduce the laws of reflection with the help of Huygens theory of secondary wavelets. *(Rajasthan 1985)*

19. What is Huygens principle ? How would you explain the phenomenon of reflection and refraction of plane waves at plane surfaces on the basis of wave nature of light ? *[Delhi (Sub.) 1986]*

20. State and explain Huygens principle of secondary waves. *(Delhi 1988)*

21. State and explain Huygens principle of secondary waves. *[Delhi ; 1992]*

8

INTERFERENCE

8.1 INTRODUCTION

The phenomenon of interference of light has proved the validity of the wave theory of light. Thomas Young successfully demonstrated his experiment on interference of light in 1802. When two or more wave trains act simultaneously on any particle in a medium, the displacement

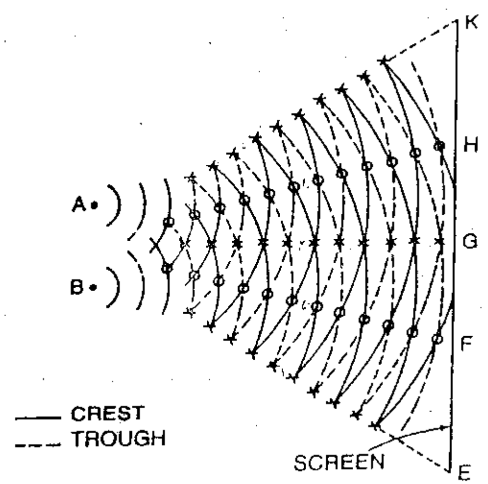


Fig. 8.1

of the particle at any instant is due to the superposition of all the wave trains. Also, after the superposition, at the region of cross over, the wave trains emerge as if they have not interfered at all. Each wave train retains its individual characteristics. Each wave train behaves as if others are absent. This principle was explained by Huygens in 1678.

The phenomenon of interference of light is due to the superposition of two trains within the region of cross over. Let us consider the waves produced on the surface of water. In Fig. 8.1 points A and B are the two sources which produce waves of equal amplitude and constant phase difference. Waves spread out on the surface of water which are circular in shape. At any instant, the particle will be under the action of the displacement due to both the waves. The points shown by circles in the diagram will have minimum displacement because the crest of one wave falls on the trough of the other and the resultant displacement is zero. The points shown by crosses in the diagram will have maximum displacement because, either the crest of one will combine with the crest of the other or the trough of one will combine with the trough of the other. In such a case, the amplitude of the displacement is twice the amplitude of either of the waves. Therefore, at these points the waves **reinforce** with each other. As the intensity (energy) is directly proportional to the square of the amplitude ($I \propto A^2$) the intensity at these points is four times the intensity due to one wave. It should be remembered that **there is no loss of energy due to interference.** The energy is only transferred from the points of minimum displacement to the points of maximum displacement.

8.2 YOUNG'S EXPERIMENT

In the year 1802, Young demonstrated the experiment on the interference of light. He allowed sunlight to fall on a pinhole S and then at some distance away on two pinholes A and B (Fig. 8.2).

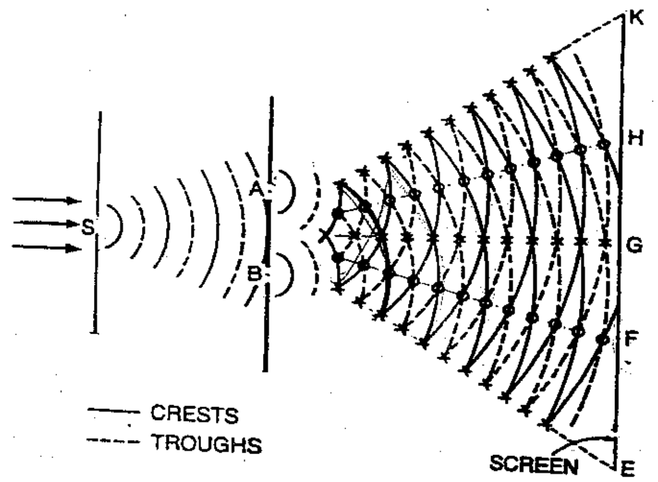


Fig. 8.2

A and B are equidistant from S and are close to each other. Spherical waves spread out from S. Spherical waves also spread out from A and B. These waves are of the same amplitude and wavelength. On the screen interference bands are produced which are alternatively dark and bright. The points such as E are bright because the crest due to one wave coincides with the crest due to the other and therefore they reinforce with each other. The points such as F are dark because the crest of one falls on the trough of the other and they neutralize the effect of each other. Points, similar to E, where the trough of one falls on the trough of the other, are also bright because the two waves reinforce.

