MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

DEPARTMENT OF PHYSICS

I/II SEMESTER B.Tech

PHY 1081: ENGINEERING PHYSICS LAB MANUAL BOOK

Name……………………………………………………………………

Section & Roll No ……………………………………………………

Reg. No……………………………………………………………………

MANIPAL INSTITUTE OF TECHNOLOGY

Manipal - 576 104

DEPARTMENT OF PHYSICS

CERTIFICATE

This is to certify that Ms./Mr. ....

Reg No. .... Section: .... Roll No: ....

has satisfactorily completed the course of experiments in Engineering Physics Lab [PHY 1081] prescribed by the Manipal Academy of Higher Education for First Year B.Tech. degree course in the Physics Laboratory at MIT, Manipal.

Date: ……...................................

Signature
Faculty in Charge

Signature
Head of the Department

CONTENTS

Sl. No.	Experiment Title	Page No.
1	Energy Band Gap	1
2	Fermi Energy of a Metal	4
3	Photoelectric Effect	9
4	Black Body Radiation	12
5	Resistivity of Semiconductor by Four Probe Method	16
6	Hall Effect	21
7	Determination of Boltzmann Constant	25
8	Numerical Aperture of OFC	30
9	Wavelength of Laser using Diffraction Grating	34
10	Newton's Rings	37
11	Refractive Indices of Uniaxial Crystals (Demo)	42
12	Michelson's Interferometer (Demo)	47

Course Objectives:

- To understand the basic experimental techniques related to optics.
- To learn the elementary experimental techniques in modern physics.
- To study the electrical properties of materials.

Course Outcomes (COs):

At the end of the Physics Lab course, the student should be able to:

- Comprehend the phenomenon of interference, diffraction and polarization of light.
- Realize the theory and concepts of modern Physics.
- Figure out the electrical properties of conductors and semiconductors.

INSTRUCTIONS TO THE STUDENTS

Pre-Lab Session Instructions

1. Students should carry the practical record book and other necessary stationery items such as pen, pencil, eraser, scale and non-programmable calculator to every lab session.
2. Follow the institution dress code and be in time.
3. Collect the necessary equipment from the issue counter against your signature.
4. If you find any damage to the equipment issued, then inform the staff in charge at the counter immediately.
5. Make sure that you answer the attendance and then go to the allotted work area.
6. Adhere to the rules and maintain discipline & decorum.

In-Lab Session Instructions

1. Follow the instructions on the allotted experiment.
2. Perform the experiment and write the readings in the record book using pen.
3. Show the readings & calculations to the instructor on completion of experiment and get them evaluated.
4. Make sure that your marks are entered in the register.
5. Return the instruments taken at the counter, after the experiment.

General Instructions

1. Students should not bring any other note book, text book, lab manual, mobile phones and other electronic gadgets to the lab.
2. Students should not go out of the lab without permission.
3. Plagiarism (copying from others) is strictly prohibited and would invite severe penalty in evaluation.
4. In case a student misses a lab class due to genuine reason, he/she should complete that missed experiment in the subsequent lab sessions. If he/she failed to do so then zero mark will be awarded for those experiments.
5. It is mandatory to have 75% attendance in order to appear for the end semester lab examination.

Scheme of Evaluation

- **Internal Assessment Marks: 60 %**

Continuous evaluation component (for day to day experiments)

1.	Preparation / Write-up *Completeness, neatness and additional information*	03 Marks
2.	Performance and Understanding the experiment *Setting up the experiment, taking proper readings, Understanding the experiment, neatness and discipline*	04 Marks
3.	Calculation *Plotting the graph (if any) properly, Appropriate substitution of the values in the formula, accuracy of the result and presenting result with significant digits and unit.*	03 Marks
	Total	10 Marks
	(Average marks of 9 experiments) × 6	**60 Marks**

- **Marks for end semester examination of 2 hour duration: 40 %**

Students will have to perform one of the allotted experiments in the examination.

1.	Preparation / Write-up *Drawing the circuit / ray diagram and model graphs.* *Writing the formula with explanation of terms and units.* *Writing the observations and tabular columns.*	08 Marks
2.	Performance and Understanding the experiment *Setting up the experiment, taking proper readings.*	13 Marks
3.	Calculation *Drawing appropriate graph, accuracy of the result*	07 Marks
4.	Viva voce	12 Marks
	Total	**40 Marks**

Ex. No.: ....   Date:..............................

ENERGY BAND GAP

Aim: To determine the forbidden energy gap of semi-conductor.

Apparatus: A semiconductor diode, constant current source, current meter, voltmeter, water bath, thermometer etc.

Principle: Forbidden energy gap E_g of a material is the energy difference between the upper limit of its valance band and the lower limit of its conduction band. The semi conductor used is in the form of a p-n junction diode. For a small forward current (I < 0.1 mA), the voltage V across the diode varies approximately with the absolute temperature T as

$$eV = E_g - \eta kT$$

where E_g is the energy gap of the semiconductor, η is a constant that depends on the type of the semiconductor, $e = 1.6 \times 10^{-19}$C is the electronic charge and $k = 1.38\times10^{-23}$ J/K is the Boltzmann constant.

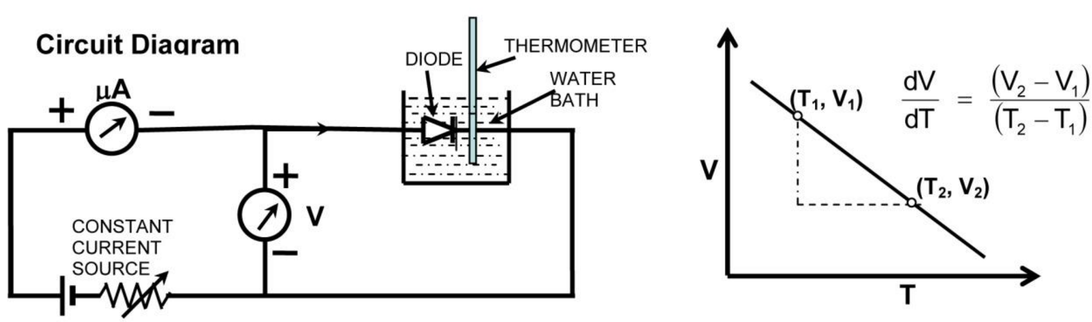

Fig: Experimental set up and graph of voltage versus temperature.

A graph of V versus T is a straight line with a V-intercept = $\frac{E_g}{e}$ at T = 0 K. Thus the energy gap of the semiconductor can be determined by calculating the V- intercept.

Procedure: Construct the electrical circuit as shown in the figure. Connect the diode under forward bias and pass a constant current (I_F < 0.1 mA) through the diode. Note down the junction voltage at room temperature. Suspend the diode along with a thermometer in a hot water bath at about 90° C taking care to see that the bulb of the thermometer is at the same level as the diode. As the water bath cools down, note down the voltage across the diode for different temperatures. Draw a graph with the temperature in Kelvin on the X-axis and voltage across the diode along the Y-axis. Find the V-intercept of the line at zero Kelvin using the slope of the straight line obtained and calculate the energy gap of the semiconductor.

Observations and Calculations:

The p-n junction diode used: ....

Constant forward current through the diode, I_F = ... mA

To find the voltage across the junction at various temperatures :

Temperature in °C	**Temperature in K (T)**	**Junction Voltage (V)**

From the graph, Slope $\dfrac{dV}{dT}$ = ...

$$E_g = e\left[V_1 - \left(\frac{dV}{dT}\right)T_1\right] \text{ joule}$$

$$E_g = V_1 - (slope \times T_1) \text{ electron-volt}$$

$$= \text{...}$$

$$= \text{.. eV}$$

Result: The energy gap of the given semiconductor, E_g = ... eV

*****

Review Questions:

1. Define energy band gap of a soild.
2. Differentiate metal, semiconductor and insulator based on band theory of solids.
3. Why the conductivity of a semiconductor increases with increase in temperature ?

Reference Book: Solid State Physics by Dekker, 1957, Macmillan, India Ltd.

Ex. No. : .... Date : ....

FERMI ENERGY OF A METAL

Aim: To determine the Fermi energy of Copper.

Apparatus: Copper wire, DC regulated power supply, digital milliammeter, digital millivoltmeter, water bath, thermometer.

Theory:

The simplest model that describes conducting electrons in a metal considers no interaction between electrons. Introduction of quantum mechanical ideas into this model gives rise to a concept of Fermi energy of a metal. In metals, valence electrons are loosely bound to the nucleus. Due to this, valence electrons can easily get dissociated from the parent atom leaving behind a positive ion. The Coulombic repulsion between large number of free electrons can be considered as balanced by attraction by the positive ions. The screening of positive charge occurs because of increased negative charge in its surroundings. Hence under such effects, free electrons can be assumed to be moving in a region of constant potential energy instead of a region of periodic Coulombic potential. Under such conditions, electrons can be treated as particles confined in a three dimensional infinite potential well.

The *Fermi energy* (E_F) is the energy of the highest energy level occupied by an electron in a metal at zero kelvin temperature. The average speed of the electrons at Fermi level is *Fermi speed* (v_F).

$$E_F = \frac{1}{2} m v_F^2 \tag{1}$$

where m is the mass of electron. *Fermi temperature* (T_F) is related to the Fermi energy by the relation,

$$E_F = kT_F \tag{2}$$

where k is Boltzmann constant.

