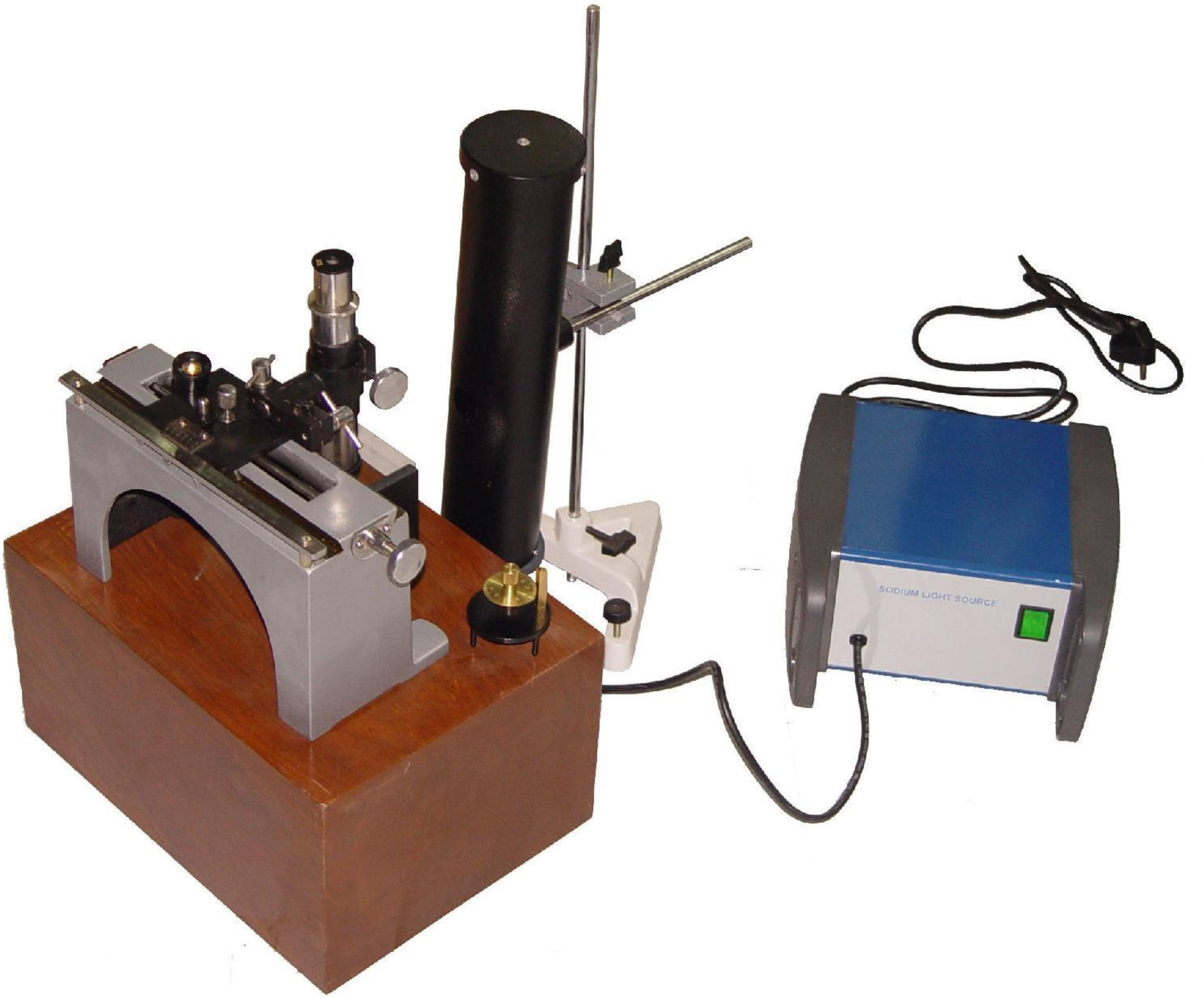
PHYSICS
LABORATORY MANUAL

Department of Applied sciences
National Institute of Technology Goa

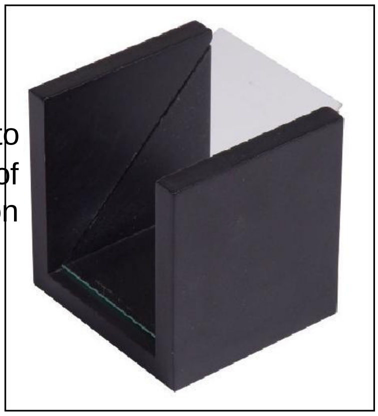
CONTENT:

EXP1. TO DETERMINE THE WAVELENGTH OF SODIUM LIGHT



It consists of following item:

1. Newton's rings Apparatus with reflector



It consists of a frame with a plane glass plate mounted at 45^0 to reflect the light downwards on a planoconvex lens (50mm dia) of large focal length placed on a plane glass plate which rests on the base of the box.

2. Sodium Light Source: Consists of housing for sodium vapour lamp which has a circular aperture of dia 25mm and a transformer. Lamp house provided with bulb holder made of Brass.The complete set up is mounted on rod using bosshead mounted on a stand base.Operating voltage 220 Volts, 50 Hz. Sodium lamp 35W.

3. Bridge type microscope SPA13: This type of microscope is suitable for Newton's Rings experiment. Microscope has provision to work either in horizontal or vertical direction at a time. The microscope with rack and pinion arrangement is fitted on the vertical carriage and can be clsmped in a vertical or horizontal position.It has eyepiece ramsden 10X, objective 3x, scale length 110mm and least count 0.01mm.

4. Wooden Block: The bridge type microscope and Newton ring apparatus with reflector can be put over it during experiment.

5. Plano-convex lens with plane glass plate
6. SPHEROMETER (DISC BRASS)

Radius of curvature of planoconvex lens can be measured with this. It is double disc type. It consists of 3 legs. Scales, top and bottom disc are made of Brass. Vertical scale section size 6mm x 6mm (Width x Thickness). Diameter of micrometer head disc 40mm. Lower bigger disc having Diameter 60mm is black powder finished. Supplied with glass plate. Range 10-0-10 mm, least count 0.01mm.

A Plano-convex lens is placed with its convex surface on the optically plane glass plate so as to enclose a thin film of air of varying thickness between the lens and the plate. Light from an extended monochromatic source (i.e.sodium lamp) of light is converted into a parallel beam of light by using a convex lens L of short focal length and made to fall on an optically plane glass plate inclined at an angle of 45^0 to the vertical, where it gets reflected on to the Plano-convex lens L as shown in Fig.1 2

Interference takes place between the rays of light reflected from the upper and the lower surfaces of the wedge shaped air film enclosed between lens L and glass plate P and circular interference fringes (alternate dark & bright) called Newton's rings are produced as shown in Fig.2

The center will be dark because at the center, lens is in contact with the glass plate and thickness of air film at the center is zero. By Stoke's law, a phase change of (or path difference of Fig.2) takes place due to reflection at the lower surface of the air film (Fig. 3) as the ray of light passes from rarer to denser medium. As we proceed outwards from the center, the thickness of the air film gradually increases being the same all along the circle with the center at the point of contact. Thus the fringes produced are concentric circles and localized in the air film. The fringes can cbe viewed by means of a low power traveling microscope 'M' as shown in Fig.1

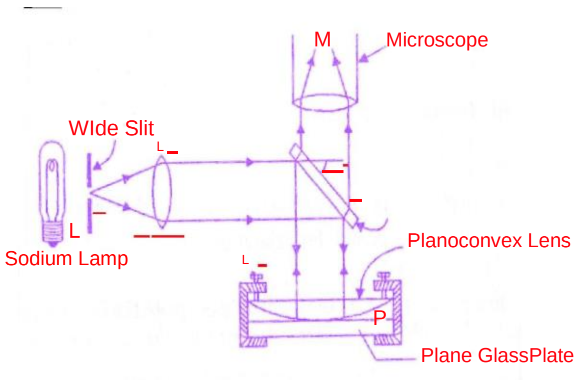


Fig. 1

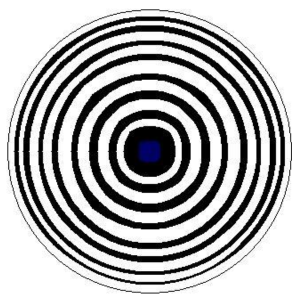


Fig. 2

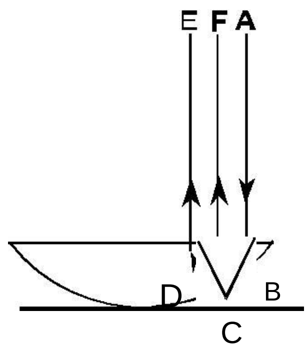


Fig. 3

The fringes are circular due to the fact that air film is symmetrical about the point of contact. The locus of all the points at same thickness is a circle i.e. all the points where the air film has a given thickness lie on a circle whose center is at 'O'.

