Dr. B. C. Roy Engineering College

Durgapur, West Bengal – 713206

Physics-I

[BS-PH-191/BS-PH-291]

Lab Manual


First Year (1st Semester/2nd Semester)

Department of Physics, BCREC

SESSION – ________

Name of the student: ____

Stream____ **Group:**____________

College Roll. No. ____

University Roll. No.____

Registration No.____

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Date: ____________

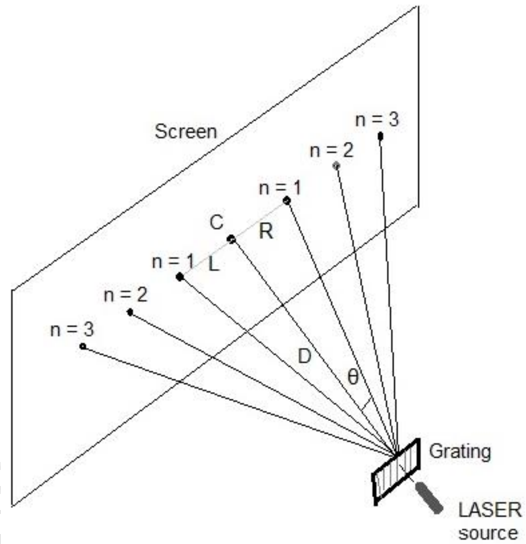
Experiment No: 1

Aim: **To determine the wavelength of a LASER by diffraction method**

Apparatus: LASER source, Transmission grating, meter scale, screen with mm graph paper.

Theory:

The bending of light from the sharp corners of an obstacle or slit (whose size is comparable with the wavelength of light) and spreading into the regions of the geometrical shadow is called diffraction of light.



If a parallel beam of light of wavelength λ is coming out from diffraction grating, placed vertically on the optical bench, then the diffracted rays from the grating will form on a screen, a number of primary maxima of different order numbers (n) on both sides of the central maximum of zero order. If θ be the angle of diffraction of nth order primary maximum then, $\sin\theta = mn\lambda$, where m is the number of ruling per cm of the grating surface.

Hence,

$$\lambda = \frac{\sin\theta}{mn}$$

If the value of m is known, the wavelength λ of unknown rays can be found out.

Procedure:

1. Switch on the LASER source. If the grating is so placed that the ruling are vertical then a horizontal series of spots will be observed on the screen. Place the screen at a large distance so that the spots are well separated. Measure the distance (D) of the screen from the grating with a scale.
2. Remove the grating. You will observe one spot on the screen, which is the central spot. Mark that with a marker.
3. Put back the grating. Mark the other fringes (1^{st}, 2^{nd}, 3^{rd}) both side of the central fringe Measure the distance of the fringes from the central fringe with the help of a meter scale.
4. Change the distance between the screen and the grating, then repeat step no-3 twice more.

Observations:

Table – 1 : Measurement of angle of diffraction for different orders

No. of Obs.	Distance between Screen and the grating D (cm)	Order of the spot n	Distance from the central spot			$\sin\theta = \frac{w}{\sqrt{w^2 + D^2}}$
			Right side, R (cm)	Left side, L (cm)	Mean distance W=(R+L)/2 (cm)	
1		1				
		2				
		3				
2		1				
		2				
		3				
3		1				
		2				
		3				

Table – 2: Calculation of wavelength

m =_______________ /cm

Order no. n	No of obs. (from Table 1)	Value of sin θ (from Table 1)	Mean sin θ	$\lambda = \frac{\sin\theta}{mn}$ (cm)	Mean Wavelength(λ) (cm)	Mean Wavelength(λ) (nm)
1	1					
	2					
	3					
2	1					
	2					
	3					
3	1					
	2					
	3					

Calculations:

Calculate wavelength λ using the working formula

Calculation of Maximum percentage error:

We know that $\lambda = \dfrac{\dfrac{w}{\sqrt{(w^2 + D^2}}}{mn}$

Therefore the proportional error is

$$\left(\frac{\delta\lambda}{\lambda}\right)_{max} = 2\frac{\delta w}{w_{min}} + \frac{\delta D}{D_{min}}$$

Where, $\delta w = \delta D = 2 \times 0.1$ cm

Calculate dλ/λ putting values of w and D and multiply it by 100 to get maximum percentage error.

Conclusion:

1. Wavelength of the given LASER is λ = __________nm
2. Percentage error in λ = ________%

Precautions and Discussions:

1. Do not stare into the LASER beam.
2. The grating plane must be parallel to the screen.
3. The LASER source should be steady.

Date: ____________

Experiment No: 2

Aim: To determine the value of unknown resistance by Carey Foster's bridge

Apparatus: Carey Foster's bridge, Unknown resistance, three resistance boxes of low value, Galvanometer, Plug commutator(C), connection wires, etc.

Theory:

Figure-1 shows a Carey Foster's bridge circuit. Here P and Q are two nearly equal resistances (each of 1 Ω); S is a thick copper strip having zero resistance; R is known resistance.

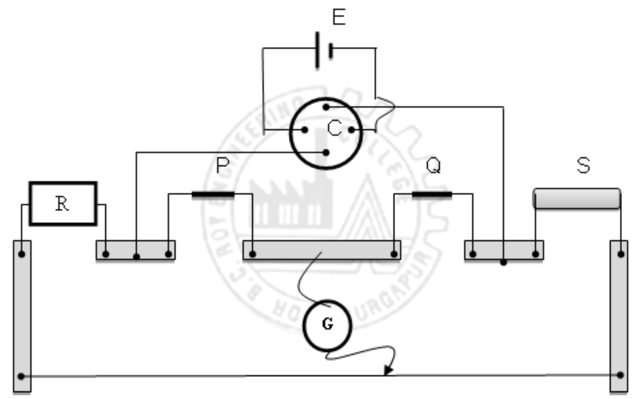


Figure 1: Circuit diagram of Carry Foster bridge

When the bridge is balanced, let the null point be l_1 cm from the left end of the bridge wire. If, by interchanging R and S, the null point is obtained at l_2 cm from the same end, we have R= $\rho(l_2-l_1)$

or, $\rho = \dfrac{R}{(l_2 - l_1)}$ ------------------------------ (1)

where ρ is the resistance per unit length of the bridge wire.

Let the thick copper strip S be replaced by known resistance r and R be replaced by the unknown resistance X. Suppose that the $l_1^/$ is the distance of the null point from the left end of the bridge wire obtain with this circuit. Let $l_2^/$ be the distance of the null point from the same end obtained with the circuit when r and X are interchanged. Then

$X = r - \rho(l_2^/ - l_1^/)$ ----------------------------- (2)

Equations (1) and (2) are the working formulas of the experiment.

Procedure:

1. The copper strip is connected at the left gap (or right) and a resistance of R is connected at other gap.
2. A small resistance (say 0.4 Ω) is applied in the resistance box R. The null point (when the galvanometer shows zero deflection) reading are noted for both direct and reverse currents. The resistance is gradually increased (say, in step of 0.2Ω) and each time the null point (l_1) is recorded for both direct and reverse current.
3. Now the copper strip S and the resistance box R are interchanged. The same resistances which were used before are applied in the resistance box and the null point (l_2) are recorded in the previous manner.
4. From the above observations the resistance per unit length ρ is calculated.
5. To find the unknown resistance X, it is connected in place of copper strip. A resistance box r is connected in the other gap. The null point readings are noted with different resistance

values for direct and reverse currents.

6. Then r and X are interchanged and the null points for the same resistance are observed. X is calculated using Eqn. (2)

Observations:

Instrumental Specifications:

1. DC voltage source:_______________________

2. Range of the Galvanometer:_______________

Table – 1: Determination of Resistance per unit length (ρ) of the bridge wire

No. of Obs.	**Resistance in (Ω)**		**Positions of the null points (cm)**			**(l_2-l_1) (cm)**	$\rho = \frac{R}{(l_2 - l_1)}$ (Ω/cm)	**Mean ρ** (Ω/cm)
	Left gap	**Right gap**	**For direct current**	**For reverse current**	**Mean**			
1	**R=**	**0**			**l_1=**			
	0	**R=**			**l_2=**			
2	**R_1=**	**0**						
	0	**R_1=**						
3	**R_2=**	**0**						
	0	**R_2=**						

Table – 2: Determination of Unknown Resistance X

No. of Obs.	**Resistance in the (Ω)**		**Positions of the null points for (cm)**			**(l_2'-l_1') (cm)**	**X =** $r - \rho(l_2' - l_1')$ **(Ω)**	**Mean X (Ω)**
	Left gap	**Right gap**	**Direct current**	**Reverse current**	**Mean**			
1	**r =**	**X**			l_1' **=**			
	X	**r=**			l_2' **=**			
2	**r_1=**	**X**						
	X	**r_1=**						
3	**r_2=**	**X**						
	X	**r_2=**						

Calculations:
Calculate the value of ρ and X using working formulae (1) and (2)

Calculation of Maximum Percentage Error:

We have, $\rho = \frac{R}{(l_2 - l_1)}$

$\therefore$ The maximum proportional error, $\left(\frac{\delta\rho}{\rho}\right)_{\max} = \frac{\delta(l_2 - l_1)}{(l_2 - l_1)} = 2\frac{\delta l}{(l_2 - l_1)}$

Where, δl = 0.1 cm (one division of meter scale)

Using a typical observed value of (l_2-l_1) we can calculate maximum percentage error in ρ as $\left(\frac{\delta\rho}{\rho}\right)_{\max} \times 100\%$

As $X = r - \rho(l_2' - l_1')$

$$\left(\frac{\delta X}{X}\right)_{max} = \left(\frac{\delta\rho}{\rho}\right)_{max} + 2\frac{\delta l}{(l_2' - l_1')_{min}}$$

Now using a typical set of observed data we can calculate $\left(\frac{\delta X}{X}\right)_{\max} \times 100\%$ as maximum percentage error.