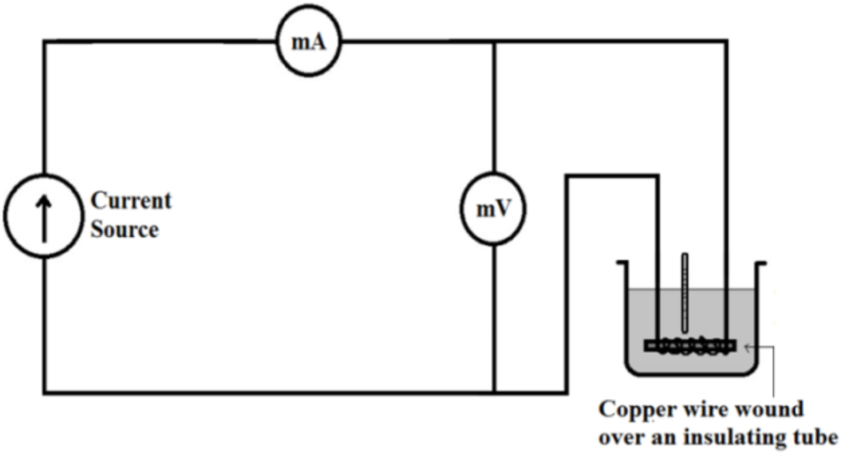

Fig: Experimental set up and graph of resistance versus temperature

In quantum statistics, it is shown that the probability of a particular energy state E being occupied by an electron is given by,

$$f(E) = \frac{1}{\exp\left(\frac{E - E_F}{kT}\right) + 1}$$

where $f(E)$ is called the Fermi-Dirac distribution function and E_F is the Fermi energy.

The electrical conductivity (σ) of the metal is given by the relation,

$$\sigma = \frac{L}{R \times A} \tag{3}$$

where L is the length of the metal wire, R is the resistance of the wire, $A = \pi r^2$ is the area of cross-section of the wire and r is the radius of cross section of the wire.

The mobility (μ) of the electrons drift is the metal lattice upon the application of electric field is given by the relation,

$$\mu = \frac{\sigma}{n_e \times e} \tag{4}$$

where e is the electronic charge.

The Fermi energy E_F of a metal is given by the equation,

$$E_F = \frac{h^2}{2m}\left(\frac{3 n_e}{8 \pi}\right)^{2/3} \tag{5}$$

where m is the mass of the electron and h is Planck's constant.

Procedure:

- Take a long copper wire of known length (L) and radius of cross section (r). Construct the electrical circuit using this long copper as shown in the figure.
- Pass a constant current (I) through the Copper wire at room temperature using a constant current source and note down the voltage (V) across copper wire. Calculate the resistance ($R = V/I$) at this temperature.
- The value of electron mobility (μ) is provided in the chart. Calculate the conductivity (σ) and electron density (n_e) using equations (3) and (4).
- The copper wire and a thermometer are housed in a test tube and this tube is then suspended in a hot water bath.
- As the water bath cools down, the voltage across the copper wire and hence its resistance values are noted at various temperatures in steps of 5°C. Calculate n_e at different temperatures and determine the average value of n_e at the end.
- Calculate the *Fermi energy* of copper using the equation (5). Also determine the *Fermi speed* of the conduction electrons using equation (1) and *Fermi temperature* using equation (2).

Observation and Calculations:

Electron charge, $e = 1.602 \times 10^{-19}$ C

Length of copper wire, L = ________________ m

Radius of cross section of copper wire, r = ________________ m

Area of cross section of the wire, $A = \pi r^2$ = ____________ = ____________ m^2

Current passed through the copper coil, I = _______________ mA

Temp t (°C)	**Electron Mobility in Copper** μ (m^2/Vs)	**Voltage across Copper wire** V (mV)	**Resistance** R = V/I (Ω)	**Conductivity** $\sigma = \frac{L}{R \times A}$ (S/m)	**Electron density** $n_e = \frac{\sigma}{\mu \times e}$ (/m^3)
70	0.00268				
65	0.00271				
60	0.00275				
55	0.00281				
50	0.00288				
45	0.00291				
Room Temp	0.00301				

Mean electron density, n_e = _______________/m^3

Fermi energy of Copper, $$E_F = \frac{h^2}{2\,m}\left(\frac{3\,n_e}{8\,\pi}\right)^{2/3}$$

= ....

= .... J

= .... eV

Boltzmann Constant, $k = 1.38 \times 10^{-23}$ J/K

Electron mass, $m = 9.1 \times 10^{-31}$ kg

Fermi temperature, $T_F = \frac{E_F}{k}$ =……………………………….= ……………………………………..K

Fermi speed, $v_F = \sqrt{\frac{2E_F}{m}}$ = ……………………..………………… = ……………………..…..……… m/s

Result:

Fermi Energy (E_F) (eV)		Fermi Temperature (T_F) (K)		Fermi Speed (v_F) (m/s)	
Observed	**Theoretical**	**Observed**	**Theoretical**	**Observed**	**Theoretical**
	7.0		8.12×10^4		1.57×10^6

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Review Questions:

1. Define Fermi energy.
2. What do you mean by Fermi temperature ?
3. Why the resistance of a metal increases with increase in temperature ?
4. Explain the probability of occupation of electron in the energy states of the metal as the temperature increases from zero Kelvin.

Reference Book : Serway & Jewett; Physics for Scientists and Engineers with Modern Physics, Vol 2; 6e (1982), Thomson-Brooks/Cole

Ex. No.: .... Date:...............................

PHOTOELECTRIC EFFECT

Aim: To determine the Planck's constant and the work function of the material of the photo cathode in the given photo-emissive cell.

Apparatus: Photo-emissive cell, a white light source, optical filters, a micro-ammeter, a voltmeter, connecting wires.

Principle: When light of a particular frequency falls on a photo-cathode, photo electrons are ejected. The kinetic energy (K_{max}) of the most energetic photo electron depends on the frequency (f) of the incident light. These electrons can be retarded by the application of a retarding potential and the electrons can be stopped completely by increasing the retarding potential to a value called stopping potential (V_o). Then no current (I_p) flows in the external circuit.

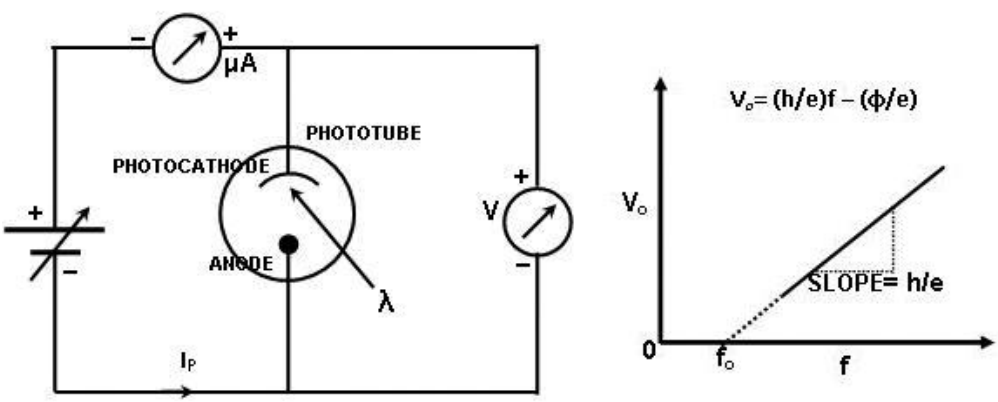

Fig: Circuit Diagram and variation of stopping potential with frequency.

In the experiment the stopping potentials are measured for lights of different frequencies. White light source and optical filters are used to get the light of a particular frequency. Einstein's photo electric equation is $K_{max} = hf - hf_o$, where h is the Plank's constant and f_o, is the threshold frequency. In the experiment $K_{max} = eV_o$ where e is the electronic charge. Hence the equation takes the form $eV_o = hf - hf_o$. A plot of V_o versus f gives a straight line graph with a slope equal to h/e and f-intercept f_o. The work function of the photo-cathode is given by $\phi = hf_o$.

Procedure: Build up the circuit as shown in the circuit diagram. Place an optical filter in the path of the light from a white light source. Note down the wavelength of the light from the filter and calculate the frequency. Illuminate the photo cathode using this light. Apply a retarding potential and increase its value so as to make the photo-electric current zero. Note down this stopping potential value. Similarly find the stopping potentials for lights of different frequencies using other filters. Draw a straight line graph of stopping potential versus frequency of the light. Find the slope and calculate the Planck's constant. Also, find the threshold frequency and calculate the work function of the photo cathode.

Observations and calculations:

To find the stopping potential for lights of different frequencies:

Optical filter		**Frequency** $f = \frac{3\times10^8}{\lambda}$ **(Hz)**	**Stopping potential** V_0 **(Volt)**
Colour	**Wavelength** λ **(m)**		
Red	635×10^{-9}		
Yellow - I	570×10^{-9}		
Yellow - II	540×10^{-9}		
Green	500×10^{-9}		
Blue	460×10^{-9}		

From the graph, *slope* = ……………………

$\therefore$ Planck's constant, $h = slope \times e$

$= \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \times 1.6 \times 10^{-19}$

$= \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ Js

From the graph, *threshold frequency* $f_o = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ Hz

$$\therefore \text{ Work function, } \phi = h f_o = \frac{(6.62 \times 10^{-34} \text{ Js})\ (\qquad\qquad\qquad\qquad \text{Hz})}{(1.6 \times 10^{-19} \text{ J/eV})}$$

$= \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ eV

Result:

Planck's constant, $h = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ Js

Work function of the photo-cathode in the photo-emissive cell, $\phi = \ldots\ldots\ldots\ldots\ldots$ eV

*****

Review Questions:

1. What is photoelectric effect?
2. What is work function of the metal?
3. What is the significance of threshold frequency?
4. Whether the kinetic energy of the emitted photo electron depends upon the intensity of the incident electromagnetic radiation?