Let 'R' be the radius of curvature of the surface of plano-convex lens in contact with the glass plate P,
D_n= diameter of the n^{th} dark ring n

λ = Wavelength of monochromatic source of light used 2
then, $D_n^2 = 4nR\lambda$

It may be pointed out that surfaces of the lens and the plate may not be clean and the lens may not be perfect contact with the glass plate at the center. Then the center will not be dark. To eliminate the error due to this problem,

the diameter of any two dark rings say, n and m may be determined.
Therefore ,
$D_n^2 = 4nR\lambda$ ....….......(1)
$D_m^2 = 4nR\lambda$ ....(2)

from equations (1) and (2),we get

$\lambda = D_n^2 - D_m^2 / 4(n-m)R$…..........……(3)

since, this formula involves the difference of the squares of the diameters of two rings and is independent of the thickness of the air film at the point of contact 'O', the above error is minimized.

If the measurements are made on bright rings of the diameter of n bright ring is given by $D_n^2 = 2(2n+1)R$

Therefore Diameter of the ring depends upon the wavelength of light used.

If white light is used in place of monochromatic light, a few coloured rings are observed. Each color gives rise to its own system of rings. These colored rings soon superimpose and overlap thereby resulting in almost uniform illumination after a few rings.

If a plane mirror is placed in place of glass plate below the plano-convex lens, a uniform illumination is observed as whole of light gets reflected from the mirror.

PROCEDURE

1. Find the least count of microscope scale.
2. Clean the surface of glass plate, and the Plano-convex lens L .Put them in position as shown in Fig.1 in front of the sodium lamp.
3. Switch on the sodium lamp and see that only parallel beam of light coming from the convex lens falls on the glass plate.
4. Adjust the position of the microscope so that it lies vertically above the center of the lens .Focus the microscope so that alternate dark and bright rings are clearly visible.
5. Adjust the position of the microscope till the point of intersection of the cross-wires coincides with the center of the ring system and one of the vertical cross-wires is perpendicular to the horizontal scale.
6. Move the microscope to the left with the help of micrometer screw so that the vertical cross wire lies tangentially at one of the extreme ends of the 20th dark ring.

7. Note the reading of the micrometer scale of the microscope.
8. Slide the microscope backward with the help of micrometer screw and go on noting the readings when the cross wire lies tangentially at the extreme ends of horizontal diameter of 16 th,12th ,8 th and 4 th dark rings respectively.
9. Continue sliding the microscope to the right and note the readings when the vertical cross wires lies tangentially at the other extreme end of the diameter of 4 th,8 th ,16 th and 20 th dark rings respectively.
10. Now slide the microscope backwards and again note down the readings corresponding to the same rings on the right and then on the left to the center of the ring system.
11. Remove the Plano-convex lens and find the radius of curvature of its convex surface by using a sphero meter.

The radius of curvature may also be determined by plotting a graph between D_n^2 along Y-axis and then number of the ring(n) along X-axis as explained in part-2 of the experiment.

LEAST COUNT = Pitch / 100 = 0.001 cm OBSERVATIONS: Pitch of the micrometer scale= 0.1 cm

Ring No.	Microscope reading		Diameter	Microscope reading		Diameter	Mean diameter
	Left(a) cm	Right (b) cm	=(a-b) or =(b-a)	Right (c) cm	Left(d) cm	=(c-d) or =(d-c)	
20							
16							
12							
8							
4							

*Microscope reading = main scale reading + circular scale division x Least count

Radius of curvature of surface of plano-convex lens in contact with the glass plate

Pitch of spherometer = distance moved on mm scale/no. of rotations =o.1cm Least count= pitch/no. of divisions on circular scale = 0.0005 cm

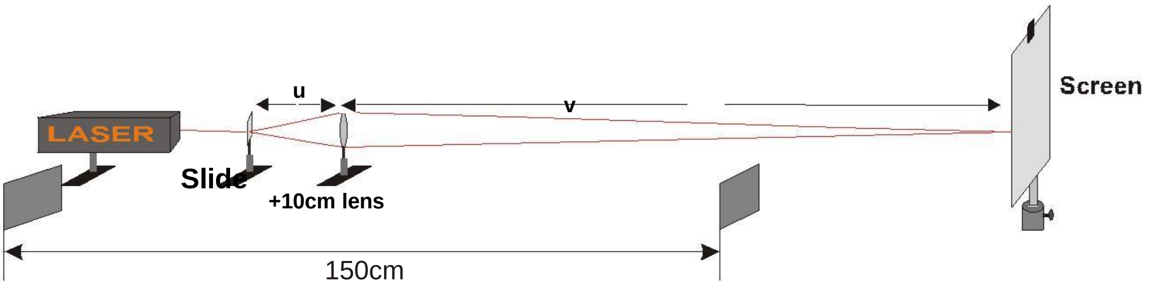
Distance between the tips of two legs of spherometer:

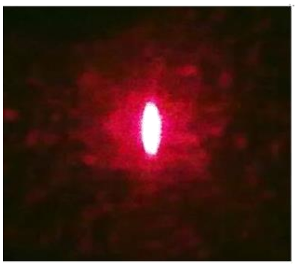
Ex1: L_1 = 5.05 cm 2. L_2 = 5.05 cm 3. L_3 = 5.05 cm 3

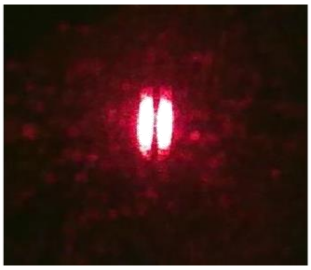
Mean L = (L_1 + L_2 +L_3) / 3 = 5.05 cm

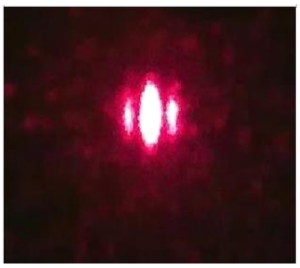
EXP. 2: DIFFRACTION PATTERN BY PINHOLE, SINGLE SLIT & DOUBLE SLIT

1. In place of slit blade in Exp. 1, In Exp. 2 mount the slide with single slit, pinhole or double slit as required.







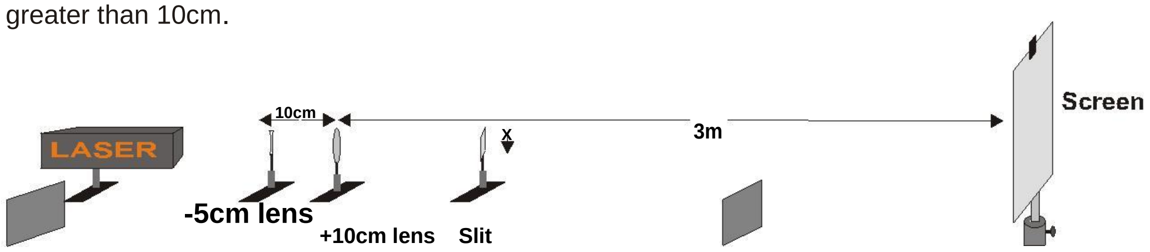


Single Slit **Double Slit** **Triple Slit** **Four Slit** **Pin Hole**

2. Place a lens of +10 cm focal length between slit holder and screen.
3. Adjust the lens such as a sharp image of the slits/ pin holes formed on the screen.
4. Subsidiary maxima will now show in the form of spots (from slits) or rings (from pinholes)
5. ***Measurement of slit or pinhole width.***
   a) Form a very sharp image of aperture itself on the screen, using the He-Ne laser as an illuminant, measure u, v and width of the image.
   b) Calculate, aperture width = (image width) x u / v
6. Measure the Aperture width using Traveling microscope to verify your answer.