It is not possible to show interference due to two independent sources of light, because a large number of difficulties are involved. The two sources may emit light waves of largely different amplitude and wavelength and the phase difference between the two may change with time.

8.3 COHERENT SOURCES

Two sources are said to be coherent if they emit light waves of the same frequency, nearly the same amplitude and are always in phase with each other. It means that the two sources must emit radiations of the same colour (wavelength). In actual practice it is not possible to have two independent sources which are coherent. But for experimental purposes, two virtual sources formed from a single source can act as coherent sources. Methods have been devised where (*i*) interference of light takes place between the waves from the real source and a virtual source (*ii*) interference of light takes place between waves from two sources formed due to a single source. In all such cases, the two sources will act, as if they are perfectly similar in all respects.

Since the wavelength of light waves is extremely small (of the order of 10^{-5} cm), the two sources must be narrow and must also be close to each other. Maximum intensity is observed at a point where the phase difference between the two waves reaching the point is a whole number multiple of 2π or the path difference between the two waves is a whole number multiple of wavelength. For minimum intensity at a point, the phase difference between the two waves reaching the point should be an odd number multiple of π or the path difference between the two waves should be an odd number multiple of half wavelength.

8.4 PHASE DIFFERENCE AND PATH DIFFERENCE

If the path difference between the two waves is λ, the phase difference $= 2\pi$.

Suppose for a path difference x, the phase difference is δ.

For a path difference λ, the phase difference $= 2\pi$

$\therefore$ For a path difference x, the phase difference $= \frac{2\pi x}{\lambda}$

Phase difference $\quad \delta = \frac{2\pi x}{\lambda} = \frac{2\pi}{\lambda} \times \text{(path difference)}$

8.5 ANALYTICAL TREATMENT OF INTERFERENCE

Consider a monochromatic source of light S emitting waves of wavelength λ and two narrow pinholes A and B (Fig. 8.3). A and B are equidistant from S and act as two virtual coherent sources. Let a be the amplitude of the waves. The phase difference between the two waves reaching the point P, at any instant, is δ.

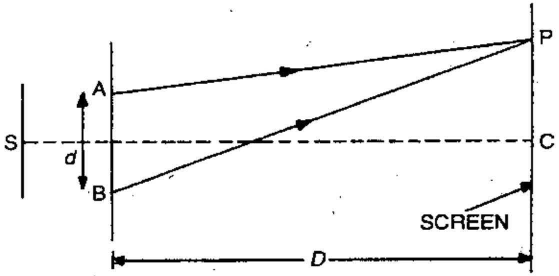


Fig. 8.3

If y_1 and y_2 are the displacements

$$y_1 = a \sin \omega t$$

$$y_2 = a \sin (\omega t + \delta)$$

$$\therefore \quad y = y_1 + y_2 = a \sin \omega t + a \sin (\omega t + \delta)$$

$$y = a \sin \omega t + a \sin \omega t \cos \delta + a \cos \omega t \sin \delta$$

$$= a \sin \omega t (1 + \cos \delta) + a \cos \omega t \sin \delta.$$

Taking $\quad a(1 + \cos \delta) = R \cos \theta \quad$ ...(*i*)

and $\quad a \sin \delta = R \sin \theta \quad$ ...(*ii*)

$$y = R \sin \omega t \cos \theta + R \cos \omega t \sin \theta$$

$$y = R \sin (\omega t + \theta) \quad \text{...(iii)}$$

which represents the equation of simple harmonic vibration of amplitude R.

Squaring (*i*) and (*ii*) and adding,

$$R^2 \sin^2 \theta + R^2 \cos^2 \theta = a^2 \sin^2 \delta + a^2 (1 + \cos \delta)^2$$

or $\quad R^2 = a^2 \sin^2 \delta + a^2 (1 + \cos^2 \delta + 2 \cos \delta)$

$$R^2 = a^2 \sin^2 \delta + a^2 + a^2 \cos^2 \delta + 2 a^2 \cos \delta$$

$$= 2a^2 + 2a^2 \cos \delta = 2a^2 (1 + \cos \delta)$$

$$R^2 = 2a^2 . 2 \cos^2 \frac{\delta}{2} = 4a^2 \cos^2 \frac{\delta}{2}$$

The intensity at a point is given by the square of the amplitude

$$\therefore \quad I = R^2$$

or $\quad I = 4a^2 \cos^2 \frac{\delta}{2} \quad$ ...(*iv*)

Special cases : (*i*) When the phase difference $\delta = 0, 2\pi, 2(2\pi), \ldots n(2\pi)$, or the path difference $x = 0, \lambda, 2\lambda, \ldots n\lambda$.

$$I = 4a^2$$

Intensity is maximum when the phase difference is a whole number multiple of 2π or the path difference is a whole number multiple of wavelength.