Reference Book: Physics, Vol 2, 6 ed, by Serway & Jewett, 2004, Thomson Brooks / Cole

Ex. No. : .... Date :........................

BLACK BODY RADIATION

Aim: To determine Stefan-Boltzmann constant by measuring the temperature and power emitted by a black body.

Apparatus: Spherical black body radiator, digital temperature indicator, digital DC voltmeter, digital DC ammeter. The apparatus consists of a hollow sphere of copper with surface blackened by chemical process, fitted with an electrical heater (of power about 2W) inside the sphere. The space inside the sphere is filled with a heat sink material which can conduct heat from heater to the copper sphere. A thermocouple temperature sensor is attached to the surface of the black body and a digital indicator shows the temperature of the black body. The black body is heated by passing an electric current through the heater coil using a DC regulated power supply. A digital ammeter and a digital voltmeter are used to measure the current through the heater and voltage across the heater. The heater is operated in the range of 1W - 2W.

Theory:

According to Stefan-Boltzmann law the power (P) radiated from the surface of an object is given by,

$$P = \sigma A e T^4$$

where σ is *Stefan-Boltzmann constant*, A is the total surface area of the object, T is the surface temperature in kelvin and e is the emissivity of the surface; for a perfect black body $e = 1$.

Hence the Stefan-Boltzmann constant for a perfect black body is given by, $\sigma = \frac{P}{AT^4}$

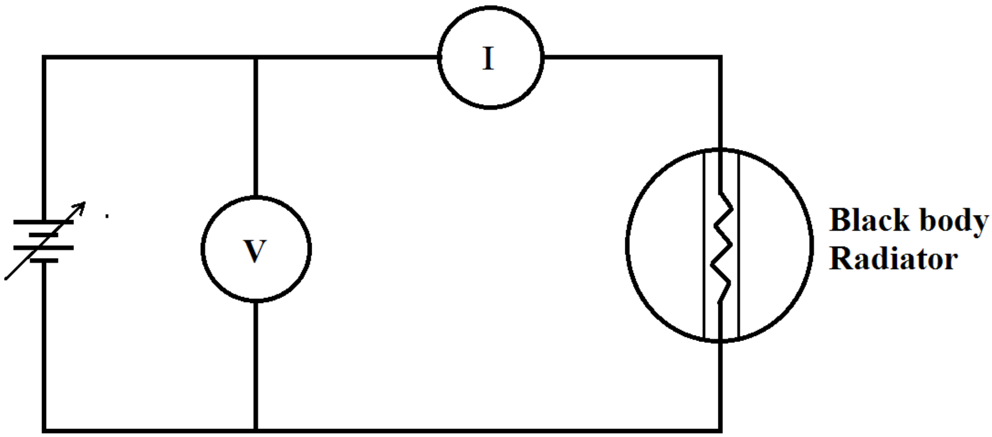

Fig: Circuit diagram

Procedure:

1. Make electrical connections as shown in the circuit diagram.
2. Apply a voltage of about 3 volts to the electric heater inside the spherical black body. Wait for the black body to be heated up (about 15 minutes) until its surface temperature become steady. Note down the steady values of voltage (V), current (I) and temperature (t).
3. Repeat the procedure 2 for some more values of the voltages like 3.3V, 3.6 V and 3.9 V.
4. In each case calculate the power ($P = V \times I$) emitted by the black body, surface temperature (T) in kelvin and hence the Stefan-Boltzmann constant (σ). Finally calculate the average value of this constant.

Observation and Calculations:

Diameter of the black body radiator, d = ... m

Radius of the black body radiator, r = ... m

Surface area of the black body, $A = 4\pi r^2$ = ... = ... m^2

Voltage initially set (volt)	**Steady voltage (after 15 min) V (volt)**	**Steady current I (amp)**	**Power $P = V \times I$ (watt)**	**Steady Temperature**		**Stefan-Boltzmann constant $\sigma = P/(AT^4)$ ($Wm^{-2}K^{-4}$)**
				t (°C)	**$T = t + 273$ (K)**	
3						
3.3						
3.6						
3.9						

Mean σ =........................

Result:

The calculated value of Stefan-Boltzmann constant, σ = ... $Wm^{-2}K^{-4}$ which is nearly equal to the standard value 5.67×10^{-8} $Wm^{-2}K^{-4}$.

*****

Review Questions:

1. When do you say that an object is a Black body ?
2. State and explain Stefan-Boltzmann Law.
3. As the temperature increases what happens to the wavelength and intensity of the radiation emitted from the black body ?

Reference Book : Serway& Jewett; Physics for Scientists and Engineers with Modern Physics, Vol 2; 6e (1982), Thomson-Brooks/Cole

Ex. No. : .... Date :........................

RESISTIVITY OF SEMICONDUCTOR BY FOUR PROBE METHOD

Aim: To determine the resistivity of the given semiconductor by four probe method.

Apparatus: Constant current source, Four probes with connecting wires, Semiconductor sample in the form of a square plate, digital milliammeter, digital millivoltmeter.

Theory: The electric resistance (R) of a material is given by $R = V/I$ where V is electrical potential difference across the material and I is the current through the material. The resistance depends on the dimension of the material. For a wire $R = \rho L/A$, where L is the length of the area, A is the cross sectional area of the wire and ρ is the electrical resistivity of the material of the wire. Thus for a wire, the resistivity,

$$\rho = \frac{R \times A}{L}$$

When two probes are used for measurement of voltage and current, and hence for the calculation of resistance in the case of a semiconductor, the probe resistance, the contact resistance, the spreading resistance, and the sheet resistance due to the semiconductor will come into effect. Using four probes one can eliminate the probe resistance, contact resistance and the spread resistance in the measurement.

In the four probe method the four metal probes are equidistant, the current is passed through the outer probes and the voltage is measured across the inner probes. The resistivity measured using the four probes may vary with the geometry (thickness and shape) of the semiconductor sample and placement of the probes on the surface of the sample. It may also vary with the probe gap, nature of the surface of the sample, the size of the sample.

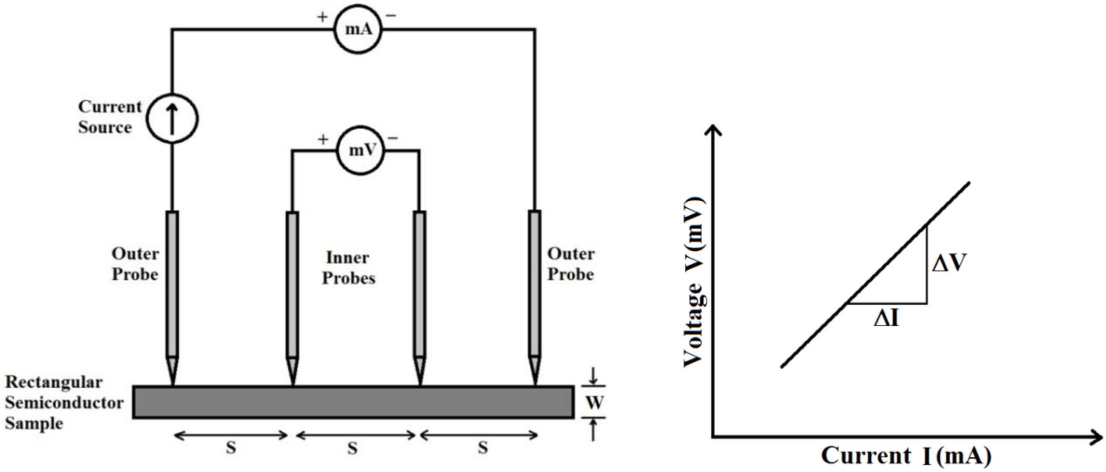

Fig: Experimental setup and graph of voltage versus current.

Mathematical calculations show that the resistivity of a semi-infinite sample is given by

$$\rho_0 = \frac{V}{I} \times 2\pi S$$

where I is the current through the outer probes, V is the voltage across the inner probes, S is the distance between the probes and $2\pi S$ is the geometric factor of the semi-infinite sample.

For a finite rectangular sample of thickness W, a dimension correction function $f\,(W/S)$ is introduced in the resistivity expression as,

$$\rho = \frac{\rho_0}{f(W/S)}$$

i.e.,

$$\rho = \frac{2\pi S}{f(W/S)} \times \frac{V}{I}$$

According to the standard data chart, for a germanium crystal of thickness 0.5mm (W) and distance between the probes 2mm (S), the value of the dimension correction function $f\,(W/S)$ is 5.85. In the experiment the value of the electrical resistance (V/I) of the sample can be obtained by calculating the slope of straight line in the graph of voltage versus current.

Hence the resistivity of the germanium crystal is given by,

$$\rho = \frac{2\pi S}{5.85} \times slope$$

Procedure:

- Note the values of the sample thickness (*W*) and probe gap (*S*). Place the sample under the four probes with probes coming at the center and along the length of the rectangle.
- Build up the circuit with the four probes, current source, DVM (digital milli voltmeter), DCM (Digital milli ammeter) and the semiconductor sample as shown in the circuit diagram.
- Pass a small current (*I*) about 0.2 mA through the outer probes and note the value of the voltage (*V*) across the inner probes.
- Repeat the procedure by increasing the current value in steps of 0.2 mA.
- Plot a graph of V versus I and calculate the slope $\Delta V/\Delta I$ of the straight line obtained.
- Calculate the resistivity of the germanium sample using the equation,

$$\rho = \frac{2\pi S}{5.85} \times slope$$

Observation and Calculations:

Material of the semiconductor sample : Germanium crystal

Distance between the probes, $S = 2 \times 10^{-3}$ m

Sample thickness, $W = 0.5 \times 10^{-3}$ m

Dimension correction function, $f(W/S) = 5.85$

Current I **(mA)**	**Voltage** V **(mV)**

From the graph, *slope* = $\frac{\Delta V}{\Delta I}$ =..