Conclusion:

1. The resistance per unit length of the bridge wire, ρ=___________ (Ω/cm)

2. Percentage error in ρ = __________%

3. The value of unknown resistance, X= ___________ (Ω)

4. Percentage error in X =__________%

Precautions and Discussions:

1. If the bridge wire is not perfectly uniform, R is to be chosen such that the length between two null points is as large as possible.
2. Also the unknown resistance X should be measured by selecting values of r which give greater lengths between the null points l_1' and l_2'.
3. The error due to the "end correction" does not appear in this method of measurement since the difference of the lengths between the null points is involved.
4. The experiment is to be performed with direct as well as reverse current to eliminate the effect of current due to thermo-emf.
5. The specific resistance of the bridge wire can be obtained by multiplying ρ with the area of cross-section of the wire.

Date: ____________

Experiment No: 3

Aim: To determine the Young's modulus of elasticity of the material of a bar by the method of Flexure.

Apparatus: Iron bar, Travelling microscope, Hanger with slotted weight, Meter scale, Slide calipers, Screw gauge,

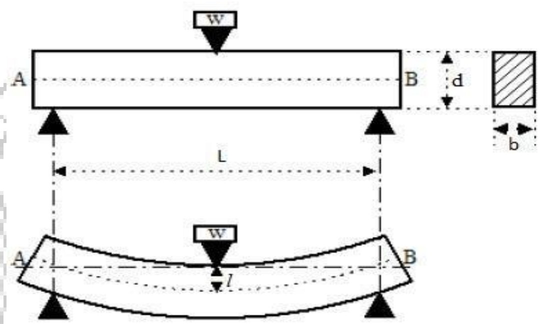
Theory:

Young's modulus is defined as the ratio of longitudinal stress and longitudinal strain within elastic limit.

If a light bar of breadth *b* and depth *d* is placed horizontally on two knife-edges separated by a distance *L*, and a load of mass *m*, applied at the midpoint of the bar, produces a depression *l* of the bar, then Young's modulus *Y* of the material of the bar is given by,

$$Y = \frac{gL^3}{4bd^3}\frac{m}{l}$$

Where, *g* is the acceleration due to gravity. This is the *working formula* of the experiment, and is valid as long as the slope of the bar at any point with respect to the unstrained position is much less than unity. Here Y is determined by measuring the quantities *b, d, L* and the mean depression *l* to a load *m*. If *b, d, L* are measured in cm, m in gm, and g is expressed in cm/sec^2, then Y is expressed in dyne/cm^2.



Procedure:

1. Measure the length of the given bar with a meter scale, and mark its mid-point by a transverse line on the bar. Draw a pairs of marks L_1L_1', which are equidistant from the central mark and lie on both sides of this mark. Choose L_1L_1' =80 cm. Mount a frame F carrying a knife-edge on the mid-point of the bar. Now place the bar, with its least dimension vertical, on the knife-edges N_1 and N_2 such that the. L_1L_1' marks coincide with the knife-edges. Mount a spirit level on the bar and adjust the leveling screws until the bar is horizontal.
2. Bring the knife-edge of the frame F on the transverse mark of the bar. Place the microscope and view the pointer P. Adjust the leveling screws of the microscope until the vertical scale is perfectly vertical and the axis of the microscope is horizontal. Focus the eye-piece on the cross-wires by keeping one of the cross-wires horizontal. Focus the tip of the pointer and adjust the vertical position of the microscope until the image of the tip of the pointer touches that of the horizontal cross-wire. As far as possible, avoid *parallax*.
3. Determine the vernier constant of the microscope. With zero loads on the hanger, record the position of the microscope on the vertical scale. Place a load of 500 gm on the hanger. This will produce a depression of the bar. Alter the position of the microscope until the image of pointer touches that of the horizontal cross-wire. Note again the vertical scale-reading of the microscope. The difference of the two microscope readings gives the depression of the bar for the load of 500 gm. Increase gradually the load in steps of 500 gm, and at each steps record the vertical scale-reading of the microscope. Collect data for 6 or 8

such observations. Now decrease the load to zero in the same steps as used for increasing the load, and record the corresponding vertical scale-readings of the microscope. Thus for a given load two readings, one when the load is increasing, and the second when the load is decreasing, are obtained. Determine the mean of these readings, and calculate the depression by subtracting the zero-load reading.

4. Remove the bar without disturbing the positions of the stands, and measure accurately the distance between the knife-edges (i.e. L_1L_1') by placing vertically the marked face of a meter scale across the knife-edges. This gives the length L.
5. Determine the vernier constant of the slide calipers and measure with it the breadth b of the bar at three different positions. Calculate the mean breadth of the bar. Note the zero error, if any, of the slide calipers and obtain the correct value of b.
6. Determine the least count of the screw gauge and measure with it the depth d of the bar at three different positions along the length of the bar. Find the mean value. Note the zero error, if any, of the screw gauge and obtain the correct value of d.
7. Draw a graph with the load *m* in gm along the x –axis and the corresponding depression *l* in cm along the y-axis. The nature of this graph, known as the load- depression graph, will be a straight line passing through the origin (0,0). Take a value of *m* except the experimental value as far away from the origin as possible and measure corresponding depression (*l*) from the graph. Calculate $\frac{m}{l}L^3$ for that particular point.
8. Determine Y from the mean value of $\frac{m}{l}L^3$, the given value of *g*, and the measured values of *b* and *d*.

Observations:

Table – 1: Vernier constant (V.C.) of the travelling microscope

Value of one smallest main scale division (*x*) (cm)	**Total number of division in vernier scale (n) = No. of division in the main scale (m)**	**Vernier constant $V.C. = x - \frac{m}{n} \times x$ (cm)**

Table – 2: Load-depression data for length L =___________cm

S. No.	Load m (gm)	Microscope reading for increasing load (cm)			Microscope reading for decreasing load (cm)			Mean reading (cm)	Depression *l* (cm)
		Main scale	Vernier scale	Total	Main scale	Vernier scale	Total		
1	0							**………..(a)**	**0**
2	500							………..(b)	(a)-(b)
3	1000							………..(c)	(a)-(c)
4	1500							:	:
5	2000							:	:

Table – 3: Measurement of breadth (b) of the bar by slide calipers

Vernier constant (V.C.) of the slide calipers = _________ cm

No. of obs.	Reading (cm) of the		Total reading b (cm)	Mean b (cm)	Instrumental error (cm)	Correct breadth b (cm)
	Main scale	Vernier scale				
1						
2						
3						

Table – 4: Measurement of depth (d) of the bar by screw gauge

Least count of the screw gauge = $\frac{\text{Pitch of the screw}}{\text{No.of division n on the circular scale}}$ = __________ **mm**

No. of obs.	Reading of the		Total reading d (mm)	Mean d (mm)	Instrumental error (mm)	Correct d (mm)	Depth d (cm)
	Main scale (mm)	Circular Scale (mm)					
1							
2							
3							

Draw Load-depression (m-*l*) graphs corresponding to lengths L.