(*ii*) When the phase difference, $\delta = \pi, 3\pi, \ldots (2n + 1)\pi$, or the path difference $x = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \ldots (2n + 1)\frac{\lambda}{2}$,

$$I = 0$$

Intensity is minimum when the path difference is an odd number multiple of half wavelength.

(*iii*) **Energy distribution**. From equation (*iv*), it is fount that the intensity at bright points is $4a^2$ and at dark points it is zero. According to

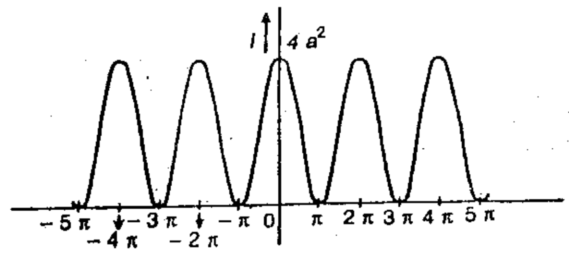


Fig. 8.4

the law of conservation of energy, the energy cannot be destroyed. Here also the energy is not destroyed but only transferred from the points of minimum intensity to the points of maximum intensity. For, at bright the back of the mirrors. The polishing should extend up to the line of intersection of the two mirrors and the line of intersection must be parallel to the line source (slit).

The distance between the two virtual sources A and B can be calculated as follows. Suppose the distance between the points of intersection of the mirrors and the source S is Y_1.

θ is known. The angle of separation between A and B is 2θ.

$$\therefore \quad d = 2\theta\, y_1$$

When white light is used the central fringe C is white whereas the other fringes on both sides of C are coloured because the fringe width (β) depends upon the wavelength. Only the first few coloured fringes are observed and the other fringes overlap. Therefore, the number of fringes seen in the field of view with a monochromatic source of light are more, than with white light.

8.8 FRESNEL'S BIPRISM

Fresnel used a biprism to show interference phenomenon. The biprism *abc* consists of two acute angled prisms placed base to base. Actually, it is constructed as a single prism of obtuse angle of about 179° (Fig. 8.7A). The acute angle α on both sides is about 30′. The prism is placed with its refracting edge parallel to the line source S (slit) such that Sa is normal to the face bc of the prism. When light falls from S on the lower portion of the biprism it is bent upwards and appears to come from

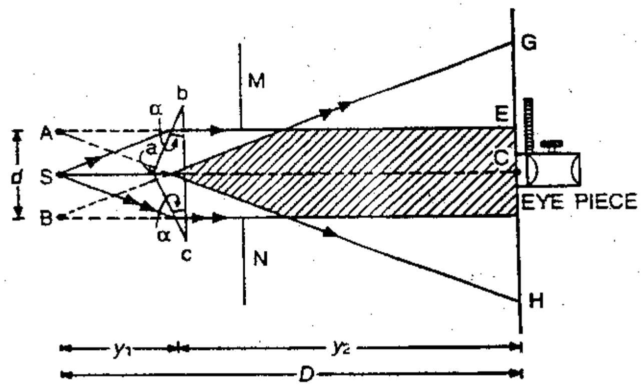


Fig. 8.7A

thevirtual source B. Similarly light falling from S on the upper portion of the prism is bent downwards and appears to come from the virtual source A. Therefore A and B act as two coherent sources. Suppose the distance between A and $B = d$. If a screen is placed at C, interference

fringes of equal width are produced between E and F but beyond E and F fringes of large width are produced which are due to diffraction. MN is a stop to limit the rays. To observe the fringes, the screen can be replaced by an eye-piece or a low power microscope and fringes are seen in the field of view. If the point C is at the principal focus of the eyepiece, the fringes are observed in the field of view.