Resistivity of the germanium crystal,

$$\rho = \frac{2\pi S}{f(W/S)} \times slope$$

$$= \frac{2\pi S}{5.85} \times slope$$

= ....

= ....Ωm

Result:

Resistivity of the given semiconductor, $\rho =$ ....Ωm

*****

Review Questions:

1. Define resistivity of a material.
2. What is the relation between resistance and resistivity of a material ?
3. What are the advantages of four probe method over two probe method ?

Reference Book: W.R. Runyan, Semiconductor Measurements and Instrumentation; McGraw – Hill Book Company (1975)

Ex. No.: ....   Date:..............................

HALL EFFECT

Aim: To determine Hall coefficient of a given semiconductor and hence its charge carrier density.

Apparatus: Electromagnet, Hall probe, variable DC power supply, milliammeter, millivoltmeter.

Principle: Consider a semiconductor (assumed to be n-type) in the form of a rectangular strip of width ***w*,** thickness *t* and electron density *n*. Let a current ***I*** flow along its length in X direction and a transverse magnetic field ***B*** be applied across its thickness **t** along the Y direction.

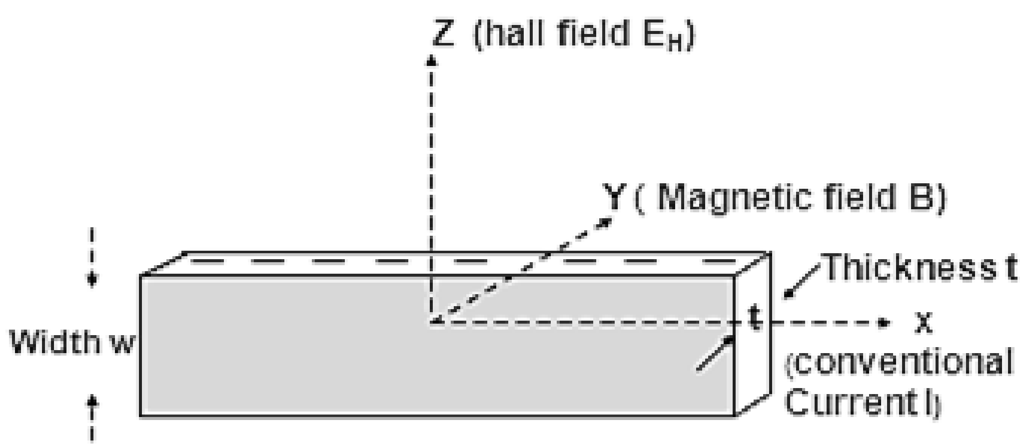

Fig : Hall Effect in *n*-type semiconductor

The moving electrons experience a force F_M due to the magnetic field. Due to F_M, the electrons tend to move in the Z direction leaving behind the positive charges.

$$F_M = e\, v_D\, B$$

where, v_D is the drift speed of the electrons and e is the charge on the electron.

This separation of charges results in an electric field E_H across the widthof the specimen (in Z direction). E_H exerts a force on the electrons given by

$$F_E = - e E_H$$

Under equilibrium conditions $e E_H = e v_D B$ $\therefore$ $E_H = v_D B$

We have $$E_H = \frac{V_H}{w} \quad \text{and} \quad v_D = \frac{I}{n e w t}$$

Substituting these values, we get

$$V_H = \frac{I B}{n e t} \quad \text{or} \quad V_H = \frac{R_H I B}{t}$$

Where, the quantity $\frac{1}{n e} = R_H$ is called the Hall coefficient of the specimen.

$$\therefore R_H = \left(\frac{V_H}{B}\right)\left(\frac{t}{I}\right)$$

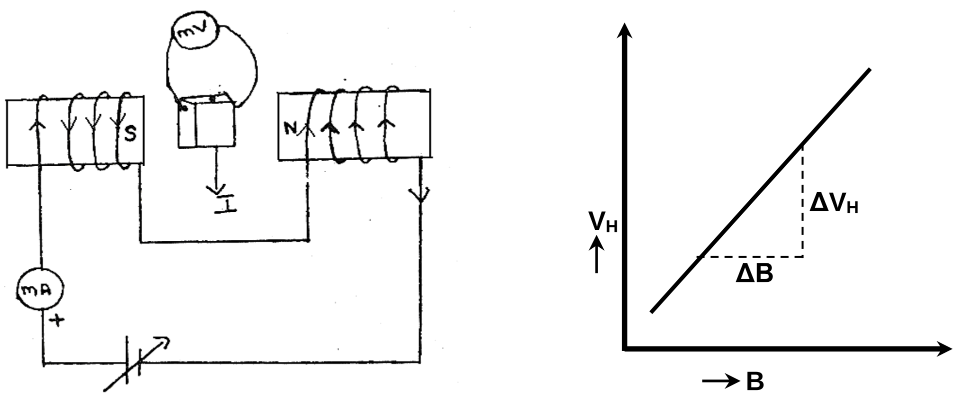

Fig: Experimental set up and graph of Hall voltage versus magnetic induction.

Procedure:

- Initially adjust the millivoltmeter to read zero hall voltage when the hall probe is **not** in the magnetic field.
- Adjust the distance between the pole pieces of the electromagnet to a prescribed value of 10 mm.

- Pass a current I (< 80 mA) through the hall probe.
- Introduce the probe midway between the pole pieces and orient it to have the hall voltage maximum.
- Vary the current through the electromagnet (in the given range 100-500mA) and note down the corresponding values of the Hall voltage V_H.
- Read the values of the magnetic induction B corresponding to these magnet currents from the chart provided.
- Draw a graph of V_H versus B.
- Find the slope of the straight line obtained. Calculate R_H and n.

Observations and Calculations:

Material of the Hall specimen : Indium Arsenide

Thickness of the Specimen : t =........................ mm = ... m

Current in the Probe : I =.........................mA = ... A

Charge on the electron : $e = 1.6 \times 10^{-19}$ C

Magnet Current (mA)	**Magnetic Induction, B (Tesla)**	**Hall Voltage, V_H (mV)**
50	0.025	
100	0.043	
150	0.063	
200	0.083	
250	0.102	
300	0.124	
350	0.142	
400	0.161	
450	0.182	
500	0.202	

From the graph, slope of the straight line = $\dfrac{\Delta V_H}{\Delta B}$ = ... volt/tesla

Hall coefficient of the specimen,

$$R_H \quad = \quad \left(\frac{t}{I}\right)(slope) \; = \; \left(\frac{\qquad\qquad}{}\right)(\qquad\qquad\qquad)$$

$$= \; ....\; m^3 / C$$

Number of charge carriers per unit volume of the specimen

$$n \quad = \quad \left(\frac{1}{e\, R_H}\right) = \frac{1}{(\qquad\qquad)(\qquad\qquad)} = \; .... \; /m^3$$

Result:

Hall coefficient of the given semiconductor, R_H =..m^3/C

Charge carrier density of the given semiconductor, n =..$/m^3$

*****

Review Questions:

1. Explain Hall Effect.
2. What are the two forces acting on the electron in Hall Effect setup?
3. What do you mean by charge carrier density of a material ?
4. What are the applications of Hall Effect ?

Reference Book: Physics, Vol 2, 6 ed, by Serway & Jewett, 2004, Thomson Brooks / Cole

Ex. No. : .... Date : ....

DETERMINATION OF BOLTZMANN CONSTANT

Aim: To determine the Boltzmann constant *k* using a silicon transistor.

Apparatus: Silicon transistor (SL100), variable DC power supply, digital milliammeter, digital voltmeter, thermometer.

Theory: A transistor is a three-terminal two-junction semiconductor device. It consists of either a thin layer of p-type semiconductor sandwiched between two n-type semiconductors or thin layer of n-type semiconductor sandwiched between two p-type semiconductors. The former is *npn*-transistor and the latter is *pnp*-transistor. The middle layer is called the base. The two outer layers are called the emitter and collector. The three possible modes of configuration are common base (CB), common emitter (CE) and common collector (CC).

In a common base mode of *npn* transistor, when the Base-Emitter junction is forward biased and Base-Collector junction is shorted, the transistor is referred to as a diode-connected transistor and it is working in *active mode*.