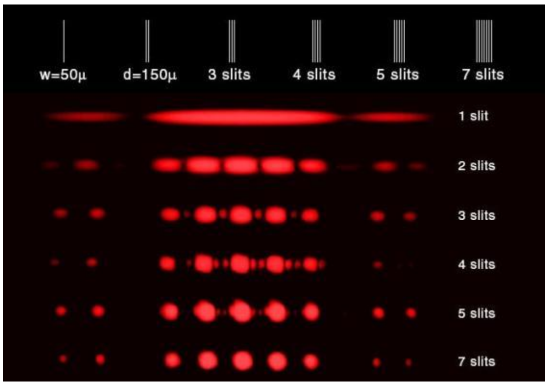
EXP. 3: TO DEMONSTRATE YOUNG'S FRINGES.

1. First, place a Lens of -5 cm focal length in front of laser source.
2. Now place +10 cm focal length lens between -5 cm focal length and screen.
3. Adjust the position of +10 cm focal length lens to get the sharpest possible spot on the screen i.e. -5cm lens is at focal point of +10cm lens..
4. Place the slit between +10 cm focal length lens and screen. The distance between 10cmkens and slit is greater than 10cm.



5. To measure slit separation, use method as in Exp. 2.

a). Leave the components exactly where they are and interpose the + 5cm lens at position 'x' (as shown in fig.), to obtain image of the slits on the screen.



EXP.4: TO MEASURE WAVELENGTH USING A MILLIMETRE SCALE AS A GRATING.

Apparatus

A He-Ne laser, a vernier calliper, a meter scale, millimeter graph paper etc.

Introduction

Schawlow in 1965 performed the experiment using a vernier calliper and He-Ne laser to determine the wavelength of laser light by studying the diffraction pattern obtained from millimeter scale of a ruler when laser light is made to fall on it. This is done here using the main scale of the vernier calliper in which the scale is engraved.

Theory

The unexpanded laser beam is allowed to fall at the grazing angle ($i=87.0^{o}$) on the vernier calliper placed on a horizontal table and he diffraction pattern is observed at a distance of 3 to 4 meters from the scale. The beam is suitably aligned so that a well defined diffraction pattern is obtained (figure 1 b) .

Diffraction takes place at the engraving on the scale and is governed by the equation

$$d(\sin i - \sin \theta_m) = m \lambda \qquad \text{---------- (1)}$$

where, m is the order and d is the grating constant. i, the angle of incidence and θ_m is the angle corresponding to m order. th

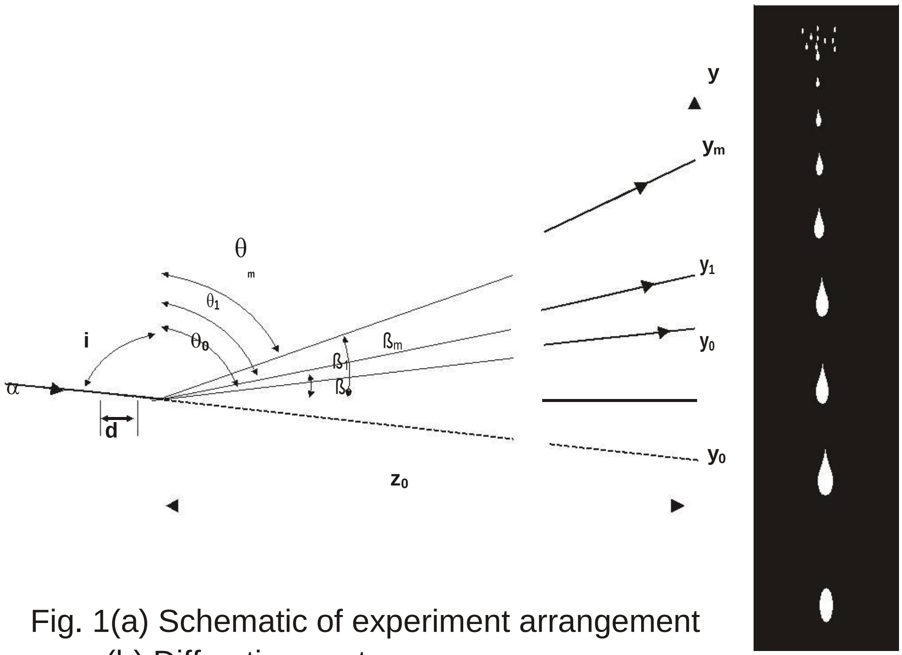


Fig. 1(a) Schematic of experiment arrangement
(b) Diffraction spots

If m= 0, then beam is reflected.

In the figure, $\propto = \dfrac{\pi}{2} - i$ and $\beta_m = \dfrac{\pi}{2} - \theta_m$

and z_0 is the distance between the region of incidence at the ruler and the screen.

y_m is the position of mth spot where the diffraction spots are taken to lie along y-axis.

$\therefore$ Equation (1) becomes : $d(\cos \propto - \cos \beta_m) = m\lambda$ ------- (2)

For zero th order, $\propto = \beta_0$

From the figure,

$$\cos \beta_m = \left[1 - \left(\frac{y_m}{Z_0}\right)^2\right]^{1/2} = 1 - \frac{1}{2}\,\frac{y_m^2}{z_0^2} + \ldots\ldots \qquad \text{-------.(3)}$$

Similarly

$$\cos \propto = \cos \beta_0 = 1 - \frac{1}{2}\frac{y_0^2}{z_0^2} + \ldots\ldots\ldots \quad \text{------- (4)}$$

Subtracting eqn. (3) from eqn. (4), we get :

$$\cos \propto = \cos \beta_0 = \frac{(y_m^2 - y_0^2)}{2 Z_0^2} \quad \text{------- (5)}$$

From eqn. (2),

$$\lambda = \frac{d (\cos \propto = \cos \beta_m)}{M}$$

Substituting eqn. (5) in eqn. (2), we get :

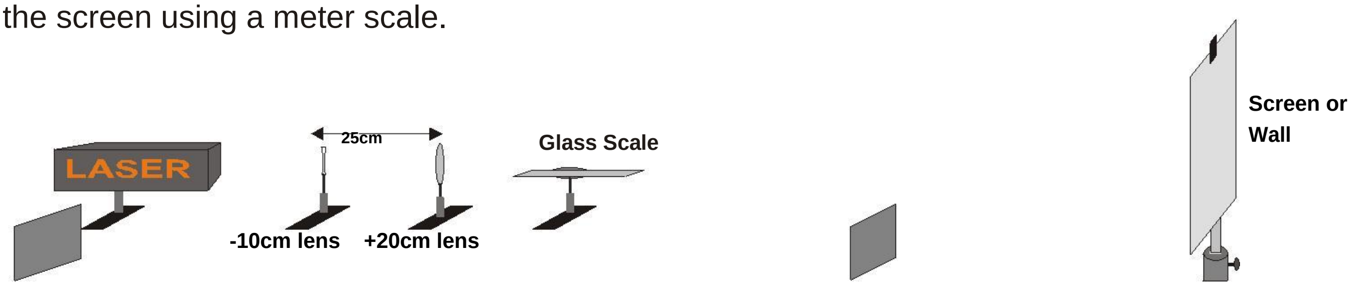
$$\lambda = \frac{d}{m} \cdot \frac{(y_m^2 - y_0^2)}{2 Z_0^2}$$