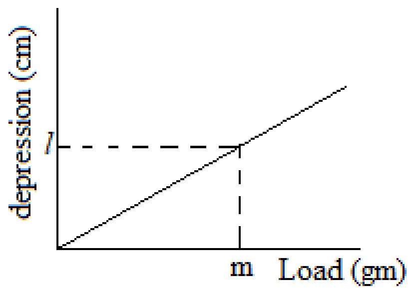


Table – 5: Determination of $\frac{m}{l}L^3$ **from load-depression graph**

Chosen value of load m on the graph (gm)	Length L (cm)	Depression *l* from graph (cm)	$\frac{m}{l}L^3$ (gm-cm^2)

Table – 6: Determination of Y

Mean $\frac{m}{l}L^3$ From Table 5 (gm-cm^2)	Breadth b from Table 3 (cm)	Depth d from Table 4 (cm)	Given g (cm/sec^2)	Young's Modulus $Y = \frac{gL^3}{4bd^3}\frac{m}{l}$ (dyne/cm^2)

Calculations:

Calculate the value of Y using the working formula

Calculation of Maximum Percentage Error:

We know Young's modulus, $Y = \frac{gL^3}{4bd^3}\frac{m}{l}$

Therefore the maximum proportional error

$\left(\frac{\delta Y}{Y}\right)_{\max} = 3\frac{\delta L}{L} + \frac{\delta b}{b} + 3\frac{\delta d}{d} + \frac{\delta l}{l}$ (Assuming m to be known fairly accurately)

Where, δL= 0.2 cm, δb = 0.01 cm, δd = 0.001 cm, and δl = 2×0.001 cm (2×v.c. of traveling microscope as l is measured by taking the difference of two readings)

Now substituting a typical set of L, b, d and l, we can calculate $\frac{\delta Y}{Y}$, then multiplying it by 100 to obtain the maximum percentage error in Y.

Conclusion:

1. Value of Young's modulus Y =____________________ dyne/cm^2
2. The percentage error in Y = __________%

Precautions and Discussions:

1. In the expression for Y, both the lengths L between the knife-edges and the depth d of the bar occur in powers of three. But as d is much smaller than L, much care should be taken to measure d to minimize the proportional error in Y.
2. Care should be taken to make the beam horizontal and to load the bar at its mid-point.
3. Try to avoid parallax and back-lash error during measurements.

Date: ____________

Experiment No: 4

Aim: To determine the rigidity modulus of the material of a wire by dynamic method.
Apparatus: Barton's rigidity apparatus, screw gauge, slide calipers, weight box, meter scale.

Theory:
The modulus of rigidity of a wire is defined as the ratio of shearing stress and shearing strain within elastic limit.
If a solid cylinder be suspended by a long wire from a torsion head, forming a torsional pendulum. Suppose the length of the wire = l, radius of the wire = r, load placed on each of the pans = m, the diameter of the cylinder C = d, twist in the wire = θ radian,

then the moment of torsional couple = $\frac{\pi\eta\theta r^4}{2l}$,

where η= modulus of rigidity of the material of the wire.
The moment of the external couple exerted by the load on the pans = *mgd.*
For equilibrium

$$\frac{\pi\eta\theta r^4}{2l} = mgd$$

$$\text{Or, } \eta = \frac{mgd2l}{\pi\theta r^4}$$

If the angle of twist is expressed in degrees and if it be ϕ degree then $\phi^0 = \frac{\pi\phi}{180}$ radian = θ

$$\text{So } \eta = \frac{mgd2l\times180}{\pi r^4\pi\phi} = \frac{360gld}{\pi^2 r^4}\left(\frac{m}{\phi}\right)$$

The modulus of rigidity of a wire is given by

$$\eta = \frac{360ldg}{\pi^2 r^4}\left(\frac{m}{\phi}\right)$$

This is the working formula for determination of modulus of rigidity of the material of the wire.
where, *l* = length of the wire, g = acceleration due to gravity, d = diameter of the cylinder, r = radius of wire, m = mass of the weight, ϕ = angle of twist in degree

Procedure:
1. Measure the radius (r) of the wire with the help of a screw gauge.
2. Measure the diameter (d) of the cylinder with the help of a slide calipers.
3. Keeping no load on the pans read the position of the pointer p on the upper and lower circular scales .This is the initial reading.
4. Place gently equal loads on each pan and this will twist in the wire. Note the reading of the pointer at the new position. Increase load on the pans by equal amounts till maximum permissible loads is reached and note down the readings of the pointer for each time.
5. Now remove the loads from the pans by the same equal till the pans becomes empty and

note down the readings of the pointer after the removal of each load. Thus we will have two readings for each load .take the mean for individual load. The difference between these readings from the initial reading without load will give the angle of twists for various loads.

6. Plot a graph between m and ϕ and then find m/ϕ from the graph.
7. Substituting the value of m/ϕ in the above equation, calculate the value η

Observations:

1. Length of the wire (l_1) ________ cm (up to upper circular scale)
2. Length of the wire (l_2) ________ cm (up to lower circular scale)

Table – 1: Determination of radius of the wire (r)

Least count of the screw gauge = _______mm

No. of obs.	Linear scale reading (mm)	Circular scale reading	Total reading D (mm)	Mean diameter D (mm)	Radius r = D/2 (mm)	Radius r (cm)
1						
2						
3						

Table – 2: Determination of diameter of the cylinder (d)

Vernier constant of the slide calipers = ________cm

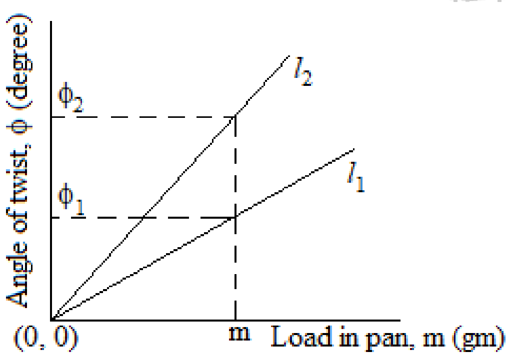
No. of obs.	Main Scale Reading (cm)	Vernier scale reading	Total reading d (cm)	Mean diameter d (cm)
1				
2				
3				

Table – 3: Determination of angle of twist for various loads

No of obs.	Load on each pan, m (gm)	Pointer readings in degree				Mean reading $\frac{1}{2}(a+b)$ (degree)		Angle of twist, ϕ (degree)	
		When load increasing *a*		When load decreasing b					
		Upper scale	Lower scale	Upper scale	Lower scale	Upper scale	Lower scale	Upper scale	Lower scale
1	**0**								
2	**50**								
3	**100**								
4	**150**								
5	**200**								
6	**250**								

Graph:

Plot of angle of twist for various loads



Calculations:

From the graph: m/ϕ_1 =_______________ (for l_1), m/ϕ_2 = _______________ (for l_2)

Modulus of rigidity of the material of the given wire by the static method is

$$\eta_1 = \left[\frac{360.gdl_1}{\pi^2 r^4}\right]\left(\frac{m}{\phi_1}\right) \text{dynes/cm}^2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \quad \text{(From the graph for } l_1\text{)}$$

$$\eta_2 = \left[\frac{360.gdl_2}{\pi^2 r^4}\right]\left(\frac{m}{\phi_2}\right) \text{dynes/cm}^2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \quad \text{(From the graph for } l_2\text{)}$$

Average $\eta = \frac{\eta_1 + \eta_2}{2}$ =________________________ dynes/cm^2

Calculation of Maximum Percentage error:

For the given relation $\eta = \frac{360ldg}{\pi^2 r^4}\left(\frac{m}{\phi}\right)$

The maximum proportional error is given by

$$\left(\frac{\delta\eta}{\eta}\right)_{max} = \frac{\delta d}{d} + \frac{\delta l}{l} + 4\frac{\delta r}{r} + \frac{\delta\phi}{\phi}$$

Where δd = 0.01 cm, δl = 2×0.1 cm =0.2 cm, δr = 0.001 cm, $\delta\phi = 0.5^0$

Substituting a set of measured value of d, l, r and ϕ we can calculate the proportional error. Then multiplying it by 100 we can get maximum percentage error in η.

$\therefore$ The percentage error is equal to $\left(\frac{\delta\eta}{\eta}\right)_{max} \times 100\%$

Conclusion:

1. Modulus of rigidity of the wire η = ________________________dyne/cm^2

2. The percentage error in η = _____________%

Precautions and Discussions:

1. Care is to be taken to see that the suspension wire may coincide with the axis of the cylinder.
2. The radius r of the suspension wire occurs in 4th power and hence it should be measured very carefully otherwise a small error in the measurement of r will increase the error in the determination of n by four time.

Date: ____________

Experiment No: 5

Aim: To determine the coefficient of viscosity of water by Poiseuille's capillary flow method.

Apparatus: Viscosity apparatus, capillary tube, steady water supply, measuring cylinder, stop clock, thermometer, meter scale, etc.

Theory:

The tangential force acting per unit area of the two adjacent layers of a liquid (water) for unit velocity gradient is referred as the coefficient of viscosity.

If the pressure difference under which the liquid flows in a horizontal capillary tube is small, the liquid particles move in straight paths parallel to the axis of the tube. This type of liquid motion is termed as streamline motion.