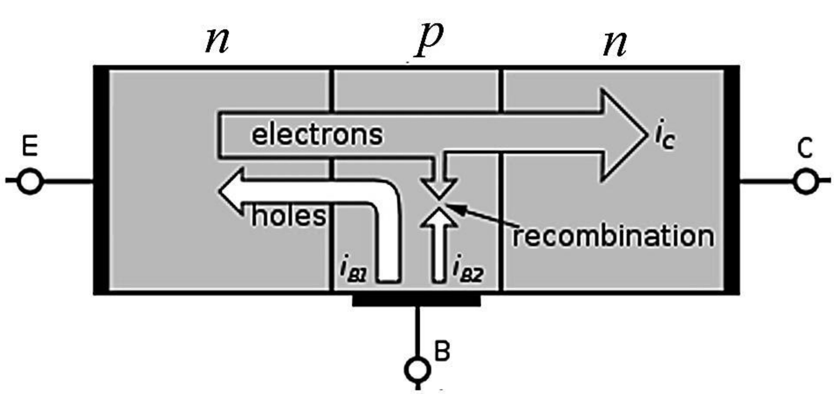

Fig : Block diagram of a *npn* transistor

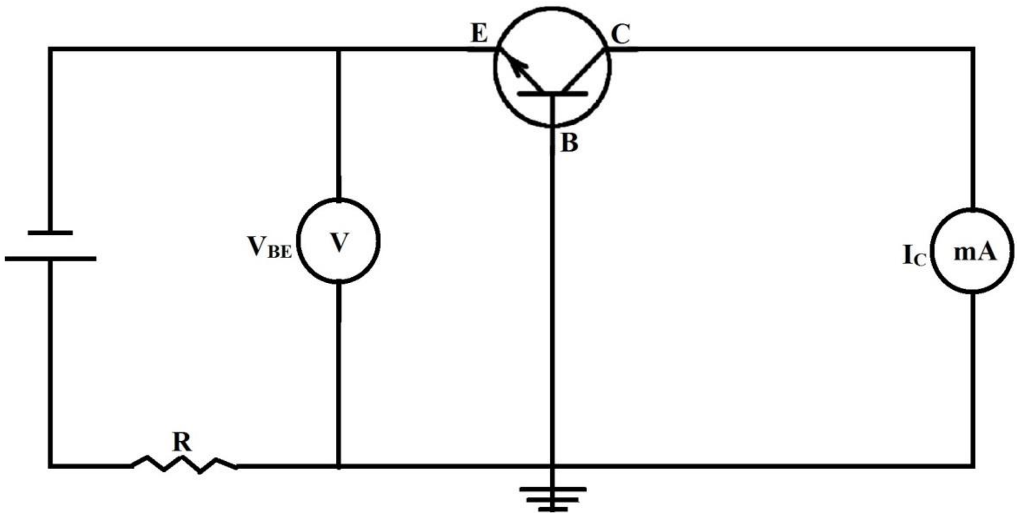

Fig : Circuit connections for determination of *k*

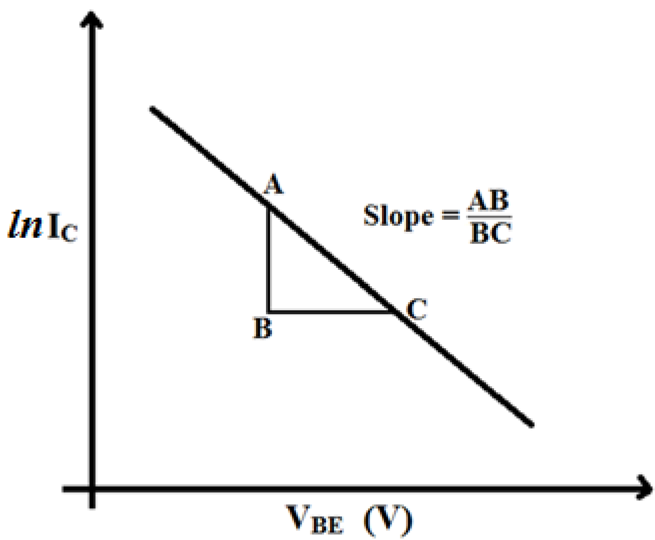

Fig: Variation of magnitude of $ln\ I_C$ versus V_{BE}

In active mode operation of the transistor, the Base-Emitter Voltage (V_{BE}) controls Collector Current (I_C). By neglecting the base saturation current, the collector current (I_C) of a transistor is given by,

$$I_C = I_{CO}\left[exp\left(\frac{eV_{BE}}{\eta kT}\right) - 1\right]$$

where I_{CO} is collector reverse saturation current, T is temperature of the device in kelvin, e is electronic charge, k is Boltzmann constant, V_{BE} is the voltage across the Base-Emitter junction and η is the ideality factor (its value ranging from 1 to 2).

Taking natural logarithm on both sides of the above equation, we can write

$$\ln I_C = \ln I_{CO} + \frac{eV_{BE}}{\eta kT}$$

This equation represents a straight line in *ln* I_C versus V_{BE} graph such that,

$$Slope = \frac{e}{\eta kT}$$

Hence *Boltzmann Constant,*

$$k = \frac{e}{\eta T}\left(\frac{1}{slope}\right)$$

Procedure:

- Make the circuit connections as shown in the figure.
- Note the room temperature T (in kelvin) using a thermometer.
- Set the emitter-base voltage (V_{BE}) to an initial value using the voltage control knob and note the correponding collector current (I_C).
- Repeate the experiment by varying the emitter-base voltage in steps of 0.005V up to the maximum value and note the correponding collector current.
- Draw a graph by taking the magnitude of *ln* I_C along Y-axis and magnitude of V_{BE} along X-axis. Claculate the *slope* of the straight line.
- Determine Boltzmann Constant using the formula

$$k = \frac{e}{\eta T}\left(\frac{1}{slope}\right)$$

Observations and Calculations:

Room temperature, T = ………………… K

Ideality factor for silicon p-n junction at room temperature, η = 1.5

Electronic charge, e = 1.6×10^{-19} C

V_{BE} **(Volt)**	I_C **(mA)**	**ln** I_C (I_c in A)

Magnitude of the slope, $\dfrac{\Delta ln\, I_C}{\Delta V_{BE}}$ = ……………………..……..

Botzmann constant ,

$$k = \frac{e}{\eta T}\left(\frac{1}{slope}\right)$$

= ....

= .... J/K

Result:

The calculated value of Boltzmann constant, k = ... J/K which is nearly equal to the standard value 1.38×10^{-23} J/K.

*****

Review Questions:

1. What is a transistor? Mention its different modes of configuration.
2. Write diode equation and explain reverse saturation current.
3. What are the applications of transistors?

Reference Book: John D Ryder, Electronic fundamentals and applications, 5th Edition, Prentice-Hall of India Private Ltd (1978)

Ex. No. : .... Date : ....

NUMERICAL APERTURE OF OFC

Aim: To measure the numerical aperture of an optical fiber cable (OFC).

Apparatus: Optical fiber cable (OFC), diode laser, travelling microscope bed carrying fixed screen and a movable chuck.

Theory: Numerical aperture is one of the important parameters of an optical fiber cable. Numerical aperture (NA) of an optical system is a dimensionless number that characterizes the range of angles over which the system can accept or emit light. In other words, the numerical aperture also indicates the amount of light linking the optical fiber cable and the detector (screen) or the source. Smaller the numerical aperture better will be the optical fiber cable.

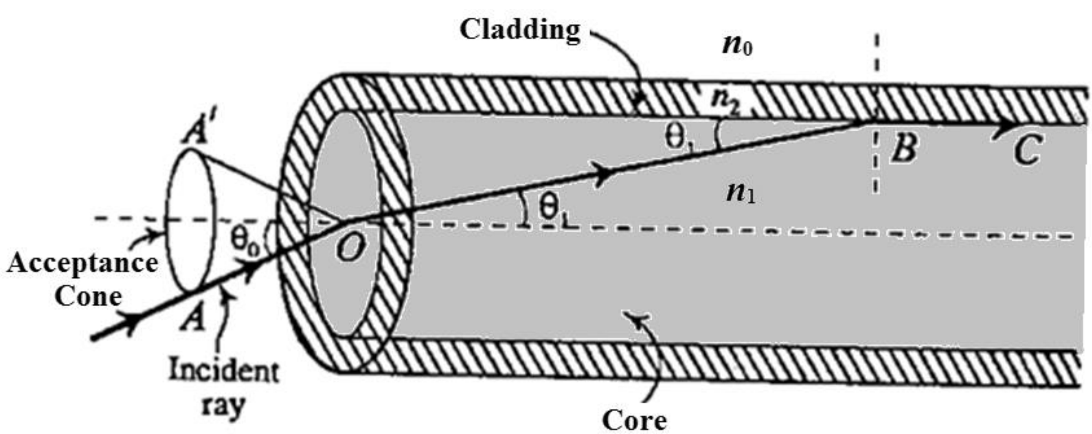

Fig.1: Acceptance cone.

Let n_1 and n_2 be the refractive indices of the *core* and the *cladding* of the optical fiber respectively, placed in air (n_0=1). Now, Snell's law can be used to calculate the maximum angle within which light will be accepted in to and conducted through a fiber.

Hence,

$$\sin\theta_0 = \sqrt{n_1^2 - n_2^2}$$

where the term *sin* θ_0 is called *numerical aperture*.

The light propagation through the optical fiber takes place based on the principle of total internal reflection at the core-cladding interface. Hence the semi angle θ_0 of an acceptance cone for a fiber is decided by the critical angle $\theta_c = sin^{-1}(n_2/n_1)$. For a ray with incident angle less than θ_0, it undergoes total internal reflection at core cladding interface and is called the guided ray.

In a short length of straight fiber, ideally a ray launched at angle θ_0, at the input end should come out at the same angle θ_0 from output end. Therefore the far field at the end will also appear as a cone of semi angle θ_0 originating from the fiber end. It is then simpler to make measurements on this far field to determine the NA of the fiber.