. ˙ . Wavelength of light is given by

$$\lambda = \frac{d}{2 Z_0^2} \cdot \frac{(y_m^2 - y_0^2)}{m} \quad \text{----(6)}$$

Procedure

1. Place the vernier calliper on the horizontal table at a distance of about 3-4 meters from the wall/ screen.
2. Clamp the He- Ne laser in its stand. Switch on the helium- neon laser and adjust its position so that unexpanded laser beam is incident at grazing angle on the engraving on the scale as shown in the figure 1(a).
3. Paste a millimeter graph paper on the screen.
4. For measuring he distances from the horizontal, mark the position of the direct beam (in the absence of the vernier calliper) on he screen.
5. Replace back the vernier calliper in its position so that laser light is incident at grazing angle on it. Observe the diffraction pattern on the screen. Diffraction spots on the screen as shown in figure 1(b) are observed.
6. Measure the distances of various diffraction spots from the position of the direct beam. (In the absence of the vernier calliper) on the screen and reduce them to the position midway between the direct beam and specularly reflected beam positions. These distances can be measured on a millimeter graph paper pasted on the screen.
7. Measure the distance (Z_0) between the point of incidence of laser light on the vernier calliper and the screen using a meter scale.



Observations

Spacing of the engravings on main scale of vernier calliper, d = 1 mm

Horizontal distance of screen from the point of incidence of laser beam on the vernier main scale, Z_0 =

S.No	Positions of spot (mm)	Reduced Positions y_m	y^2_m	$y^2_m - y^2_0$
1	0	0	0	
2	y_0 =	$y_0/2$ =	$(y_0/2)$ = A_0	
3	y_1=	$y_1 - y_0/2$ =	$(y_1 - y_0/2)^2 = A_1$	$(A_1 - A_0)$ =
4	y_2=	$Y_2 - y_0/2$ =	$(y_2 - y_0/2)^2 = A_2$	$(A_2 - A_0)$ =
5	y_3=	$Y_3 - y_0/2$ =	$(y_3 - y_0/2)^2 = A_3$	$(A_3 - A_0)$ =
6	y_4=	$Y_4 - y_0/2$ =	$(y_4 - y_0/2)^2 = A_4$	$(A_4 - A_0)$ =
7	y_5=	$Y_5 - y_0/2$ =	$(y_5 - y_0/2)^2 = A_5$	$(A_5 - A_0)$ =
8	y_6=	$Y_6 - y_0/2$ =	$(y_6 - y_0/2)^2 = A_6$	$(A_6 - A_0)$ =
9	y_7=	$Y_7 - y_0/2$ =	$(y_7 - y_0/2)^2 = A_7$	$(A_7 - A_0)$ =
10	y_8=	$Y_8 - y_0/2$ =	$(y_8 - y_0/2)^2 = A_8$	$(A_8 - A_0)$ =
11	y_9=	$Y_9 - y_0/2$ =	$(y_9 - y_0/2)^2 = A_9$	$(A_9 - A_0)$ =
12	y_{10}=	$y_{10} - y_0/2$ =	$(y_{10} - y_0/2)^2 = A_{10}$	$(A_{10} - A_0)$ =

Calculations & Result

The wavelength of laser light,

$$\lambda = \frac{D}{2 Z_0^2} \cdot \frac{y_m^2 - y_0^2}{m} \text{ mm.}$$

Standard value of wavelength of laser light, $\lambda = 6328 \times 10^{-10}$ m

$= 6328 \times 10^{-10} \times 1000$ mm

$= 6328 \times 10^{-7}$ mm

∴ Percentage error =

Precaution

1. The distance should be measured from the horizontal plane.
2. In the absence of the vernier calliper, the position of the direct beam should be marked on the screen and the distances of various diffraction spots are measured from this position and later reduced to the position midway between the direct beam and secularly reflected beam positions.
3. No laser light should enter the eyes.

EXP.5: TO DETERMINE THE WAVELENGTH OF SODIUM LIGHT USING A PLANE DIFFRACTION GRATING.

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Apparatus Spectrometer, diffraction grating, sodium light source

Formula used

Wavelength of the light,

$$\lambda = \frac{(a+b)\ \text{Sin}\ \theta}{m}$$

where, (a+b) is the grating element. θ is the angle of diffraction corresponding to m^{th} principal maxima on either side of the central slit image. .

Theory

DIFFRACTION OF LIGHT

When a beam of light falls on obstacles or aperture whose size is comparable to the wavelength of light. It is observed that the light bends round the corners of these narrow obstacles and enters into the geometrical shadow. This bending of light round the corners of obstacles is known as diffraction of light.

The diffraction of light is generally classified into two types as:

1. *Fresnel's diffraction*: In Fresnel's diffraction either the light source or the screen or both of them are kept at finite distance from the aperture causing diffraction. In this type of diffraction the incident wavefront is either spherical or cylindrical.

2. *Fraunhofer's diffraction*: In this type of diffraction, the light source and the screen are effectively at finite distance from the aperture. In Fraunhofer's diffraction the incident wavefront is always a plane wavefront.

PLANE TRANSMISSION DIFFRACTION GRATING

It is simple and most useful instrument for studying spectra. It consists of a grid of fine parallel lines uniformly spaced on a transmitting surface. A diffraction grating makes use of the phenomenon of Fraunhofer's diffraction. The lines are generally ruled with a fine diamond point & generally number several thousand lines per centimeter.

Let 'a' be the width of each slit and 'b' the separation between two adjacent slits then (a+b) is known a s the grating element. If n lines are ruled per unit length in a grating then the grating element (a + b) = 1/ n.

The schematic diagram of grating spectrometer is shown in fig. (1)

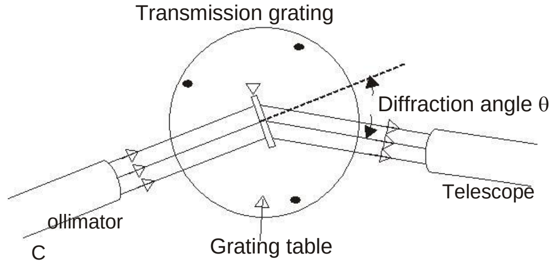


Fig. 1

The collimator directs parallel light onto the grating, in turn, acting as a dispersive element. It separates the bundles of parallel light of different wavelengths and directs them into the telescope. The observer adjusts the telescope for proper focus and sees the characteristic line or band spectrum of the source in the focal plane of the telescope.

The diffraction angle θ is unique for each wavelength.

The diffraction angle θ, wavelength λ of the light grating element (a+b) and the order number 'm' are related as

$$m\,\lambda = (a+b)\,(\sin i + \sin\theta) \qquad ....(1)$$

where, i is the angle that the incident collimated beam makes with a normal to the grating surface.

The collimator beam, in fig (1) is perpendicular to plane of the grating so that for this orientation angle $i = 0$ Therefore, for normal incidence, the equation (1) reduces to

$$m\,\lambda = (a+b)\sin\theta......... \qquad (2)$$

*w*here, m =0, $\underline{+}1$, $\underline{+}2$ ... refers to different orders of diffractions.