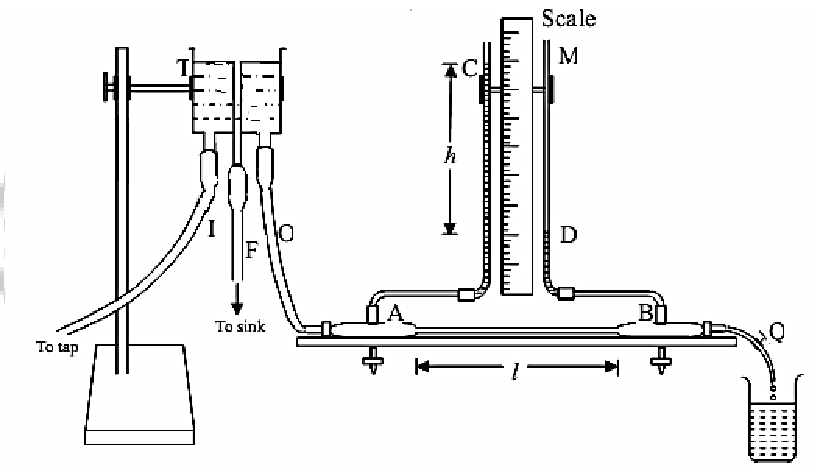
If a liquid flows in streamlines through horizontal capillary tube of internal radius r and length l, then the volume V of this liquid that flows out per second under steady pressure difference P between its ends is given by,

$$V = \frac{\pi \mathrm{P} r^4}{8\eta l}$$

Where, η is the coefficient of viscosity of the given liquid.

Thus, $\eta = \frac{\pi \mathrm{P} r^4}{8Vl}$ ------------------(1)

In the given experimental setup, P is measured from the difference of water level $h=(h_1-h_2)$ in the manometer arms. Thus P = hρg, where ρ is the density of water at room temperature.



Equation (1) represents the working formula of the present experiment.

The unit of η in C.G.S system is dyne.sec/cm^2 or gm/cm/sec or poise. In S.I system of unit, it is newton.sec/m^2. The dimension formula of ηis [$ML^{-1}T^{-1}$]

Procedure:

1. Measure the length (*l*) of the capillary tube by a meter scale.
2. Control the pinch cock Q so that water flows through the capillary tube at a slow and steady rate. When the water levels in the two arms (C and M) of the manometer tube becomes steady, collect some amount of water about 25 cc in a measuring cylinder and note down the time of collection . Find rate of flow of water.
3. Changing the rate of flow by the pinch cock Q, Repeat the procedure for more two sets.
4. Record the temperature of the water and find the density of water at this temperature.
5. Calculate η from the experimental data using the above equation.
6. Plot a graph between h and V. Find h/V from the graph and using this calculate η.

Observations:

Measurement of the following parameters

Length of the capillary tube *l* = __________cm

Radius of the capillary tube r = __________cm

Temperature of the water t = __________^{0}C

Density of water ρ = __________gm/cc.

Table – 1: To determine the rate of flow of water

No. of obs.	Volume of water collected $V^/$ (cc)	Time of collection(t) (sec)	Rate of flow of water $V = V^/ / t$ (cc/sec)
1			
2			
3			
4			
5			

Table – 2: Determine the pressure difference from manometer reading

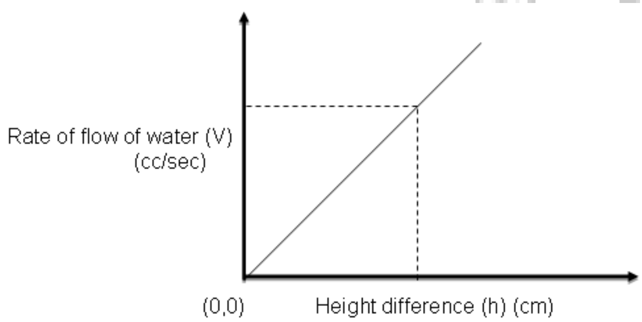
No. of obs.	Rate of flow of water *V* (From Table-1) (cc/sec)	Height of the water level in arm C h_1 (cm)	Height of the water level in arm M h_2 (cm)	$h = (h_1 - h_2)$ (cm)	$P = h\rho g$ (dynes/cm^2)
1					
2					
3					
4					
5					

Table – 3: Calculation of η from experimental data

No. of obs.	V (cc/sec)	P (dynes /cm^2)	r^4 (cm)^4	$\eta = \frac{\pi . P . r^4}{8LV}$ (Poise)	Mean η (Poise)
1					
2					
3					
4					
5					

Graph:

Plot a graph between h and V. Find h/V from the graph and using this calculate η, using the formula $\eta = \frac{\pi h \rho g r^4}{8Vl}$



Plot of h vs. V

Calculations:

Calculate **η** from experimental data and as well as **from graph**.

Calculation of maximum Percentage Error:

$$\left(\frac{\delta\eta}{\eta}\right)_{\max} = \frac{\delta h}{h} + \frac{\delta V^{/}}{V^{/}} + \frac{\delta t}{t} + \frac{\delta l}{l}$$

Where δh=0.2cm [two divisions of a meter scale, where such a scale is used to measure h; if cathetometer is used δh =2×v.c.]

δh = 0.1cm; δ$V^{/}$ = 1 cc; δt=0.5 sec (error in stop watch); δ*l* =0.2cm

Now, substituting a set of measured value of h, l, t, and $V^{/}$ we can calculate $\left(\frac{\delta\eta}{\eta}\right)_{\max}$ and then multiplying it by 100 we can get percentage error in η.

Conclusion:

1. From experimental calculation η = _________________ dyne.sec/cm^2

2. From graphical calculation η = _________________ dyne.sec/cm^2

3. The percentage error in η = ___________%

Precautions and Discussions:

1. The pressure difference under which the liquid flows must not be high to make the flow turbulent.
2. For greater accuracy, the quantity of liquid collected should be appreciable.
3. The temperature of the liquid should be noted carefully, for the value of the coefficient of viscosity changes rapidly with temperature.

Date:_______________

Experiment No: 6

Aim: Determination of Specific Charge of electron (e/m) by J.J Thomson's method

Apparatus: Cathode ray tube, wooden stand with graduated scale to mount Cathode ray tube, power supply, magnetometer, bar magnets.

Specific Charge: It is the charge to mass ratio of a charged fundamental particle like electron, proton, etc.

Theory:

The measurement of e/m is carried out by investigating the deflection properties of electron due to the application of electric and magnetic field with the aid of CRT, bar magnets and other accessories. In this experiment the electrostatic deflection is compensated by the magnetic deflection produced due to magnetic field perpendicular to the electron beam over a short distance along its path

The working formula is given by

$$\frac{e}{m} = \frac{V \times 10^7 \times Y}{l\,L\,H^2 D} \quad \text{emu./gm.............(1)}$$

Where, various parameters are

l = Length of the deflection plates.

L = Distance of screen from edges of plates, P, Q of CRT

Y = Total deflection of the spot on the screen.

H = Applied Magnetic field.

D = Separation between the plates, P, Q of CRT

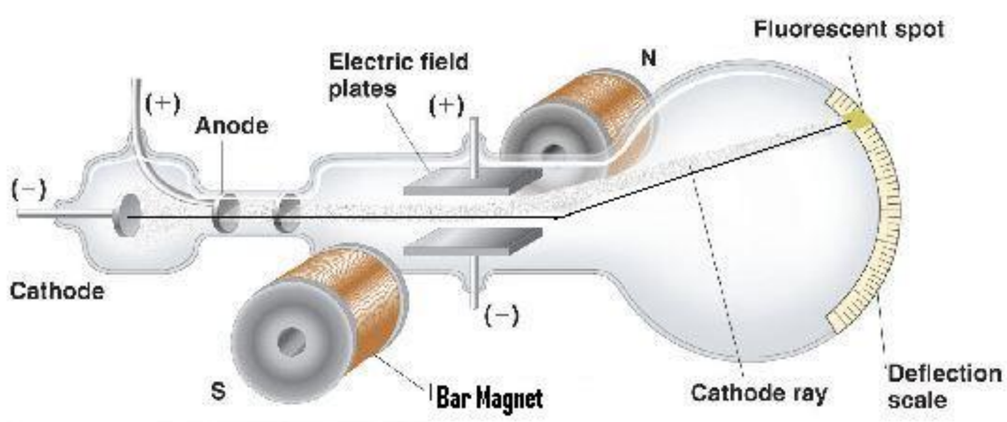


Figure-1: Schematic diagram of J. J. Thomson's experiment

Procedure:

(A) First part:

1) Place C.R. tube in a wooden stand such that the cathode ray tube faces towards north and south.
2) Switch on power supply and adjust the intensity of the spot (clear as small as a point) on the screen.