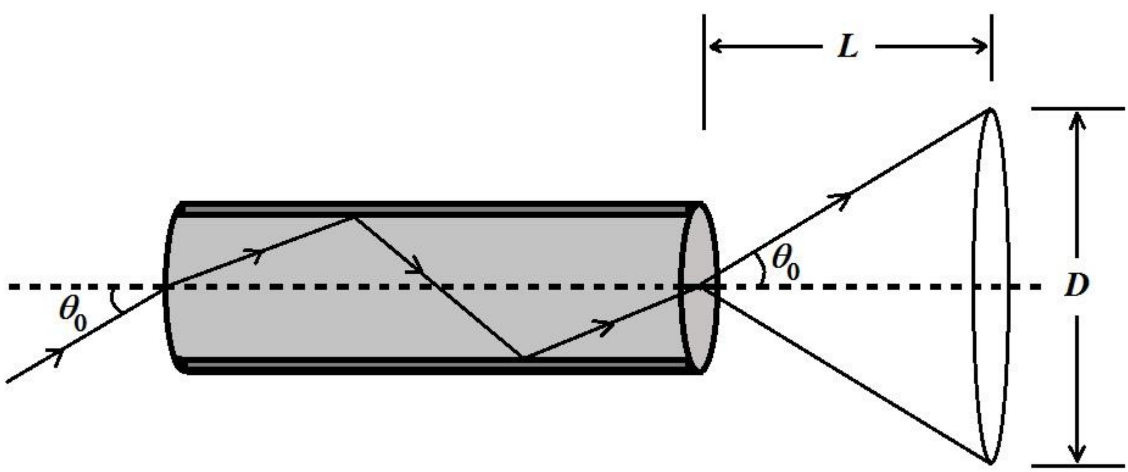

Fig. 2: Laser light emerging from the cable and forming a divergent cone of rays.

Numerical aperture of a cable is also defined as sine of the half angle of the cone generated due to the divergence of rays. The light emerges out in the form of a cone and produces a circular spot on the screen at a distance L (Fig. 2). If D is the diameter of the circular spot then

$$tan\ \theta_0 = \frac{D/2}{L} = \frac{D}{2L}$$

By measuring *D* and *L*, $tan\ \theta_0$ can be determined; hence the numerical aperture can be calculated from the equation,

$$\text{NA} = sin\ \theta_0 = sin\ [tan^{-1}(D/2L)]$$

Procedure

- The optical cable is coupled to the laser and the laser light propagating through other end of the cable is verified.
- The other end of the cable is coupled to the chuck fixed on the transverse motion bench.
- The chuck carrying the OFC is brought close to the graduated screen and the laser spot is seen on the graduated screen.
- By adjusting the fine motion screw of the microscopic bench, the spot diameter *D* is adjusted to the preferred value.
- The distance *L* between the fixed screen and chuck carrying OFC is noted on the graduated scale fixed along the X-axis.
- NA is calculated using the equation $sin\ \theta_0 = sin\ [tan^{-1}(D/2L)]$
- The trial is repeated for different values of *D*, and the average value of NA is calculated.

Observations and Calculations:

Trial No.	Spot Diameter D (mm)	Distance between fiber and screen L (mm)	$\frac{D}{2L}$	$NA = sin\left[tan^{-1}\left(\frac{D}{2L}\right)\right]$
1				
2				
3				
4				
5				

Mean NA =

Result:

Numerical aperture of the given optical fiber = ____________________

*****

Reference Book: Introduction to fiber optics – A. K. Ghatak and Thyagarajan, Cambridge University Press (1999)

Ex. No.: .... Date:...............................

WAVELENGTH OF LASER USING DIFFRACTION GRATING

Aim: To determine the wavelength of the given laser beam using a diffraction grating.

Apparatus: Diffraction grating, laser, measuring scale, screen etc.

Principle: An arrangement of large number of equidistant parallel slits constitutes a grating. It is prepared by drawing fine lines extremely close together on the surface of an optically flat glass plate using a diamond point. The lines act like opacities and region between two lines act like transparencies. When a light beam of wavelength λ is incidenton a transmission grating (with N number of slits per unit length) normally, the diffracted beams of m^{th} order are observed at angles θ with respect to the undeviated beam (zeroth order beam), on either side. The relation between these parameters is, $\sin\theta = m N \lambda$.

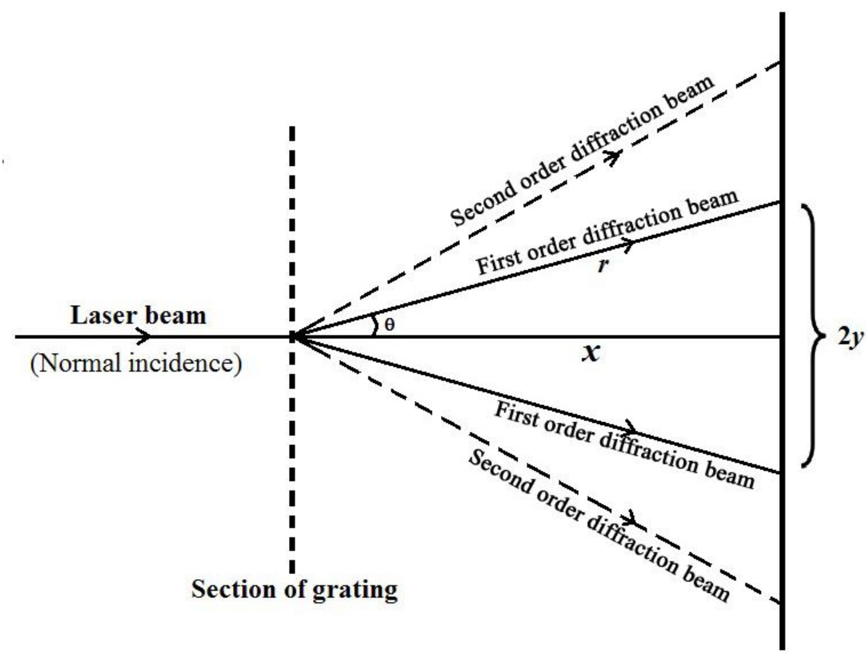

Fig : Schematic representation of diffraction of light through grating

Procedure: Switch on the laser unit and adjust the laser beam to be (approximately) normal to the surfaces of the grating as well as the screen. Identify the spots on the screen, most intense one due to undeviated beam (zeroth order) and two others two due to first order diffracted beams on either side of the zeroth order. Measure the distance 2*y* between the spots due to first order diffracted beams, and the normal distance (*x*) of the screen from the grating. Repeat the measurements for the second (and third) order diffracted beams. Calculate $r = \sqrt{x^2 + y^2}$ and mean value of $\sin\theta = \frac{y}{r}$, where *θ* is the diffraction angle. Calculate the wavelength of the laser beam using $\lambda = \frac{\sin\theta}{m N}$, where *m* is the order of the diffracted beam and *N* is the number of slits per unit length in the grating.

Observations and calculations:

N is the number of slits per unit length in the given grating.

Measurement of m^{th} order diffraction angle θ:

N **(m^{-1})**	**Order *m***	***x*** **(m)**	***2y*** **(m)**	***y*** **(m)**	$r = \sqrt{x^2 + y^2}$ **(m)**	$\sin\theta = \frac{y}{r}$	$\lambda = \frac{\sin\theta}{m N}$ **(m)**
6×10^5	1						
3×10^5	2						
1×10^5	3						

Mean λ = ...nm

Result:

The wavelength of the given laser beam is =...................................... nm.

*****

Review Questions:

1. What is LASER ?
2. Define the phenomenon of diffraction of light?
3. What is grating ? Mention grating equation.
4. What happens to the diffraction pattern when the distance between slits within the grating is increased?
5. What happens to the diffraction pattern when the number of slits within the grating (with same grating spacing) is reduced?

Reference Book: Course of Experiments with He-Ne Laser 2001, New Age International, New Delhi

Ex. No.: .... Date:...............................

NEWTON'S RINGS

Aim: To determine the radius of curvature of the given lens by Newton's rings method.

Apparatus: Traveling microscope, sodium vapour lamp, plano-convex lens of large radius of curvature, optically flat glass plate, reflecting glass plate etc.

Principle: Newton's rings are circular interference fringes formed at a thin air film between a plane and curved surface or two curved surface of large radii of curvature.

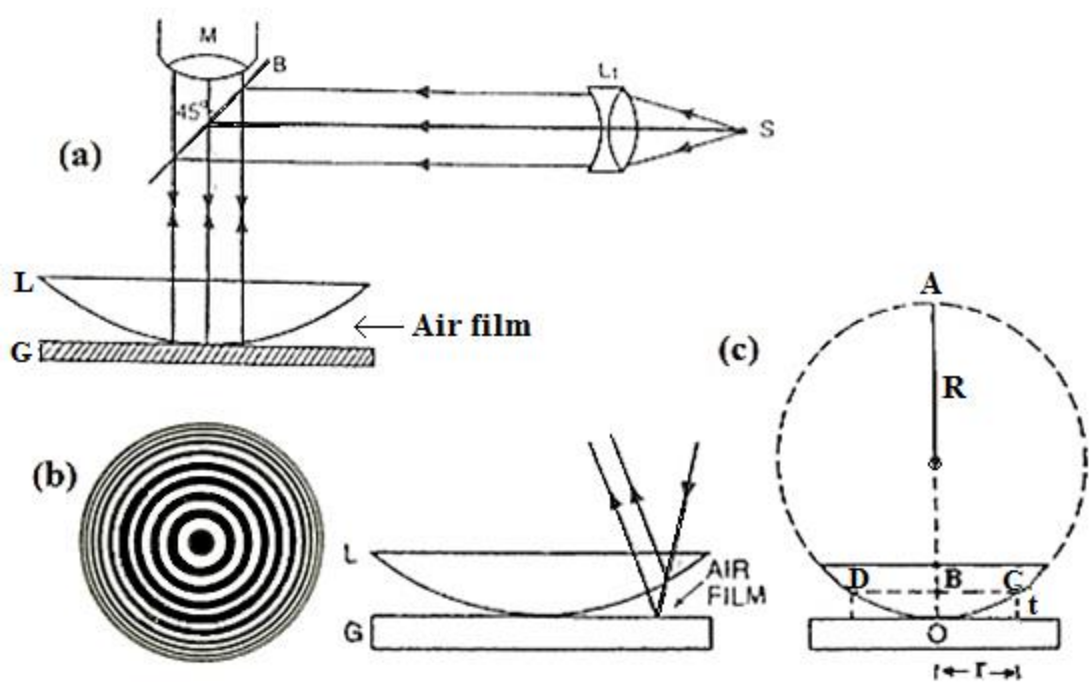

Fig: (a) Experimental setup (b) Interference fringe pattern (c) Ray diagram of interference from thin air film (between convex lens and glass plate).