Theory. For complete theory refer to Article 8.6. The point C is equidistant from A and B. Therefore, it has maximum intensity. On both sides of C, alternately bright and dark fringes are produced. The width of the bright fringe or dark fringe, $\beta = \frac{\lambda D}{d}$. Moreover, any point on the screen will be at the centre of a bright fringe if its distance from C is $\beta = \frac{n\lambda D}{d}$, where $n = 0, 1, 2, 3$ *etc.* The point will be at the centre of a dark fringe if its distance from C is

$$\frac{(2n+1)\,\lambda D}{2d},$$

where $n = 0, 1, 2, 3$ *etc.*

Determination of wavelength of light. Fresnel's biprism can be used to determine the wavelength of a given source of monochromatic light.

A fine vertical slit S is adjusted just close to a source of light and the refracting edge is also set parallel to the slit S such that bc is horizontal

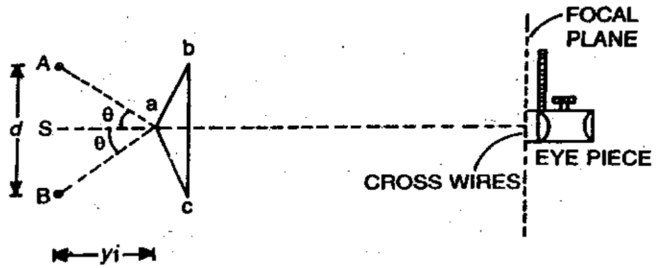


Fig. 8.8

(Fig. 8.8). They are adjusted on an optical bench. A micrometer eyepiece is placed on the optical bench at some distance from the prism to view the fringes in its focal plane (at its cross wires).

Suppose the distance between the source and the eyepiece $= D$ and the distance between the two virtual sources A and $B = d$. The eyepiece is moved horizontally (perpendicular to the length of the bench) to determine the fringe width. Suppose, for crossing 20 bright fringes from the field of view, the eyepiece has moved through a distance l.

Then the fringe width, $\beta = \frac{l}{20}$

But the fringe width $\beta = \frac{\lambda D}{d}$

$\therefore \quad \lambda = \frac{\beta d}{D}$ ...(*i*)

In equation (*i*) β and *D* are known. If *d* is also known, λ can be calculated.

Determination of the distance between the two virtual sources (*d*). For this purpose, we make use of the displacement method. A convex lens is placed between the biprism and the eyepiece in such a position, that the images of the virtual sources *A* and *B* are seen in the field of view of the eyepiece. Suppose the lens is in the position L_1 (Fig. 8.9). Measure the distance between the images of *A* and *B* as seen in the eyepiece. Let it be d_1

In this case,

$$\frac{d_1}{d} = \frac{v}{u} = \frac{n}{m} \quad ...(ii)$$

Now move the lens towards the eyepiece and bring it to some other position L_2, so that again the images of *A* and *B* are seen clearly in the field of view of the eyepiece. Measure the distance between the two images in this case also. Let it be equal to d_2.

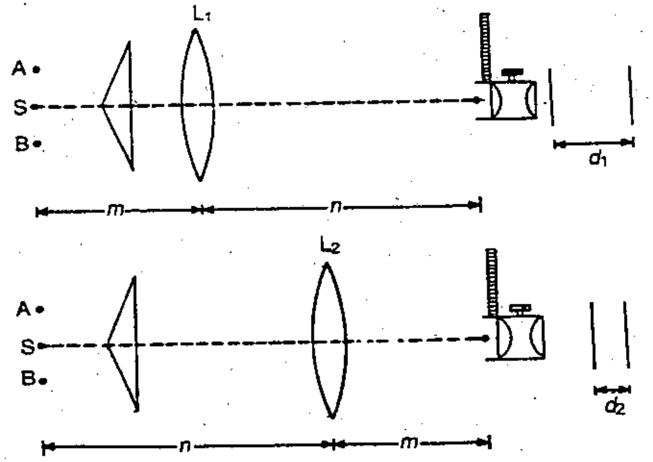


Fig. 8.9

Here, $v = m$ and $u = n$,

$$\therefore \quad \frac{d_2}{d} = \frac{v}{u} = \frac{m}{n} \quad ...(iii)$$

From equations (*ii*) and (*iii*),

$$\frac{d_1 d_2}{d^2} = 1$$

or $$d = \sqrt{d_1 d_2}$$

Here d_1 will be greater than d_2 and *d* is the geometrical mean of d_1 and d_2. Therefore *d* can be calculated. Substituting the value of *d*, β and *D* in equation (*i*), the wavelength of the given monochromatic light can be determined.