The essential geometry relating θ, λ and (a+b) for order m is shown in fig. (2).

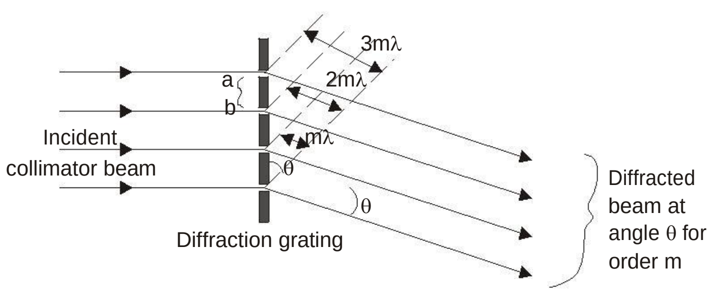


Fig. 2

Thus, the incident light is diffracted at an angle θ, which is given as $\sin\theta = m\,\lambda/(a+b)$ for a given order other than the zeroth order. Since, (a+b) and m are constant for given order, the angel θ changes with wavelength.

Therefore, the different wavelengths are observed as distinct spectrum.

If a given grating has M slits then between any two principal maxima there are (M-1) secondary minima given by the condition as

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

where , n takes all integer valves except O, M, 2M ....because for these values of n we are obtaining the principal maxima.

As in between two consecutive minima there is a maxima, thus we can say that in between (M-1) minima present between any two principal maxima, there will be (M-2) secondary maxima. The pattern obtained on the screen is as shown in figure 3.

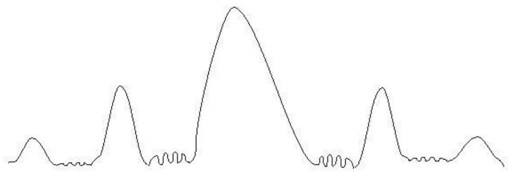


Fig. 3

Maximum number of orders of spectra

From equation(2) we cant write

$$m = \frac{(a+b)\ \text{Sin}\ \theta}{\lambda}$$

The maximum value of θ is equal to 90^o

$\therefore$ The maxima numbers of orders available with a given grating is

$$m_{maximum} = \frac{(a+b)}{\lambda}$$

Determination of λ

To determine the wavelength of light the angle of diffraction θ in the fist as well as the second order spectra is measured.

The value of λ is calculated using the formula.

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

Procedure

I *Adjustment of spectrometer*

The spectrometer with grating is used in a manner which is similar to that in which a prism is used with spectrometer.

See experiment 1 for adjustments. Once these adjustments have been made, they are not to be disturbed for the remainder of measurements. Therefore, different wavelength are observed as a distinct spectrum.

35. *Adjustment of grating*

Place the grating on the grating table (i.e. Prism Table) of spectrometer in such a way that the plane through the center of the grating table.

(In order to apply equation m λ = (a+b) sin θ without error to this experiment, the mount & leveling screens must be adjusted such that the grating is in a vertical perpendicular to the axis of the collimator and telescope.)

ii) Adust the telescope so that the vertical cross wire lies on the direct image of the slit. Note the reading on the circular scale of spectrometer using any one of the two verniers. Let this reading be θ.

iii)Rotate the telescope through 90^o . Thus, the reading of the vernier becomes ($\theta+90^o$). Clamp the telescope in this position. In this position the axis of the telescope and collimator are mutually at right angles to each other.

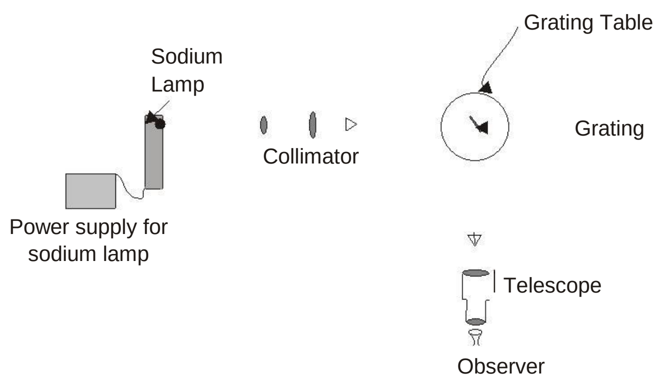


Fig. 4

iv)Rotate the turn table containing the grating till the reflected image of the slit is clearly obtained on the cross wire of the telescope. (In this position the grating is inclined at 45^o to the incident light beam as shown in figure 4.

v)Note down the reading on circular scale and then turn the table from this position through 45^o in a direction such that the grating is normal to the axis of the collimator and the ruled surface of grating is facing ht telescope. Clamp the turn table in this position.

vi) Unclamp & rotate the telescope to see first order as well as second order spectrum on either side of the direct slit image.

vii) Rotate the telescope to see the first order image on the right hand side using the fine adjustment screw and move the telescope till the vertical cross wire just falls on first order image. Note the readings of the both verniers.

viii) Set the telescope on first order image on the left hand side & note down the reading of both verniers.

ix) The difference between corresponding readings on left and right side gives 2 θ. Divide this reading in half to obtain the value of θ.

x) Repeat step no (vii) to (ix) for the second order image & find the angle of diffraction for second order image.

Observations

Least count of spectrometer =

number of lines per inch of grating, n’ = ...

grating element, (a+b) = 2.54 / n’ cm = ...cm.

3) Mean value of λ = ...

Exact value of λ (for sodium light) = 5893 Å

Calculated value of λ = ... Å

% error = ... %

Result

The value of λ = ... Å

Note: If the wave length of sodium light is given as λ = 5893 Å**.** One can also find the number of ruled lines per centimeter length of the given diffraction grating

Hint:

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

where, (a+b) is the grating element. θ is the angle of diffraction, m is the order of spectrum.

Precautions

1. The telescope & the collimator must be set for parallel rays.
2. The grating table should be leveled.
3. The experiment must be performed in a dark room.
4. The slit should be perfectly vertical & it should be made as narrow as possible.
5. The reading of both verniers should be read carefully (one can use and magnifier and a lamp).
6. Never touch the ruled surface of grating.
7. Grating should be adjusted such that the grating is in a vertical plane perpendicular to the axis of the collimator & telescope.
8. The grating should be mounted such that its ruled surface faces the telescope.

To set the grating for normal incidence

1. Reading of the scale when collimator & telescope are in line

v_1 = ...

v_2 = ...

2. Reading of the scale when telescope is rotated through an angle of 90^o.

V_1 = ...

v_2 = ...

3. Reading of scale when the slit image coincides with the vertical cross wire on rotating the grating.

v_1 = ...

v_2 = ...

4. Reading of the scale when the grating is rotated through an angle of 45^o.

v_1 = ...

v_2 = ...

Angle of diffraction

Order of the spectrum	S.No	Reading of the Vernier v_1			Reading of the Vernier v_2			Mean value of θ	
		Image on right hand side θ_R	Image on left hand side θ_L	$\theta = \frac{\theta_L - \theta_R}{2}$	Image on right hand side θ_R	Image on left hand side θ_L	$\theta = \frac{\theta_L - \theta_R}{2}$		
I Order	1								
	2								θ_1 =
	3								
II Order	1								
	2								θ_2 =
	3								

Calculations

1) First order spectrum

$$\lambda = \frac{(a+b)\sin\theta_1}{1} = \text{..................}\ \text{Å}$$

2) Second order spectrum

$$\lambda = \frac{(a+b)\sin\theta_2}{\quad} = \text{..................}\ \text{Å}$$

EXP.6: HALL EFFECT

OBJECTIVES:

To study Hall effect and to determine

Hall voltage V_H

Hall coefficient R_H

To determine the type of majority carriers i.e. whether the semiconductor crystal is of n – type or p-type.