In figure (c), curved surface DOC of air film has been completed into a circle of radius *R*. Let there be n^{th} dark ring at point C, then its radius, r_n = DB = BC.

Now, from the geometry of the circle DB × BC = AB × BO

$$r_n^2 = (AO - OB)\, OB = (2R - t)\ t \approx 2\,R\,t \qquad (1)$$

neglecting t^2 (<< 2 R t) the condition for destructive interference is

$$2\,\mu\,t = n\,\lambda \qquad (2)$$

where μ is refractive index, λ is wavelength of monochromatic light.

Substituting value of 2t from equation (1), $\mu\, r_n^2 / R = n\,\lambda$

on rearranging the terms $r_n^2 = R\,n\,\lambda / \mu$ (3)

or the diameter of n^{th} order dark ring is related as $D_n^{\,2} = \dfrac{4Rn\lambda}{\mu}$ (4)

The diameter of $(n+m)^{th}$ dark ring is related as $D^2_{(n+m)} = \dfrac{4\,(n+m)\,\lambda\,R}{\mu}$ (5)

By subtracting equation (4) from equation (5), we have, $D^2_{n+m} - D^2_{n} = \dfrac{4m\lambda R}{\mu}$

on rearranging, $$R = \frac{\mu(D^2_{n+m} - D^2_{n})}{4m\lambda}$$

The radius of curvature of the lens can be calculated using the above relation.

Procedure: Find the least count of the vernier of the traveling microscope. Place the given plano-convex lens of large radius of curvature on a plane glass plate to get an air film of circular symmetry. Place this set up below a traveling microscope. Illuminate the air film normally by reflecting the horizontal beam of sodium light using an inclined glass plate. Focus the traveling microscope and observe the Newton's rings (bright and dark circular interference fringes). Make the crosswire tangential to various dark rings on the left side, and then on the right side, note microscope readings each time. Claculate the diameters D_n of these dark rings. Find the mean value of $(D^2_{n+m} - D^2_{n})$.

Calculate the radius of curvature (R) of the convex surface of the lens using the known wavelength (λ) of the monochromatic light

Observations and Calculations:

To calculate the least count of the traveling microscope:

$$\text{Pitch of the screw} = \frac{\text{Distances travelled along pitch scale}}{\text{No of rotations given to the screw head}} = \underline{\hspace{3cm}}$$

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

Number of divisions on the head scale (HSD) = ………..………….. div

$$\text{Least count (LC)} = \frac{\text{Pitch}}{\text{Total no of HSD}} = \underline{\hspace{3cm}}$$

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

(TOTAL READING) TR = PSR + (HSD × LC)

(PITCH SCALE READING) (COINCIDING HEAD SCALE DIVISION)

Wavelength of the sodium light $\lambda = 5.893 \times 10^{-5}$ cm

To find the diameter of the dark rings:

$m = (n + m) - n = 8$

Order of the ring	**Microscope Readings (TR in cm)**			**Order of the ring**	**Microscope Readings (TR in cm)**			$D_{n+m}^2 - D_n^2$
$n + m$	**Left L (TR)**	**Right R (TR)**	**Diameter D = L – R (cm)**	n	**Left L (TR)**	**Right R (TR)**	**Diameter D = L – R (cm)**	**(cm^2)**
18				**10**				
16				**8**				
14				**6**				
12				**4**				

Mean $[D_{n+m}^2 - D_n^2]$ = ……………………… cm^2

Radius of curvature of the plano-convex lens:

$$R = \frac{(D_{n+m}^{\ \ 2} - D_n^{\ 2})}{4m\lambda} = \underline{\hspace{8cm}} = \text{..................................} \text{ cm}$$

Result:

Radius of curvature of the given plano-convex lens = ... cm.

*****

Review Questions:

1. What is interference of Light ?
2. Why the central spot of Newton's ring is always dark?
3. What is the condition for destructive interference in Newton's rings ?
4. What happens to the fringe pattern if the Newton's ring setup is immersed in water ?

Reference Book: Advanced Practical Physics by Worsnop & Flint, 1961, Asia Publishing House, Bombay

Ex. No.: .... Date:................................

REFRACTIVE INDICES OF UNIAXIAL CRYSTALS

Aim: To determine the refractive indices of uniaxial crystals for O-ray and E-ray using prism of the crystal and long-arm spectrometer with laser.

Apparatus: Long-arm spectrometer, uniaxial crystal (quartz/calcite) prisms, laser.

Principle: Double refraction in a prism cut from a negative uniaxial crystal (calcite) is shown in the figure. (Deviation angle $D_o > D_E$ for a negative crystal, $D_o < D_E$ for a positive crystal like quartz.)

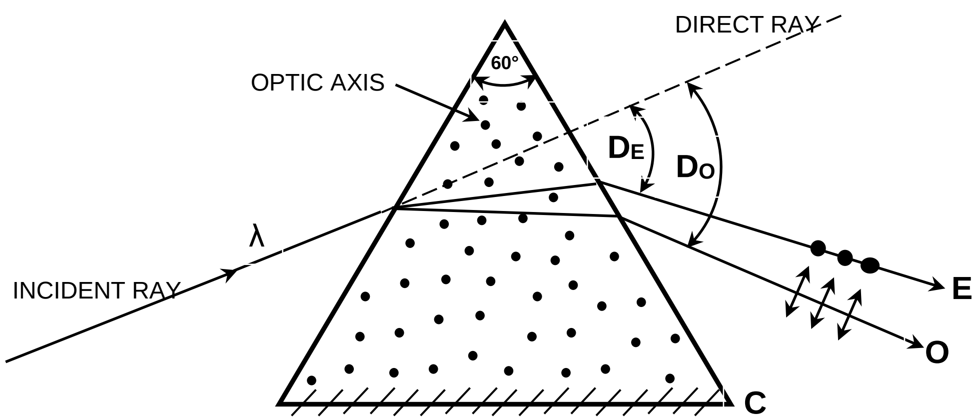

Fig: Double refraction in a prism cut from a negative uniaxial crystal (calcite).

The prism is cut from the crystal in such a manner to have the optic axis parallel to the refracting edge. In this condition, the two waves, *ordinary* (*O*) and *extraordinary* (*E*) have the maximum difference in speed when they travel perpendicular to the optic axis. The direction of the electric vector is perpendicular to the optic axis for the *O*-wave and is parallel to the optic axis for the *E*-wave.

The refractive index of the crystal is given by,

$$n_o = \frac{\mathrm{Sin}\left(\frac{A+D_O}{2}\right)}{\mathrm{Sin}\left(\frac{A}{2}\right)} \qquad \text{for } O\text{-ray,}$$

$$n_E = \frac{\mathrm{Sin}\left(\frac{A+D_E}{2}\right)}{\mathrm{Sin}\left(\frac{A}{2}\right)} \qquad \text{for } E\text{-ray}$$

where A is the angle of the prism, D_o is the angle of minimum deviation for the *O*-ray and D_E is the angle of minimum deviation for the *E*-ray.

A *Long arm Spectrometer with Laser* has a laser as the light source with wavelength λ. The arm-length for the light beam is about a meter or half a meter. (The angular-scale graduations are at this arm-length. The smallest main scale division of this scale is 0.2°)

Procedure:

Observe the angular-scale graduations and find the smallest main scale division. Note down the wavelength of the laser beam. Align the angular-scale and the laser beam to see the spot due to the direct beam passing through the center of the turn-table, on the "zero" of the angular scale.

Measurement of the angle (A) of the prism:

Place the prism on the turn table with the refracting edge at the centre of the turn table and pointing the incident laser beam. Observe the spots on the angular scale due to the beams reflected from the two faces of the prism. Measure the angle $2A$ between these reflected beams. Find the angle A of the prism.

Measurement of the angles (D_O & D_E) of minimum deviation:

Place the prism on the turn table to refract the laser beam through the prism. Observe the two spots on the angular scale due to the two refracted beams (one due to ordinary light and other due to extraordinary light). Using a polarizer, ascertain that the two refracting beams have electric vector mutually perpendicular to each other. Adjust the turn table using its arm, to refract the O-beam at the minimum deviation angle D_o. Measure the angle D_o. Then adjust the turn table to refract the E-beam at the minimum deviation angle D_E. Measure the angle D_E.

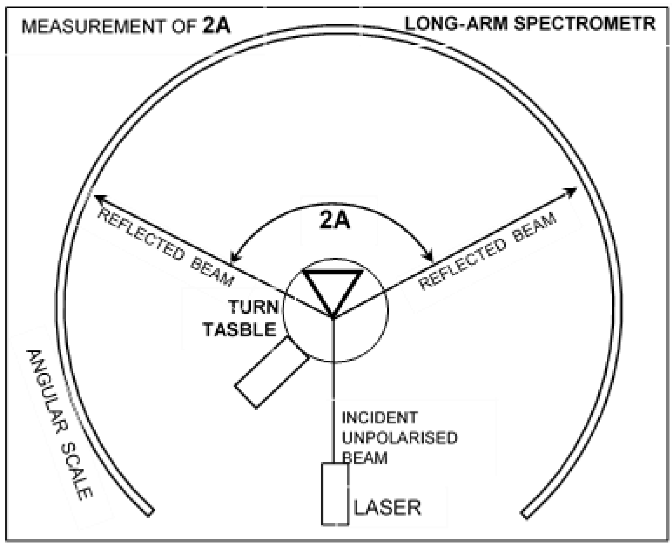

Fig: Experimental setup for the measurement of the angle *A* of the prism.