The second method to find *d* is to measure accurately the refracting angle α. As the angle is small, the deviation produced $\theta = (\mu - 1)\alpha$. Therefore the total angle between *Aa* and *Ba* is $2\theta = 2(\mu - 1)\alpha$. If the distance between the prism and the slit *S* is y_1 then $d = 2(\mu - 1)\alpha y_1$. Therefore *d* can be calculated.

8.9 FRINGES WITH WHITE LIGHT USING A BIPRISM

When white light is used, the centre of the fringe at *C* is white while the fringes on both sides of *C* are coloured because the fringe width (β) depends upon wavelength. Moreover, the fringes obtained in the case of a biprism using white light are different from the fringes obtained with Fresnel's mirrors. In a biprism, the two coherent virtual sources are produced by refraction and the distance between the two sources depends upon the refractive index, which in turn depends upon the wavelength of light. Therefore, for blue light the distance between the two apparent sources is different to that with red light. The distance of the *n* th fringe from the centre (with monochromatic light)

$$x = \frac{n\lambda D}{d}, \qquad \text{where } d = (2\mu - 1)\alpha y_1$$

$$\therefore \quad x = \frac{n\lambda D}{2(\mu - 1)\alpha y_1}$$

Therefore for blue and red rays, the *n* th fringe will be,

$$x_b = \frac{n\lambda_b D}{2(\mu_b - 1)\alpha y_1} \quad ...(i)$$

$$x_r = \frac{n\lambda_r D}{2(\mu_r - 1)\alpha y_1} \quad ...(ii)$$

$$d = 2(\mu - 1)\ \alpha y_1$$

Here $\mu = 1.5, \quad \alpha = 1° = \dfrac{\pi}{180}$ radian

$$y_1 = 20 \text{ cm}$$

$$d = \frac{2(1.5-1)\pi \times 20}{180} = \frac{2 \times 0.5 \times 22 \times 20}{7 \times 180}$$

$$= \mathbf{0.35\ cm}$$

Example 8.17. *Calculate the separation between the coherent sources formed by a biprism whose inclined faces make angles of 2° with its base, the slit source being 10* cm *away from the biprism* (μ = 1.50.) *(Delhi 1974, 1977)*

$$d = 2(\mu - 1)\alpha y_1$$

Here $\mu = 1.50$

$$\alpha = 2° = \frac{2 \times \pi}{180} = \frac{\pi}{90} \text{ radian}$$

$$y_1 = 10 \text{ cm}$$

$$d = \frac{2(1.5-1) \times 10}{90} = \frac{2 \times 0.5 \times \pi \times 10}{90}$$

$$= \mathbf{0.35\ cm}$$

Example 8.18. *In a biprism experiment, the eye-piece is placed at a distance of 1.2* m *form the source. The distance between the virtual sources was found to be 7.5 × 10⁻⁴* m. *Find the wavelength of light, if the eye-piece is to be moved transversely through a distance of 1.888* cm *for 20 fringes.* *(Delhi 1985)*

$$\beta = \frac{\lambda D}{d}; \quad \beta = \frac{l}{n}$$

$$\frac{l}{n} = \frac{\lambda D}{d}$$

$$\lambda = \frac{l\,d}{nD}$$

$$l = 1.888 \text{ cm} = 0.01888 \text{ m}$$

$$d = 7.5 \times 10^{-4} \text{ m}$$

$$n = 2.0$$

$$D = 1.2 \text{ m}$$

$$\lambda = \frac{0.01888 \times 7.5 \times 10^{-4}}{20 \times 1.2}$$

$$= 5900 \times 10^{-10} \text{ m}$$

$$= \mathbf{5900\ Å}$$

Example 8.19. *The inclined faces of a biprism of refractive index 1.50 make angle of 2° with the base. A slit illuminated by a monochromatic light is placed at a distance of 10* cm *from the biprism. If the distance between two dark fringes observed at a distance of 1* cm *from the prism is 0.18* mm, *find the wavelength of light used.*

[*Delhi (Hons) 1991*]