3) Adjust the spot on the scale attached with screen such that initial position is at zero. Now give a deflection in upward direction with the help of deflecting voltage (knob marked 'acceleration' on power supply) such that final reading is + 0.7, this is the deflection Y of the spot.
4) Note this applied deflecting voltage (for deflection 0.7 cm.) from the voltmeter of power supply. This is V.
5) Now place bar magnets symmetrically on each side such that their opposite poles face each other and their common axis is perpendicular to the axis of C.R. Tube. Adjust distance and polarity of the magnets such that the spot traces back to its initial position (which was zero). Note the distance of the poles of the magnet nearer to C.R. Tube on scales fitted in the wooden stand. Say they are r_1 and r_2.
6) Remove the magnets and reverse the polarity of the voltage V applied to deflecting plates PQ. Now initial deflection would be zero and final reading is – 0.7, which is the deflection of the spot. Place the magnets again on the stand adjust them to trace the spot back to initial reading (zero). Note the distance of poles of magnets close to C.R. tube; say they are r_1' and r_2'.

(B) Second part:

To measure magnetic field H:

Remove C.R. tube and magnets from stand and place a magnetometer compass box such that its center lies on the common axis of the magnets. Adjust the pointer of the compass box to read 0˚ - 0˚.

1) Now place the magnets exactly as they were placed in previous arrangement corresponding to distance r_1 to r_2, respectively. Read both ends of the pointer say they are Θ_1 and Θ_2.
2) After this, place the poles at r_1' and r_2' exactly as placed in point (6) of first part. Note the deflection of the both ends of the pointer. Say they are $\Theta_3$and Θ_4.
3) Mean deflection of the deflecting voltage V is calculated by taking mean of Θ_1, Θ_2, Θ_3 and Θ_4. This is

$$\theta = \frac{\theta_1 + \theta_2 + \theta_3 + \theta_4}{4}$$

So that magnetic field is $H = H_e \tan\theta$, where H_e is earth's horizontal component of the field at the place of experiment.

For various sets, vary deflecting voltage V (therefore different values of Y) and repeat the whole procedure as given in parts (A) and (B).

Observations:

i) Separation between the plates, D = _______ cm

ii) Length of horizontal pair of plates, l = _______cm

iii) Distance of the screen from the edges of the plates L = _______cm

iv) Horizontal component of the earth's field, H_e = 0.38 gauss

Table - 1: Determination of deflection of Y for different values of voltage V

Sl. no.	Applied Voltage (V)	Initial position of spot	Deflection Y (cm)	r_1 & pole	r_2 & pole	r_1' & pole	r_2'& pole
1	V_1=		Y_1=				
2	V_2=		Y_2=				
3	V_3=		Y_3=				

Table - 2: Determination of magnetic field H

Value of earth's horizontal component of the field at this place, H_e= 0.38 gauss

Voltage (V)	Readings of the two ends of the magnetic compass pointer		Readings of the two ends of the magnetic compass pointer		Mean deflection	Field $H = H_e \tan\theta$
	Θ_1	Θ_2	Θ_3	Θ_4	$\theta = \frac{\theta_1+\theta_2+\theta_3+\theta_4}{4}$	
V_1=						
V_2=						
V_3=						

Table - 3: Calculation of e/m

Voltage applied V (volts)	Value of H (From Table 2) (Gauss)	Value of H^2 $(Gauss)^2$	Value of Y shift Y (From Table 1) (cm)	$\frac{e}{m} = \frac{V \times 10^7 \times Y}{lLH^2D}$ (e.m.u./gm)	Mean $\frac{e}{m}$ (e.m.u./gm)
V_1=			Y_1=		
V_2=			Y_2=		
V_3=			Y_3=		

Calculation:

Calculate the value of e/m using the formula $\frac{e}{m} = \frac{V \times 10^7 \times Y}{lLH^2 D}$ for different value of V and Y.

Calculation of maximum Percentage Error:

Let ρ = $\frac{e}{m} = \frac{V \times 10^7 \times Y}{lLH^2 D}$

Then maximum proportional error is given by

$$\left(\frac{\delta\rho}{\rho}\right)_{max} = \left(\frac{\delta V}{V} + \frac{\delta Y}{Y}\right)$$

Using ΔV =2V and ΔY=0.2cm

Multiply the proportional error by 100 to get maximum percentage error.

Conclusion:

1. Specific charge of electron (e/m) = __________________ e.m.u./gm
2. Maximum percentage error in $\frac{e}{m}$ = __________ %

Precautions:

1. The cathode ray tube should be handled carefully.
2. The C.R. tube should point north south where as wooden stand must point east-west.
3. Axis of magnets and axis of the tube must lie perpendicular to each other but in the same horizontal plane.
4. The electric field between them is small. Error may arise due to the assumption of uniform field.

Date___________________

Experiment No: 7

Aim: Determination of Planck Constant (h) Using Photocell
Apparatus: Photoelectric cell, colour filters, light source.

Photoelectric effect: When light of frequency greater than threshold frequency is incident on certain metal (low work function) surfaces electrons are emitted from the metal surface. This phenomenon is called photoelectric effect.

Theory:

The maximum kinetic energy E_K of a photoelectron that is emitted from a metal surface when a monochromatic light of frequency ν falls on it is given by Einstein's relationship:

$$h\nu = E_K + W_0$$

$$E_K = h\nu - W_0 \text{.............(i)}$$

Where *h* is the Planck's constant and W_0 is the work function of the metal.

In this experiment the photoelectron are emitted from the metal (cathode) surface of a photoelectric cell. These electrons produce a current in the external closed circuit which can be detected with an ammeter. If a negative voltage is applied to the anode of the photoelectric cell with respect to the cathode, then for a particular value of the voltage, referred to as the stopping potential, the photoelectric current becomes zero. If V_S is the stopping potential and e the electronic charge, then,

$$E_K = eV_S = h\nu - W_0 \text{...........................(ii)}$$

If ν_0 is the threshold frequency, then $W_0 = h\nu_0$ and equation (ii) reduces to

$$eV_S = h\nu - h\nu_0 \text{...................................(iii)}$$

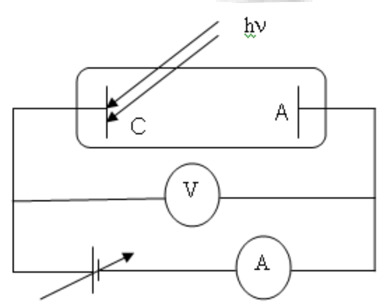


Figure-1: Circuit diagram for determination of Planck's constant

If c is the velocity of light in free space and λ and λ_0 are the wavelengths corresponding to frequencies ν and ν_0 respectively, then

$\nu = c/\lambda$ and $\nu_0 = c/\lambda_0$

Equation (iii) shows that the graph eV_S along the Y-axis and ν along the X- axis would be a straight line of slope *h*, with an intercept of ν_0 on the x-axis. This value of *h* can be determined from the slope of the straight line.

Procedure:

1. Switch on the light source and the experimental setup.

2. When a monochromatic light is incident on the cathode of the photoelectric cell current is generated and we get some current in the ammeter connected with the circuit.
3. Apply a reverse voltage in the photoelectric cell and increased the voltage very slowly, and see that current in the ammeter decreases slowly. Increase the voltage until the current in the ammeter becomes just zero. This voltage is known as stopping potential (V_S). Note this value of stopping potential. Multiply V_S by electronic charge (e) then we get energy (eV_S) in joules.
4. Put the reverse voltage at zero
5. Change the filter in front of the light source such that the wavelength (frequency) is changed then repeats the step 3 for different wavelength of light.
6. Draw a graph taking ν along X-axis and eV_S along Y-axis. The graph is a straight line as per equation (iii). Find out the slope of the straight line. The value of the slope is equal to the Planck's constant.

Observations:

Table – 1: Determination of Stopping Potential for Different Frequency of Light

Filter used	Wavelength of light (λ) (Å)	Corresponding frequency (ν) (Hz)	Stopping potential (V_S) (Volts)	Corresponding energy related to V_S is (eV_S) (joules)
RED				
ORANGE				
YELLOW				
GREEN				
BLUE				

Plot a graph taking frequency (ν) along X-axis and eV_S along Y-axis.

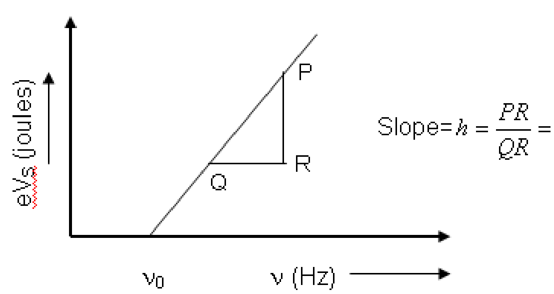


Figure-2: Frequency vs. eV_S plot

Calculations:

Calculate the value of the slope of the straight line from the graph, which is equal to the Value of the Planck's constant (*h*)

$$h = slope = \frac{PR}{QR} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$ **joule-sec.**

Calculation of Relative Percentage Error:

The relative error is given by

$$\text{Relative error} = \left|\frac{\text{Standard value - Experimental value}}{\text{Standard value}}\right|$$

Standard value of h = 6.626×10^{-34} joules-sec

Multiply the relative error by 100 to get relative percentage error.