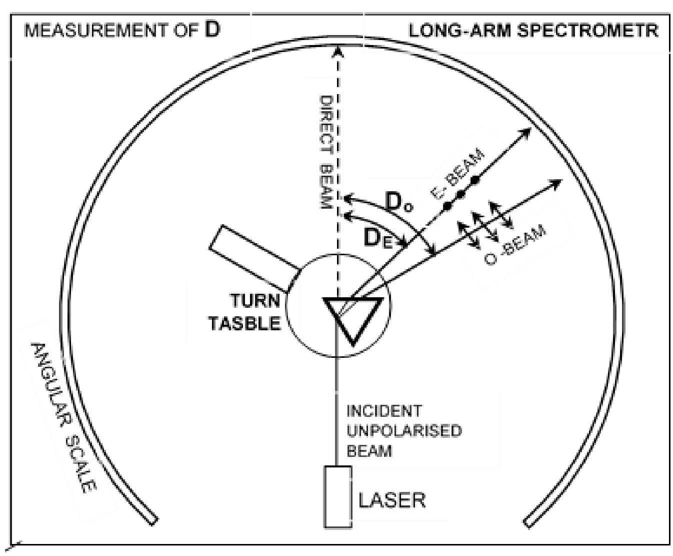

Fig: Experimental setup for the measurement of the angle of minimum deviation *D*.

Calculation of refractive index:

Calculate the refractive index of the crystal (material of the prism) for O-ray using the formula,

$$n_o = \frac{\text{Sin}\left(\frac{A+D_O}{2}\right)}{\text{Sin}\left(\frac{A}{2}\right)}$$

Calculate the refractive index of the crystal for E-ray using the formula,

$$n_E = \frac{\text{Sin}\left(\frac{A+D_E}{2}\right)}{\text{Sin}\left(\frac{A}{2}\right)}$$

Find the birefringence (Δn) using the formula, $\Delta n = n_E - n_o$

Observation and calculations:

Smallest division on the main scale: ....

Wavelength of the laser beam λ = ...

Material of the uniaxial crystal :	**Calcite**	**Quartz**
Angle $2A$:		
Angle of the prism, A :		
Angle of minimum deviation for O-ray, D_O :		
Angle of minimum deviation for E-ray D_E :		
Refractive index of the crystal for O-ray : $n_o = \frac{\text{Sin}\left(\frac{A+D_O}{2}\right)}{\text{Sin}\left(\frac{A}{2}\right)}$		
Refractive index of the crystal for E-ray : $n_E = \frac{\text{Sin}\left(\frac{A+D_E}{2}\right)}{\text{Sin}\left(\frac{A}{2}\right)}$		
Birefringence of the crystal for λ = ... : $\Delta n = n_E - n_o$		

Result:

Refractive indices of calcite, n_o = ... n_E = ...

Birefringence of calcite = ...

Refractive indices of quartz, n_o = ... n_E = ...

Birefringence of quartz = ...

*****

Review Questions:

1. When do you say that the light is plane polarized?
2. What is double refraction?
3. Define birefringence.
4. What are the differences between positive and negative crystals?

Reference Book: Fundamentals of Optics, Francis Jenkins & Harvey White, 2001, McGraw-Hill Education

Ex. No.: ....   Date:..............................

MICHELSON'S INTERFEROMETER

Aim: To determine the wavelength of the given Laser beam, using Michelson's Interferometer.

Apparatus: Michelson Interferometer set up, He - Ne Laser

Principle:

Interferometers work on the principle of interference of light. In Michelson Interferometer an interference pattern is produced by splitting a beam of light into two paths, bouncing the beams back and recombining them.

Construction and working:

The apparatus consists of two highly polished plane mirrors M_1 (movable) and M_2 (fixed) which are perpendicular to each other and a half silvered glass plate G which is at an angle of 45^0 to the incident beam of light incident on it. The motion being controlled using the micrometer screws and tilting screws. Light from the monochromatic source falls parallel on the half silvered glass plate G. This acts as a beam splitter producing two beams of the incident beam. The beams 1 & 2 travel towards mirrors M_1 and M_2 and are reflected from the mirrors to retrace their path. The light beams 1 & 2 travel different path lengths and are reunited by the glass plate G again; they interfere and move towards the screen to produce interference pattern on the screen. The mirrors M_1 and M_2 are provided with tilting screws which enable one to set them exactly perpendicular to each other. The position of the movable mirror M_1 can be read on the micrometer.

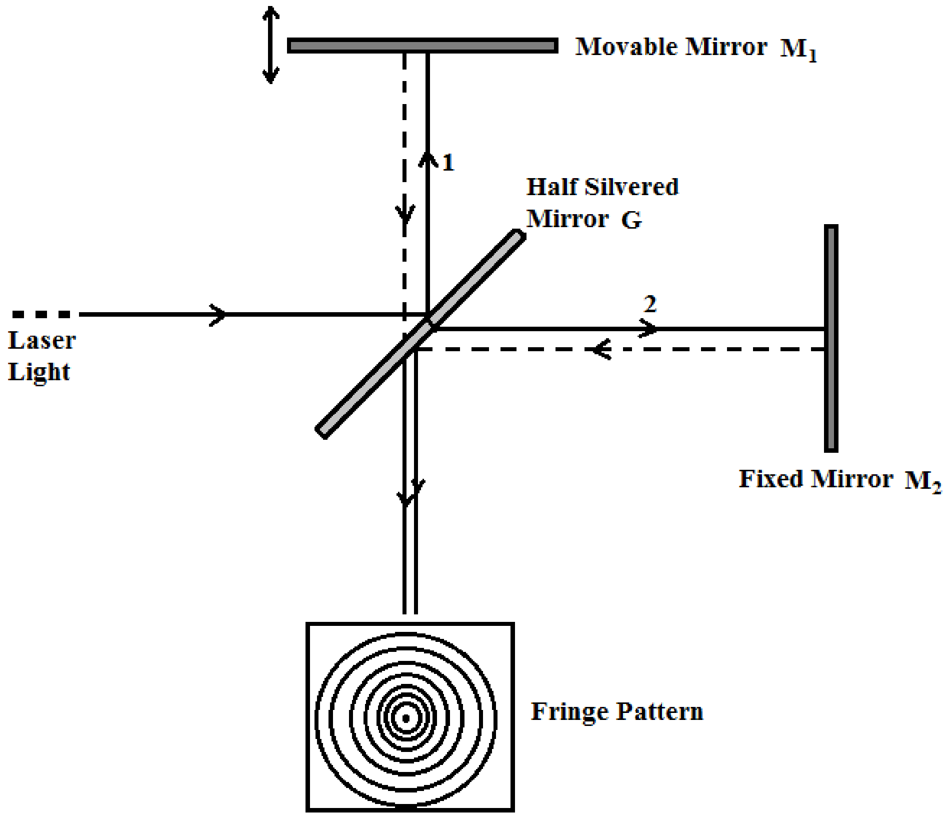

Fig. Michelson Interferometer set up

The interference pattern has circular concentric fringes of constant inclination when the angle between M_1 and M_2 is exactly 90^0. The interference pattern has equidistant straight fringes of constant thickness when the angle between M_1 and M_2 is slightly different from 90^0. If the mirror M_1 is moved by a distance $\lambda/2$, then the path difference between the beams 1 & 2 will change by λ and a fringe crosses the reference point on the screen. If the mirror M_1 is moved by a distance Δd and the number of fringes crossing the field of view during the motion of M_1 is N then,

$$\Delta d = N(\lambda/2) \qquad \text{or} \qquad \lambda = 2\Delta d/N.$$

Procedure:

Least count of the micrometer screw is calculated. Interferometer is set to get circular fringes, with the light from the He-Ne laser. The initial reading corresponding to the position of the movable mirror is recorded. The mirror is moved by counting the number of fringes that crosses the field of view. Micrometer readings corresponding to various fringes at regular intervals are recorded. The mirror shift Δd corresponding to say 100 fringes is calculated. The wavelength of the given monochromatic light source is calculated by the formula $\lambda = 2\Delta d/100$.

Observation and Calculations

Pitch of the *first* auxiliary scale =

Number of divisions on the head scale =

Least count of the of the *first* auxiliary scale, $lc_1 = \dfrac{\text{Pitch}}{\text{Number of hsd}} =$

Pitch of the *second* auxiliary scale =

Number of divisions on the head scale =

Least count of the of the *second* auxiliary scale, $lc_2 = \dfrac{\text{Pitch}}{\text{Number of hsd}} =$

Total scale reading, TR = PSR + (HSR on scale1 × lc_1) + (HSR on scale2 × lc_2)

Fringe No.	**Scale Reading TR (mm)**	**Fringe No.**	**Scale Reading TR (mm)**	**Distance moved for 100 fringes Δd (mm)**
0		100		
10		110		
20		120		
30		130		
40		140		
50		150		
60		160		
70		170		
80		180		
90		190		

Mean Δd =

Wavelength of the given monochromatic light source,

$$\lambda = \frac{2 \times \Delta d}{100} = \underline{\hspace{6cm}} =$$

Result:

The wavelength of the given monochromatic light source, λ =______________nm