To determine the charge carrier density or carrier concentration per unit volume in the semiconductor crystal.

To determine the Hall angle $Ø_H$.

INTRODUCTION:

In 1879, E.H. Hall observed that on placing a current carrying conductor perpendicular to a magnetic field, a voltage is observed perpendicular to both the magnetic field and the current. It was observed that the charge carriers, which were assumed to be electrons ,experienced a sideways force opposite to what was expected. This was later explained on the basis of band theory.

The number of conducting charges and the sign of charge carriers cannot be determined by the measurement of conductivity of a specimen. In metals/conductors ,the current carriers are only electrons whereas in semiconductors ,both electrons and holes act as current carriers .Therefore, in semiconductor, it is quite necessary to determine whether a material is of n-type or p-type .The Hall effect can be used to distinguish the two types of charge carriers and also to determine the density of charge carriers.

THEORY :

When a magnetic field is applied perpendicular to a current carrying specimen(metal or semiconductor),a voltage is developed in the specimen in a direction perpendicular to both the current and the magnetic field. This phenomenon is called Hall effect. The voltage so generated is called Hall voltage.

We know that a static magnetic field has no effect on charges unless they are in motion. When the charges flow , a magnetic field directed perpendicular to the direction of flow produces a mutually perpendicular force on the charges. Consequently, electrons and holes get separated by opposite forces and produce an electric field E_H ,thereby setting up a potential difference between the ends of a specimen. This is called Hall potential V_H.

WORKING PRINCIPLE:

Consider a semiconductor in the form of a flat strip .Let a current I flows through the strip along X-axis . P and P' are two points on the opposite faces of a b c d and a' b' c' d' respectively. If a millivoltmeter is connected between points P and P' ,it does not show any reading ,indicating that there is no potential difference setup between these points. But, when a magnetic field is applied along Y-axis , i.e. perpendicular to the direction of current, a deflection is produced in the millivoltmeter indicating that a potential difference is set up between P and P' . This potential difference is known as Hall voltage or Hall potential V_H.

As shown in fig. 1, if a current is passed along X-axis , then the electrons move along negative direction of x-axis .The force on electron due to the applied magnetic field B is given by,

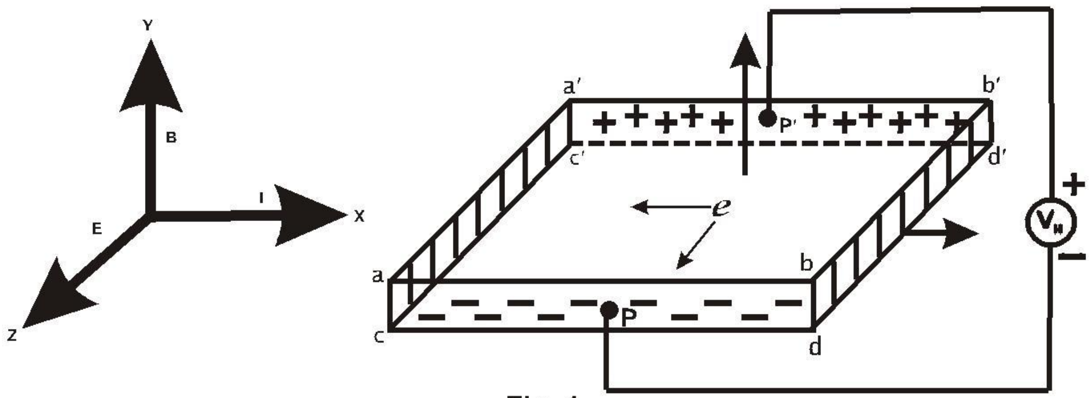


Fig. 1

$\mathbf{F} = e\,(\mathbf{v} \times \mathbf{B})$

$F = e\,v\,B \sin 90°$

Or $F = e\,v\,B$ .... (1)

where, v is the drift velocity of electron and e is the charge of electron.

Using Fleming's left hand rule it is seen that force on the electrons will be directed towards the face a b c d , i.e. along positive Z-axis ,thereby making the face a b c d negative and a' b' c' d' positive.

If the current is carried by positively charged carriers i.e. holes , the carriers move in the same direction as that of the current . The magnetic force causes the positive charge carriers to move towards the face a b c d , thereby making the face a b c d positive and a'' b' c' d' negative.
Thus, by determining the polarities of the surface of the strip , we can determine the sign of the charge carriers.

At thermal equilibrium ,when the Lorentz force exactly matches the force due to the electric field E_H (the Hall voltage) we have :

$e\,v\,B = e\,E_H$... .... (2)

If b be the width and t is the thickness of the specimen (crystal),its cross sectional area A is given by :

$A = b\,t$

The current density $J = I/A$ .... (4)

or $I = n\,e\,v\,A$... (5)

where, n is the number of charge carriers per unit volume .

Using above equations we get

$$1/ne = V_H\, b / B\, I \qquad (6)$$

The Hall coefficient is given by:

$$R_H = V_H\, b / I\, B \qquad (7)$$

and charge carrier density is given by:

$$n = 1/ e R_H \qquad (8)$$

If the conduction is primarily due to one type of charge carriers , then conductivity is related to Mobility μ_M as:

$$\mu_M = c \quad R_H \qquad (9)$$

therefore,

$$\mu_m = R_H / r \qquad (10)$$

where , r is the resistivity.

There is another interesting quantity called the Hall angle(q_H) defined by equation

$$\tan ø_H = E_H / E_X \qquad (11)$$

$$\text{but} \quad E_H = vB_X \qquad (12)$$

hence $$\tan ø_H = V_x B/E_X = \mu_m B \qquad (13)$$

HALL EFFECT EXPERIMENTAL SET-UP:

It consists of :

1. Power supply for electromagnet:
   Specifications: 0-16 V, 5 Amps.
2. Power supply (Constant current source):
   Specifications: 0-20 mA
3. Gauss meter with Hall Probe
4. Semiconductor(Ge single crystal)mounted on a PCB
   Specifications:
   - p-type Ge crystal.
   - Thickness (t): 0.5 mm
   - Width(b) : 6 mm
   - Length (l): 7mm
5. Multimeter for measuring Hall voltage.
6. Hall Effect Apparatus.