Conclusion:

1. Value of Planck's constant, h = _________________ joule-sec.

2. Relative percentage error in h = _________%

Precaution and Discussions:

1. The filtered light should be monochromatic in nature.
2. The cathode surface is not in general a pure metal and from observed gases. Therefore, the value of h obtained in the experiment will differ from the accepted value although it's expected to have the correct order.

Date___________________

Experiment No: 8

Aim: Determination of Energy Band Gap of a Semiconductor by Four Probe Method
Apparatus: Four probe setup, oven and semiconductor**.**

Energy band gap: The difference in energy between the valence band and the conduction band of a solid material is called energy band gap.
Theory:
In case of an intrinsic semiconductor the number of electrons (n) is equal to the number of holes (p) and is given by the intrinsic carrier concentration (n_i) as

$$n_i = n = p = AT^{\frac{3}{2}} \exp\left(\frac{-E_g}{2kT}\right) \text{-----------------------------(1)}$$

Where, A = constant,
E_g = Energy band gap of the semiconductor,
T = Temperature in Kelvin
k= Boltzmann constant =8.617×10^{-5} eV
The electrical conductivity (σ_i) of an intrinsic semiconductor is given by

$$\sigma_i = \sigma_n + \sigma_p = e(n\mu_e + p\mu_h)$$

$$or, \sigma_i = en_i(\mu_e + \mu_h)$$

$$or, \sigma_i = eAT^{\frac{3}{2}}(\mu_e + \mu_h)\exp\left(\frac{-E_g}{2kT}\right) \text{-------------------------- (2)}$$

Where, μ_e and μ_h are electron and hole's mobility respectively.
At high temperature, mobility changes as $T^{-3/2}$. So we can write

$$\sigma_i = B\exp\left(\frac{-E_g}{2kT}\right) \text{-- (3)}$$

Hence the resistivity is given by

$$\rho = C\exp\left(\frac{E_g}{2kT}\right)$$

$$or, \ln\rho = \frac{E_g}{2kT} + \ln C$$

$$\ln\rho = \frac{E_g}{2k\times10^3}\frac{10^3}{T} + \ln C \text{ ------------------- (4)}$$

Where, *B* and *C* are constants .
The resistivity of the sample for the given experimental four probe set up can be calculated using the following expression

$$\rho = 0.213\times\frac{V}{I} \text{.. (5)}$$

Where, the factor 0.213 incorporates all the necessary corrections to be made for the given

geometry of the set up and the given thickness of the sample.
Equation (4) along with the eqn. (5) are the Working formula. Using eqn. (4), from the slope of lnρ vs $\frac{10^3}{T}$ graph one can determine the band gap of the semiconductor.

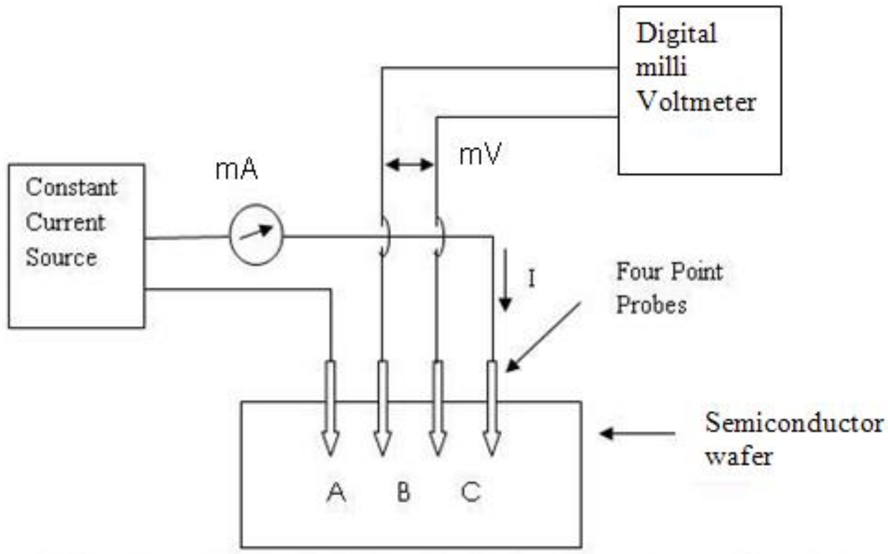


Figure-1: Experimental setup to determine the band gap of a semiconductor using Four-probe method

Procedure:

1. The given semiconductor wafer is mounted on the base plate of the four point set up. The four points are carefully lowered such that they make good contact with the surface of the semiconductor wafer.
2. The four point probe set up is kept in the oven.
3. The outer leads are connected to the constant current generator. Its inner point leads are connected to the terminals of the voltmeter. The oven leads are connected to the terminals of the power supply.
4. The mode selection switch on the constant current generator and the unit is switched on. The current through the sample is adjusted to 8 mA and kept constant.
5. Next, the mode selection switch is changed to voltage mode. The voltage is recorded and the room temperature resistivity of the material is computed.
6. The oven switch is set in LOW position so that the material will be heated up slowly. The oven is switched on.
7. The thermometer is inserted into the receptacle provided in the oven. As the temperature of the oven and hence that of the semiconductor sample rises, the voltage decreases. The voltage values for every 50C interval are recorded. The heating is done upto 1100C or 420 K. The observations are recorded in Table-1.
8. A graph for ln ρ versus 1000/T is drawn by taking 1000/T along X-axis and ln ρ along Y- axis and selecting the scales on each axis suitably.
9. In the graph, the curved portion above the straight line region indicates the extrinsic region. The straight line region is the intrinsic region.

Observations:

Room temperature: _______ ^{o}C

Voltage at room temperature: ________ mV

Current through the semiconductor: ________mA

Resistivity at room temperature: _________ ohm-cm.

Table-1: Record of voltage corresponding to the temperature of the semiconductor

Sl. No.	Temperature (^{0}C)	Temperature (T) (K)	Voltage V (mV)	Resistivity $\rho = 0.213\times\frac{V}{I}$ (Ω-cm)	$\frac{10^3}{T}$ (K^{-1})	ln ρ

Calculations:

Draw a graph taking $10^3/T$ along X-axis and lnρ along Y-axis. Calculate the slope in the linear region of the graph, m= $\frac{PR}{QR} = \frac{E_g}{2k \times 10^3}$. From the value of the slope the value of E_g is calculated.

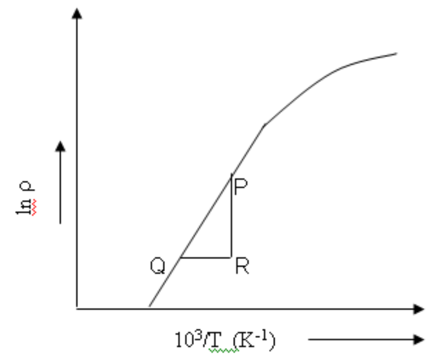


Figure-2: Plot of $10^3/T$ vs. lnρ curve

Calculate the slope in the linear region of the graph, m= $\frac{PR}{QR}$ =

Thus, $E_g = 2k \times 10^3 \times m$ (eV)= ____________ eV

Where, $k = 8.6167 \times 10^{-5}$ eV/^{0}K

Calculation of Relative Percentage Error:

The relative error is given by

$$\text{Relative error} = \left| \frac{\text{Standard value - Experimental value}}{\text{Standard value}} \right|$$

Standard value of E_g= 0.70 eV

Multiply the relative error by 100 to get relative percentage error.

Conclusions:

1. The energy gap of the given semiconductor is found to be E_g = _______eV.
2. Relative percentage error in E_g= _________%

Precautions:

1. The semiconductor wafer is very brittle. Care should be taken while mounting it on the platform below the four-point probe.
2. Minimum pressure to be exerted for obtaining proper electrical contacts to the wafer.

Date___________________

Experiment No: 9

Aim: Determination of Hall Coefficient of a Semiconductor

Apparatus: Electromagnet, gauss meter, current source, Hall setup, semiconductor sample

Hall effect: When a sheet of material (metal or semiconductor) carrying an electric current is placed in a transverse magnetic field, an electric field is developed inside the material sheet in a direction which is normal to both the current and the magnetic field. This effect is known as Hall effect.