Here, $\beta = \dfrac{\lambda D}{d} \quad \therefore \quad \lambda = \dfrac{\beta d}{D}$

$$\beta = 0.18 \text{ mm} = 0.18 \times 10^{-3} \text{ m}$$

$$d = 2(\mu - 1)\alpha y_1$$

$$m = 1.5$$

$$\alpha = 2° = \frac{2 \times \pi}{180} = \frac{\pi}{90} \text{ radian}$$

$$y_1 = 10 \text{ cm} = 0.1 \text{ m}; \quad y_2 = 1 \text{ m}$$

$$D = y_1 + y_2 = 0.1 + 1 = 1.1 \text{ m}$$

$$\lambda = ?$$

$$d = \frac{2(1.5-1)\ \pi \times 0.1}{90} = 3.49 \times 10^{-3}$$

$$\lambda = \frac{\beta d}{D}$$

$$\lambda = \frac{0.18 \times 10^{-3} \times 3.49 \times 10^{-3}}{1.1} = 5.711 \times 10^{-7} \text{ m}$$

$$\lambda = \mathbf{5711\ Å}.$$

8.10 DETERMINATION OF THE THICKNESS OF A THIN SHEET OF TRANSPARENT MATERIAL

The biprism experiment can be used to determine the thickness of a given thin sheet of transparent material *e.g.*, glass or mica.

Suppose A and B are two virtual coherent sources. The point C is equidistant from A and B. When a transparent plate G of thickness t and refractive index μ is introduced in the path of one of the beams (Fig. 8.10),

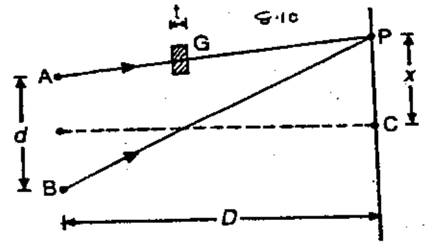


Fig. 8.10.

the fringe which was originally at C shifts to P. The time taken by the wave from B to P in air is the same as the time taken by the wave from A to P partly through air and partly through the plate. Suppose c_0 is the velocity of light in air and c its velocity in the medium

$$\therefore \quad \frac{BP}{c_0} = \frac{AP-t}{c_0}+\frac{t}{c}$$

or $$BP = AP - t + \frac{c_0}{c}t. \quad \text{But } \frac{c_0}{c} = \mu$$

$$\therefore \quad BP - AP = \mu t - t = (\mu - 1)t$$

If P is the point originally occupied by the n th fringe, then the path difference

$$BP - AP = n\lambda$$

$$\therefore \quad (\mu - 1)\,t = n\lambda \qquad ...(i)$$

Also the distance x through which the fringe is shifted

$$= \frac{n\lambda D}{d}$$

where $$\frac{\lambda D}{d} = \beta, \text{ the fringe width.}$$

$$\therefore \quad x = \frac{n\lambda D}{d}$$

Also, $$n\lambda = \frac{xd}{D}$$

or $$(\mu - 1)t = \frac{xd}{D} \qquad ...(ii)$$

Therefore, knowing x, the distance through which the central fringe is shifted, D, d and μ, the thickness of the transparent plate can be calculated. If a monochromatic source of light is used, the fringes will be similar and it is difficult to locate the position where the central fringe shifts after the introduction of the transparent plate. Therefore, white light is used. The fringes will be coloured but the central fringe will be white. When the cross wire is at the central white fringe without the transparent plate in the path, the reading is noted. When the plate is introduced, the position to which the central white fringe shifts is observed. The difference between the two positions on the micrometer scale of the eyepiece gives the value of the shift which is equal to x. Now, with the monochromatic source of light, the micrometer eyepiece is moved through the same distance x and the number of fringes that cross the field of view is observed. Suppose n fringes cross the field of view. Then from the relation

$$(\mu - 1)t = n\lambda$$

the value of t can be calculated. The value of t can also be calculated from equation (*ii*). However, if t is known, μ can be calculated.

This experiment also shows that light travels more slowly in a medium of refractive index $\mu > 1$, than in air because the central fringe shifts towards the side where the transparent plate is introduced. Had it been opposite, the shift should have been to the other side. The optical path in air $= \mu \times t$, for a medium of thickness t and refractive index μ.

Example 8.20. *When a thin piece of glass* 3.4×10^{-4} cm *thick is placed in the path of one of the interfering beams in a biprism arrangement, it is found that the central bright fringe shifts through a distance equal to the width of four fringes. Find the refractive index of the piece of glass. Wavelength of light used is* 5.46×10^{-5} cm.

[*Delhi (Hons.)*]

Here $$t = 3.4 \times 10^{-4} \text{ cm}$$
$$n = 4$$
$$\lambda = 5.46 \times 10^{-5} \text{ cm}$$
$$\mu = ?$$
$$(\mu - 1)\,t = n\lambda$$