BLOCK DIAGRAM OF EXPERIMENTAL SET-UP

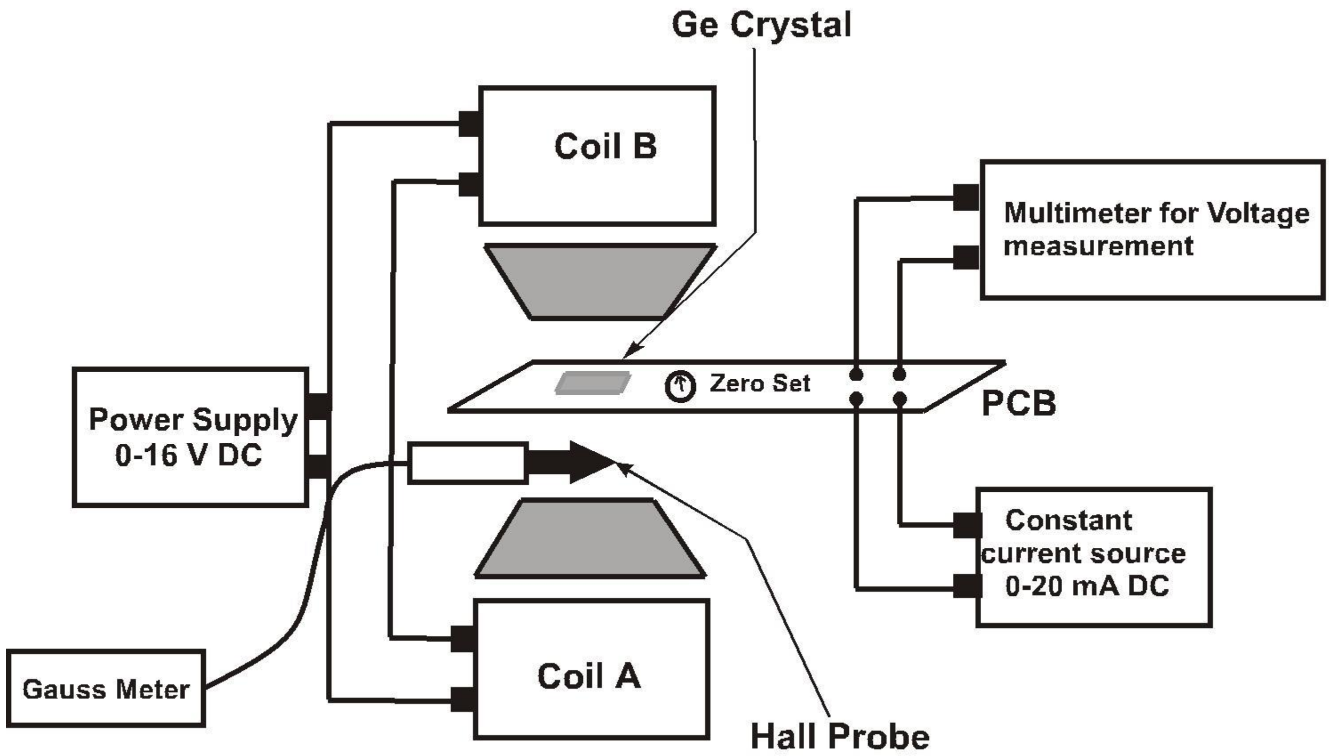


Fig. 2

Fig.2 Shows the block diagram for experimental set up with connections . A p-type Ge crystal is mounted on PCB. PCB is provided with four sockets and a pot to make the Hall voltage zero, when there is no current flowing through the crystal and also when there is no magnetic field .The lower two sockets are connected to a constant current dc source and the upper two to a multimeter/millivoltmeter.

FORMULA USED:

(1) Hall coefficient $R_H = V_H b / Bi$ m^3C^{-1}

where, V_H = Hall voltage in volts.

b = width of the sample in m.

B = magnetic flux density in Tesla. I = Current in mA.

(2) Concentration of charge carriers per unit volume

$n = 1/e R_H$ carriers m^{-3}

where, $e = 1.6 \times 10^{-19}$ C

(3) Resistivity of the material of the sample

$r = V_l\, b\, t / l\, i$ m

Where, V_l =voltage between two points situated l cm apart on one face of sample

b = width of the sample in m .

t = thickness of the specimen in m.

(4) Mobility $\mu_M = R_H / r$ $m^2 V^{-1} s^{-1}$

(5) Hall angle $ø_H = \tan^{-1}(\mu B)$

Fig. 3

EXPERIMENTAL SET-UP PROCEDURE :

6. Mount the PCB (with mounted crystal) on one of the pillars and hall probe in another pillar.
7. Complete all the connections as shown in fig.2
8. Switch ON the Gauss Meter and place the hall probe away from the electromagnet. Select the range of the gauss meter as X1 and using the adjustment knob of the Gauss Meter, adjust the reading of the Gauss Meter as zero.

   DO NOT SWITCH ON THE ELECTROMAGNET AT THIS STAGE.

9. Switch ON the constant current source and set the current, say at 5 mA in constant current source. Keep the magnetic field at zero as recorded by Gauss meter.

   DO NOT SWITCH ON THE ELECTROMAGNET AT THIS STAGE.

10. Set the voltage range of the multimeter at 0-200 mV. If needed set the voltage as recorded by multimeter to be zero by adjusting the zero set pot, as shown in fig.4, provided on the PCB using a screw driver. When a current of 5 mA is passed through the crystal without application of magnetic field the hall voltage as recorded by the multimeter should be zero.

    The zero set should be adjusted carefully and gradually.

    DO NOT SWITCH ON THE ELECTROMAGNET AT THIS STAGE.

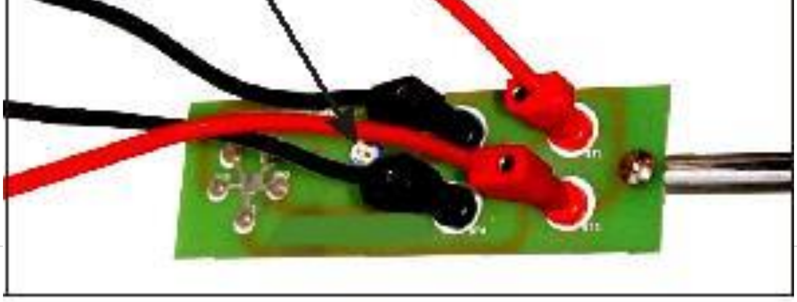


Fig. 4

6. Bring the current reading of the constant current source to Zero by Adjusting the knob of the constant current source.

1. Switch ON the electromagnet (say at about 17V, 3.5 A)

2. Select the range of the Gauss meter as x10 and measure the magnetic flux density at the center between the pole pieces. The tip of the Hall Probe and the crystal should be placed between the center of the pole pieces.
   The pole pieces should be very close to the crystal and the tip of the Hall Probe.
   POLE PIECES SHOULD NOT TOUCH THE CRYSTAL OR THE TIP OF THE HALL PROBE
   FOR CARRYING OUT THE EXPERIMENT THE MAGNETIC FLUX DENSITY SHOULD BE MORE THAN 1500 GAUSS.

2. Do not change the current in the electromagnet i.e. keep the magnetic field constant for the whole of the experiment .

10 Vary the current through the constant current source in small increments. Note the current I (mA) from the constant current source passing through the sample and the Hall voltage (mV)as recorded by the multimeter. Record these values in the observation table .

11.Reverse the direction the magnetic field by interchanging the ' +' and '-' connections of the coils(i.e by interchanging Red and Black wires to the coils of the electromagnet). Again note down the Hall Voltage for the same values of current as in step 10.
   ***Take the magnitude of magnetic flux density. In this particular case the hall voltage should* be noted without taking care of negative sign of voltage.**

OBSERVATIONS:

Width of the specimen, b = 6 mm
= 6×10^{-3} m

Length of the specimen, ℓ = 7mm
= 7×10^{-3} m

Thickness of the specimen, t = 0.5 mm
= 5×10^{-4} m

Magnetic flux density, B = ... Gauss
=......... $\times 10^{-4}$ Tesla

OBSERVATION TABLE HALL VOLTAGE VS CURRENT

S. No.	Current I (mA)	Reading of millivoltmeter (mV)		Mean value of V_H (mV)	V_H/I (ohms)
		B & I in one direction	B & I in reversed direction		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					

TABLE FOR RESISTIVITY :

S. No.	Current I (mA)	Distance between Two points between which potential Difference is measured ℓ (m)	V_ℓ (mV)	$\rho = V_\ell\ bt / I\ell$ (Ω m)
1				
2				
3				
4				

CALCULATIONS :

1. Mean value of V_H / i = ... ohms
2. R_H = V_H b / i x B
   ....
   .... $m^3\ C^{-1}$

8. Sign of Hall coefficient is positive, thus the semiconductor crystal is of p-type. (*to check whether a crystal is of p-type or n-type we have first used a crystal of known type).*

   For this the direction of magnetic field is very import ant so coils should be put in the standard configuration and direction of current through the coil should be as per standard configuration.

4. Concentration of charge carriers per unit volume
   n =1/e R_H carriers m^{-3}
   where, e = 1.6 x 10^{-19} C

5. Resistivity of the material of the sample
   r = V_l b t / i l m
   Where, V_l =voltage between two points situated l cm apart on one face of sample
   b = width of the sample in m .
   t = thickness of the specimen in m.