Theory:

A charge q moving with velocity v in a region having electric field E and magnetic field B experience a force, $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$, which is Lorentz force.

If a current I flows along the length l (X-axis) of a piece of semiconductor and a magnetic field B is set up along its thickness t (Z-axis), the moving charges (electrons or holes) of the n-type or p-type semiconductor will concentrate along one side of the breadth b (Y-axis) due to Lorentz force. The charge concentration towards one side and deficiency towards the other side of the breadth will set up an electric field E_H or potential V_H (hall voltage) along Y-direction. At equilibrium the electric field (Hall field) just cancels the Lorentz force due to the magnetic field.

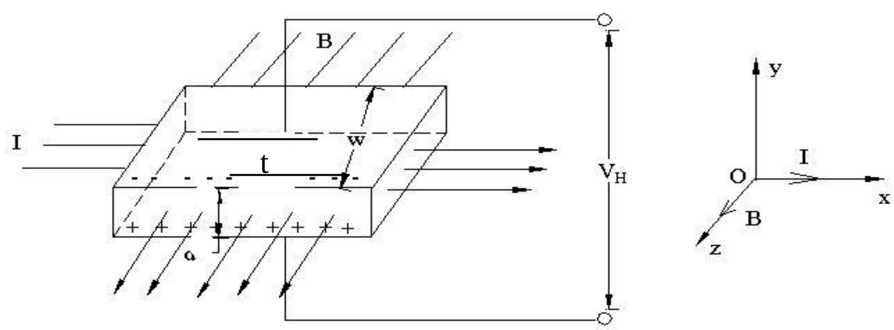


Figure-1: Schematic diagram for measuring Hall effect.

Therefore in the steady state, $qE_H = qvB$

But, J_X=nqv, thus we can substitute for v to get, $qE_H = \frac{J_x B}{n}$

Or, $E_H = \left(\frac{1}{nq}\right) J_x B = R_H J_x B$

R_H is called Hall-coefficient and is defined by $R_H = \frac{E_H}{J_x B}$

Since $E_H = \frac{V_H}{b}$ and $J_x = \frac{I_x}{bt}$, therefore, $R_H = \frac{V_H t}{I_x B}$ ------------ (1)

Eq. (1) is the working formula to determine Hall coefficient of a semiconductor.

Where, V_H is the hall voltage, t is the thickness of the semiconductor, I_x is the current through the semiconductor and B is the magnetic field intensity.

Knowing the Hall coefficient, the concentration of charge carriers in the semiconductor can be determined by the formula,

$$n = \frac{1}{R_H\ e} \quad \text{----------- (2)}$$

Where, e is the charge of electron.

Procedure:

1. Place the standard Hall Probe in the central region within the gap between pole pieces of electromagnet. Turn on the current source of electromagnet and the Gauss-meter. Turn on the knob so that the current from the sours is zero. The standard Hall probe should read zero. Adjust the zero control knob to make it zero.
2. Using Gauss-meter, values of B are measured for different values of magnetizing current passing through the electromagnet. At least five observations should be made.
3. Remove the standard hall probe. A given piece of semiconductor is placed vertically in between two magnetic pole pieces such that B is normal to the thickness (t) of the semiconductor.
4. Apply a magnetizing current, which would produce 1000Gauss magnetic field (B). Now a small current (I_x) is adjusted to flow through the semiconductor.
5. Increase the current through the semiconductor in small steps and note down the voltage (V_H) in each case .
6. Fix the current (I_x) through the semiconductor to a small value (~2.5mA). Vary the magnetizing current in small steps. Note down Hall Voltage (V_H) in each case.
7. Draw a graph of magnetic field intensity (B) Vs magnetizing current from the data of Table 1. Use this calibration curve to find out the magnetic field corresponding to the data in steps (4) and (5) (Table 2 and 3).
8. Draw a graph of Hall voltage (V_H) vs current through the semiconductor (Ix). Find the value of $\frac{V_H}{I_x}$ from the graph.
9. Draw a graph of Hall voltage (V_H) vs magnetizing field (B). Find the value of $\frac{V_H}{B}$ from the graph.

Observations:

Thickness of the semiconductor, $\mathbf{t = 5 \times 10^{-2}}$ cm

Table-1: Data for calibration curve

Current (amp)	Magnetic Field Intensity, B (gauss)

Draw a calibration curve taking current along X-axis and magnetic field along Y-axis

Table- 2: Data for current through the semiconductor and corresponding Hall voltage

Magnetizing current (amp) (Different from the values in the Table 1)	Magnetic Field Intensity, B (gauss) (Values obtained from the calibration curve)	Current through the semiconductor, I_x (mA)	Corresponding Hall voltage, V_H (mV)		
			Without magnetizing current V_0	With magnetizing current V	Corrected $V_H = (V-V_0)$

Plot a graph taking current through the semiconductor along X-axis and Hall voltage along Y-axis

Table – 3: Data for magnetic field intensity (B) and corresponding Hall voltage (V_H)

Current through the semiconductor (I_x) = _________ (mA)

Magnetizing current (I) (amp)	**Magnetic field intensity, B (gauss)** (Values obtained from the calibration curve)	**Hall voltage, V_H (mV)**	**Hall voltage, V_H (mV) (Corrected)**

Plot a graph taking magnetic field intensity along X-axis and Hall voltage along Y-axis

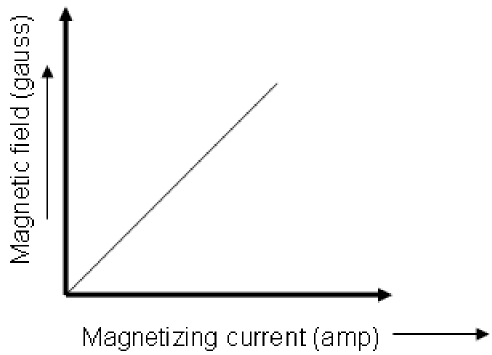


Fig.1: Calibration curve magnetic current vs. magnetic field

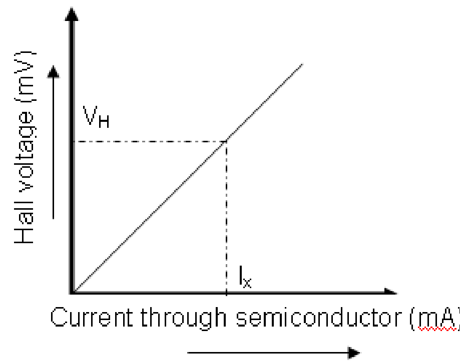


Fig.2: Plot of current through the semiconductor and Hall voltage

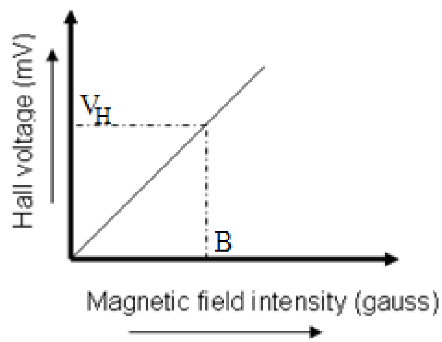


Fig. 3: Plot of magnetic field intensity vs. Hall voltage

Calculations:

1. Calculate the Hall coefficient using the equation $R_H = \frac{V_H t}{I_x B}$ once putting the value of $\frac{V_H}{I_x}$ from the graph V_H vs I_x and secondly putting the value of $\frac{V_H}{B}$ from the graph V_H vs B. Then take the average of this two value.

The value of R_H is in (ohm cm G^{-1}) multiply this experimental value by 10^8 to convert the unit in (cm^3 $coulomb^{-1}$).

2. Calculate the concentration of charge carriers in the semiconductor using the formula

$$n = \frac{1}{R_H e}\ \text{cm}^{-3}$$

Calculation of Maximum Percentage Error:

The maximum proportional error,

$$\text{Relative error} = \left| \frac{\text{Standard value - Experimental value}}{\text{Standard value}} \right|$$

Standard value of R_H = ________________ohm cm G^{-1}= ________________cm^3 $coulomb^{-1}$

Multiply the relative error by 100 to get relative percentage error.

Conclusion:

1. The value of Hall coefficient of the given semiconductor,

   R_H= ___________________ohm. cm gauss^{-1} = _______________$\times 10^8$ cm^3 $coulomb^{-1}$

2. Concentration of charge carriers in the semiconductor, n= ________________ cm^{-3}

3. The relative percentage error in R_H = __________%

Precaution and Discussions:

1. The sample is symmetrically placed at the centre between the two pole pieces of the electromagnet.
2. The current and voltage terminals of the semiconductor are properly identified and connected to the ammeter and voltmeter respectively.
3. As R_H =1/nq, the carrier concentration can be determined from the measured value of the Hall co-efficient.
4. The positive or negative value of the R_H indicates the type of semiconductor i.e. p-type or n-type.