6. Mobility μ_m= R_H / r $m^2\ V^{-1}\ s^{-1}$

7. Hall angle $ø_H$ = $\tan^{-1}(\mu B)$

SOURCES OF ERROR :

The experiment has the potential to have systematic errors which could skew the final

Calculations. This may be due to slight misalignment of the magnetic field, irregularity in the grain of germanium crystal, stray magnetic fields generated by nearby electrical equipments

■

HALL EFFECT EXPERIMENT SAMPLE RESULT
(FOR ILLUSTRATION PURPOSE ONLY)

Width of specimen, b = 6mm= 6×10^{-3} m

Length specimen, ℓ = 7mm = 7×10^{-3} m

Thickness of specimen, t =0.5mm= 5×10^{-4} m Magnetic density, B = 3110gauss= 3110×10^{-4} Tesla

OBSERVATION TABLE HALL VOLTAGE VS CURRENT

S.No	Current I (mA)	Hall Voltage V_H (mV)	Hall Coefficient $R_H=V_H/I$ Ohm
1	1.1	1.2	1.09
2	2.7	2.7	1.00
3	5.9	6.1	1.03
4	9.0	9.2	1.02
5	12.3	12.3	1.00
6	15.5	15.7	1.01
7	18.7	18.6	0.99

CALCULATIONS:

1.Mean value of V_H / I =1.02 ohm

2. $$R_H = \left(\frac{V_H}{I}\right)\frac{b}{B} = \frac{1.02 \times 6 \times 10^{-3}}{3110 \times 10^{-4}} = 1.96 \times 10^{-2}\ m^3\ c^{-1}$$

3. Sign of hall coefficient is positive.Therefore the crystal is of p-type

4. $N=1/(1.6 \times 10^{-19} \times 1.31 \times 10^{-2}) = 4.7 \times 10^{20}$ carriers per m^3

5. Resistivity

TABLE FOR RESISTIVITY

S. NO	Current	Distance between two point between which Voltage is measured (ℓ)	V_ℓ (mV)	$r = V_\ell\ b\ t / I\ \ell$ (Wm)
1.	1.1	0.206×10^{-2}m	1.2	$\frac{1.2 \times 10^{-3} \times 6 \times 10^{-3} \times 5 \times 10^{-4}}{1.1 \times 10^{-3} \times 0.206 \times 10^{-2}} = 1.59 \times 10^{-3}$
2.	2.7	0.206×10^{-2}m	2.7	$\frac{2.7 \times 10^{-3} \times 6 \times 10^{-3} \times 5 \times 10^{-4}}{2.7 \times 10^{-3} \times 0.206 \times 10^{-2}} = 1.45 \times 10^{-3}$
3.	5.9	0.206×10^{-2}m	6.1	$\frac{6.1 \times 10^{-3} \times 6 \times 10^{-3} \times 5 \times 10^{-4}}{5.9 \times 10^{-3} \times 0.206 \times 10^{-2}} = 1.5 \times 10^{-3}$

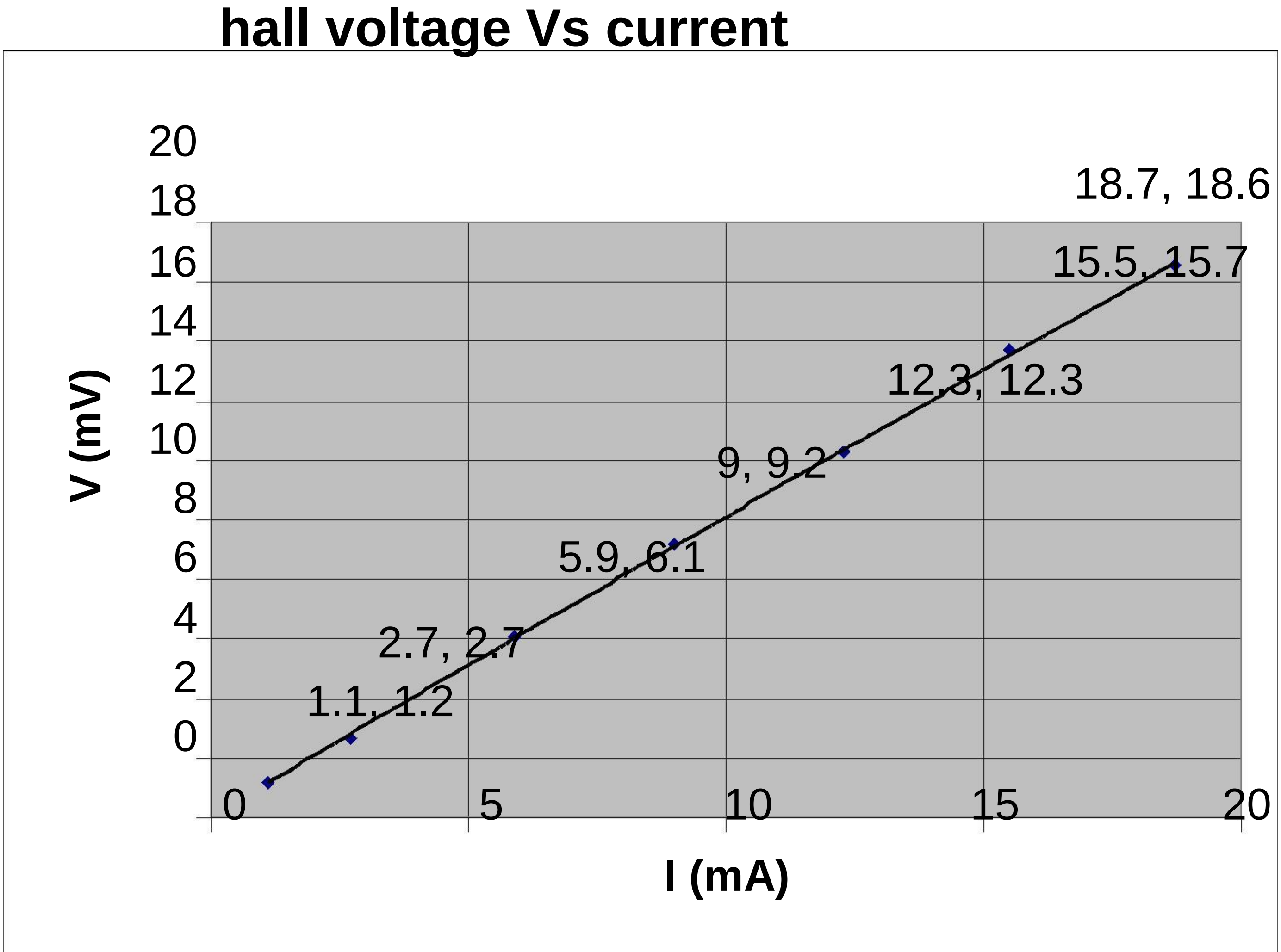
4.	9.0	0.206×10^{-2}m	9.2	$\dfrac{9.2 \times 10^{-3} \times 6 \times 10^{-3} \times 5 \times 10^{-4}}{9.0 \times 10^{-3} \times 0.206 \times 10^{-2}} = 1.48 \times 10^{-3}$

Mean of r = 1.50 x 10 Ohm-m

6. $\mu_m = R_H / r = (1.31 \times 10^{-2}) / (1.01 \times 10^{-3})$
$= 12.29\ m^3 V^{-1} s^{-1}$

7. The Hall angle, $ø_H = \tan^{-1} (\mu_m B)$
$= \tan^{-1} (12.29 \times 3110 \times 10^{-4})$
$= 75.33^o$

8. Graph between Hall Voltage V_H vs Current i



Curve shows that a linear relation exists between the current and the hall voltage.