Date___________________

Experiment No: 10

Aim: Study Current-Voltage Characteristics, Load Response, Areal Characteristics and Spectral Response of Solar Photovoltaic Cell

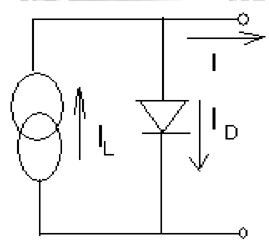
Apparatus: Solar cell, different area, different colour filters, voltmeter, ammeter,

Photovoltaic effect: The photovoltaic effect is the creation of voltage and electric current simultaneously in a material upon exposure to light.

Theory:

A solar cell is basically a p-n junction diode which converts solar energy into electrical energy. This conversion of light energy into electrical energy is known as photovoltaic effect and hence solar cell is also called photovoltaic cell.

When solar cell is illuminated by some light source, the photons incident on the cell generate electron-hole pairs and by diffusion these charge carriers reach the junction. At the junction the barrier field separates the positive and negative charge carriers. Under the action of the electric field the electron from the p-region are swept into the n-region. In this way there is increase in number of holes in p-region and of electrons in the n-region and therefore an e.m.f. is generated across the junction, which is called photo-e.m.f. and it is proportional to the intensity of the incident light and also on the size of the illuminated area for a fixed intensity. The curve which shows the variation of output power with the illuminated area is called areal characteristics. The response of a solar cell to light depends on the wavelength of the incident light and the variation of power with wavelength is called spectral response. The variation of output power with the load resistance R_L (see fig.) is called load response.



Equivalent circuit of a solar cell

The operating equation of a solar cell is

$$I = I_0\left[\exp\left(\frac{q(V+R_S I)}{AkT}\right)-1\right]+\frac{V+R_S I}{R_{Sh}}-I_L \quad \text{......................(1)}$$

Where,

A = diode identity factor, R_S= cell's series resistance, R_{Sh}= cell's shunt resistance,

I = cell's output current, I_L= Light generated current, I_0= diode saturation current,

q = electronic charge, V = cell's terminal voltage, k = Boltzmann's constant,

T = Absolute temperature.

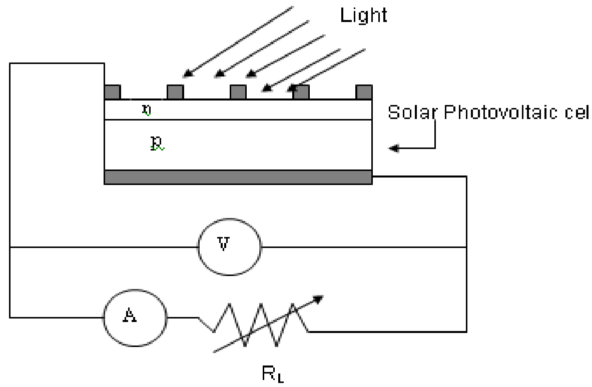


Figure-2: Circuit diagram for the characteristics of Photovoltaic solar cell

Open Circuit Voltage (V_{OC}):

The open circuit voltage V_{OC}, corresponds to the voltage drop across the p-n junction when the current through the circuit is zero, i.e the resistance in the external circuit is infinity.

$$V_{oc} = \frac{AkT}{q} \ln\left\{\frac{I_L + I_0}{I_0}\right\} = \frac{AkT}{q} \ln\left(\frac{CE_e}{I_0}\right) \quad \text{..............................(2)}$$

Where, E_e is the light intensity, C is a constant.

From equation (ii) we can see that the open circuit voltage is proportional to the $\log_e$ (ln) of intensity of light (E_e).

Short Circuit Current (I_{SC}):

The short circuit current I_{SC}, of a solar cell is the current passing through the external circuit when the output voltage in the circuit is zero.

$$I_{SC} = I_L = CE_e \quad \text{..(3)}$$

From equation (iii) we see that the short circuit current is directly proportional to the intensity of light (E_e).

Procedure:

1. **To draw the current-voltage characteristic**, the intensity of light is kept at a fixed value. The load R_L is kept at zero and the short circuit current (I_{SC}) is noted. When R_L have infinite value (open), the open circuit voltage (V_{OC}) is noted. For different values of R_L in step, the corresponding current and voltage are measured.

2. **Power load characteristics:** Using the same observation the power is calculated for each load value and the graph of power vs. load (R_L) is plotted. Find out the optimum value of the load for which the power generation is maximum.

3. **Areal characteristics:** Keeping the value of incident intensity fixed and set the load (R_L) at the optimum value obtained from the previous step. The effective illuminated areas of the solar cell are varied and the corresponding current and voltage are noted. Then the power is calculated (P=VI) and a graph of power vs. area is drawn.

4. **Spectral response:** Now, filters of different colours are used in front of the solar cell when the incident intensity and R_L have optimum constant value. The current and voltage are measured for each filter to get the power. Then a graph of power vs. wavelength is plotted.

Observations:

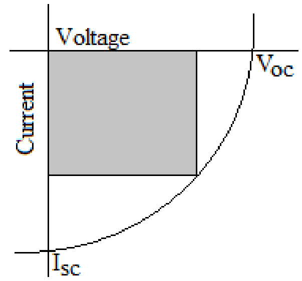
Table – 1: Data for plotting the current-voltage characteristics and load response of the solar cell

Filament Voltage= ____________volt; Intensity E_e= _____________lux,

V_{OC}= ________V, I_{SC}=________mA

No. of obs.	Load Resistance R_L (ohm)	Voltage generated in solar cell V (V)	Current generated in solar cell I (mA)	Corresponding Power P=V×I ×10^{-3} (watt)

1. Plot a graph taking solar cell voltage along X-axis and current generated in solar cell along negative Y-axis.



2. Plot another graph taking load resistance along X-axis and power generated by solar cell along Y-axis.

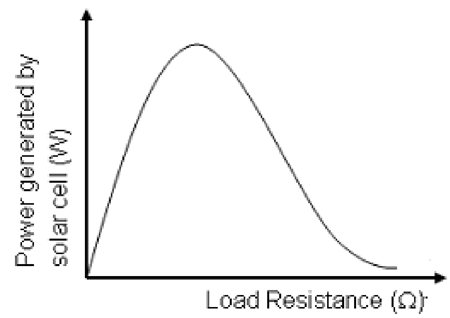


Table – 2: **Data for plotting areal characteristic of the solar cell**

Filament voltage =___________volt, Intensity of the incident light E_e =________lux

Load resistance, R_L =_________ohm

No. of obs.	Length of the chopper (cm)	Breadth of the Chopper (cm)	Diameter of the chopper (cm)	Illuminated area (cm^2)	Solar cell voltage (V)	Solar cell current (mA)	Power $\times 10^{-3}$ (W)

3. Plot a graph taking illuminated area along X-axis and power generated by solar cell along Y-axis

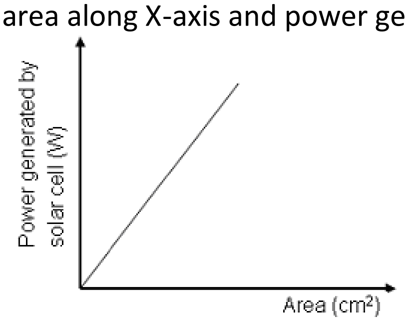


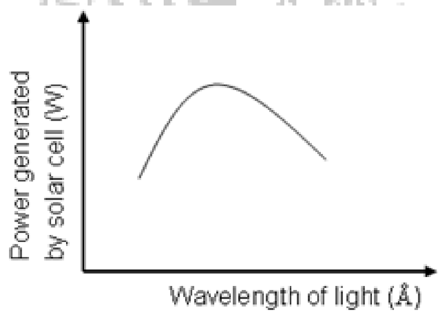
Table – 3: Data for plotting the spectral response of the solar cell

Filament voltage =___________volt, Intensity of the incident light E_e=________ lux

Load resistance, R_L =_________ohm

No. of obs.	Filters used	Wavelength (Å)	Solar cell Voltage (V)	Solar cell current (mA)	Power $\times 10^{-3}$ (W)
1	Blue	4500			
2	Green	5200			
3	Yellow	5896			
4	Orange	6250			
5	Red	6500			

4. Plot a graph taking wavelength of light along X-axis and power generated by solar cell along Y-axis



Conclusion: (Describe the nature of curve for each graph)

Precautions and Discussion:

1. The distance between the lamp and the solar cell should be fixed throughout the experiment.
2. To get better result, the solar cell is to be protected from other light source.
3. To draw the spectral characteristic, the light intensity should be kept high.
4. In this experiment setup the load response curve is slightly different from the actual one.
5. The light emerging from the lamp should fall on the solar cell normally.